



Review of the Rare Earth Elements and Lithium Mining Sectors

FINAL REPORT

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1. Executive Summary

1.1 Introduction

Rare earth elements and lithium are increasingly important resources for technological applications. Rare earths are used in green energy applications such as phosphors in flat screen displays, in the ceramics industry, and in a wide variety of military applications. Due largely to China's restrictions on its exports and growing global demand, rare earth element mining operations are beginning to look at potential Canadian sites. Lithium is a key ingredient in lithium batteries. Global demand for lithium is likely to expand considerably with increased production of hybrid and electric cars. This has resulted in junior mining companies researching the potential for new Canadian lithium mining operations.

This report provides background information on rare earth elements and lithium mining, processing and refining. An analysis of environmental management factors to consider is also provided. The report analyzes the nature of these industries in Canada and internationally, describes their current state and identifies proposed projects in Canada. The report also provides background information to support Environment Canada's planned review of the *Metal Mining Effluent Regulations* (MMER). This background information will be used to identify any unique environmental management requirements that may need to be considered for the MMER in the context of potential rare earth and lithium developments in Canada.

1.2 Rare Earths

The rare earth elements (REE) are defined by the International Union of Pure and Applied Chemistry as the 15 lanthanoid elements (with atomic numbers of 57 through 71) in addition to scandium and yttrium. All of these elements except for scandium are commonly found together, however depending upon the actual mining site in question they can occur in different proportions. The rare earth elements are separated into light rare earth elements (LREEs) and heavy rare earth elements (HREEs). The distinction tends to be based on the specific configurations of electrons within each rare earth element atom. However, has been diluted somewhat by industry, that categorizes the first five lanthanoids as LREEs.

World 2010 demand for REEs was estimated at 136,100 tonnes,¹ with global production totalling 133,600 tonnes.² Applications for rare earths include: phosphors in liquid crystal displays, light emitting diodes (LED), and compact fluorescent lamps (CFL). They are also used as important elements in permanent magnets (used in motors and wind farm operations), and in batteries.³ Some rare earths are used in fluid cracking catalysts for crude oil refining, in automotive catalytic converters, as parts of glass polishing compounds, and as elements in metal alloys. In addition, rare earth elements are used in a variety of technologically complex defence applications such as missile guidance systems and laser based targeting equipment.⁴ The following table breaks down how the global supply of rare earth elements were utilized in 2008.

Table 1: Global Rare Earth Element Oxide Consumption by Volume/Value in 2008

Use	Value	Quantity
Magnets	37%	21%
Phosphors	31%	7%
Ceramics	4%	6%
Other	3%	7%
Catalysts	5%	19%
Glass	2%	10%
Polishing	4%	12%
Metal Alloys	14%	18%

Source: Industrial Mining Corporation of Australia (IMCOA), *Meeting Demand in 2014: The Critical Issues*, <http://www.reitaglobal.org/storage/The%20Road%20to%20Commercial%20Rare%20Earths%20Production%20IMCOA.pdf>

¹ Bloomberg.com, (October 25, 2010), *Lynas Says Rare Earths Demand to Grow at 9% a Year*, <http://www.bloomberg.com/news/2010-10-25/lynas-corp-says-global-demand-for-rare-earth-to-expand-at-9-annually.html>

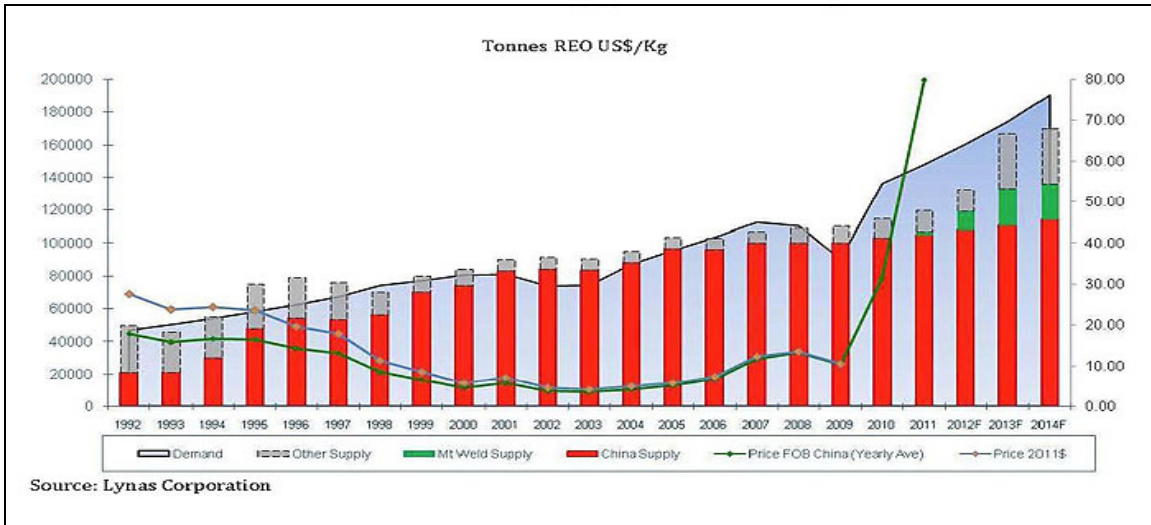
² U.S. Geological Survey, *2011 Mineral Commodity Summary for Rare Earths*

³ Technology Metals Research, LLC, *Critical Rare Earths, Global Supply and Demand Projections and the Leading Contenders for New Sources of Supply*

⁴ Congressional Research Service, (September 30th 2010), *Rare Earth Elements, The Global Supply Chain*

Global demand is expected to continue to grow, while global supply projections remain unclear. Many REE projects are currently being undertaken, however these projects tend to take over ten years to proceed from exploratory testing to actual production. They require substantial capital investment, supporting infrastructure and environmental approvals.

Figure 1: Projected Growth Supply and Demand of Rare Earth Elements



Source: Lynas Corporation. REO means rare earth oxides

Several projections for rare earth element supply and demand were identified to support this study. The figure above is from the Lynas Corporation, an Australian company that is involved in rare earths. The Industrial Minerals Company of Australia (IMCOA) and the US Congressional Research Service also have supply and demand projections that were reviewed for this report. According to IMCOA, global demand for REEs may reach 185,000 tonnes per year by 2015.⁵ China's output may reach 140,000 tonnes per year by 2015, while their demand is predicted to rise from 73,000 to 111,000 tonnes by the same date.⁶ Overall, non-Chinese output of REEs will need to be between 45,000 tonnes and 70,000 tonnes annually in order to meet global REE demand. New mine production will make up the difference for some of the REEs, however some forecasts show that there could be shortfalls of other REEs such as dysprosium, terbium, neodymium, europium and erbium.⁷ The Lynas Corporation's Mt. Weld project is expected to produce 40,000 tonnes per year by 2013, and Molycorp's Mountain Pass mine is expected to add 20,000 tonnes of production.

⁵ IMCOA, (March 2011), *Meeting Rare Earth Demand in the Next Decade*

⁶ *ibid*

⁷ Congressional Research Service, (2011), *Rare Earth Elements, The Global Supply Chain*

The unique supply and demand situation surrounding the rare earth elements bears explanation. Around 1965 the Mountain Pass Mine in California (currently owned by Molycorp) began to supply the majority of rare earth metals produced globally. This remained the case until the early 1990s, when China began flooding the market with rare earth elements at prices that undercut those from the Mountain Pass Mine and other sources. It is not certain how China was able to do this, however industry sources have indicated that the ionic clay deposits in China allow for very inexpensive extraction in comparison with any other deposits in the world.⁸ Within a fairly short period of time this situation resulted in the near collapse of global rare earth element production outside of China. As of 2007, China was thought to produce roughly 95% of the global supply of rare earth metals.^{9, 10}

The Chinese have recently begun to scale back their production. China has recognized that rare earth elements are a strategically important resource and that if business-as-usual practices continued they could run out of their supply in roughly 30 years.¹¹ This has resulted in diminishing export quotas from China, as shown below.

**Table 2: Trend in Chinese Rare Earth
Export Quotas
(Tonnes Rare Earth Oxide)**

Year	Rare Earths Export Quota	Percent Change*	Global Demand	Rest-of-World Demand
2004	65,609	0%	90,000	57,000
2005	65,609	0%	98,000	47,000
2006	61,821	-6%	110,000	52,000
2007	59,643	-4%	120,000	54,000
2008	56,939	-5.5%	124,000	52,000
2009	50,145	-12%	-	-

*Cumulative average reduction in quotas (2005-2009) is 6-7% per annum.

From 2009, therefore 2009 demand not yet known.

Source: Industrial Minerals Company of Australia, *Meeting Demand in 2014: The Critical Issues*, <http://www.reitaglobal.org/storage/The%20Road%20to%20Commercial%20Rare%20Earths%20Production%20IMCOA.pdf>

⁸ Personal Interview with Neo Materials, Sept 1st, 2011.

⁹ CBC News, (June 21st, 2007), *Rare Earths: An Abundance of Riches in the Hands of a Few*, <http://www.cbc.ca/news/background/tech/rare-earths.html>

¹⁰ Molycorp announced the takeover of Neo Materials in March 2012. The Globe and Mail, *Molycorp buys Neo Material for \$1.3-billion*. Available at: <http://www.theglobeandmail.com/globe-investor/molycorp-buys-neo-material-for-13-billion/article2363776/>. Accessed: March 15, 2012.

¹¹ Industrial Minerals Company of Australia, *Meeting Demand in 2014: The Critical Issues*, <http://www.reitaglobal.org/storage/The%20Road%20to%20Commercial%20Rare%20Earths%20Production%20IMCOA.pdf>

1.2.1 Presence in Canada

With demand continuing to increase and Chinese supply shrinking, the market is expected to open up to new potential competitors. Some of these companies are exploring options in Canada. The following list shows some of the main players identified by Rare Metal Blog (a Canadian trade association). A more complete account of these businesses and others is provided in the body of the report:

- Avalon Rare Earths;
- Great Western Minerals Group;
- Matamec Explorations;
- Rare Earth Industries; and
- Rare Earth Metals Inc.

1.3 Lithium

Global production of lithium was estimated to be 25,350 tonnes excluding U.S. production in 2010,¹² a 34% increase over 2009 production. The following table shows lithium production in 2010, although US production is not shown in order to protect confidential company information.

Table 3: Global Lithium Production (2010)
(tonnes)

Country	Production
Chile	8,800
Australia	8,500
China	4,500
Argentina	2,900
Zimbabwe	470
Brazil	180
United States	Unavailable
World Total (excluding USA)	25,350

Source: U.S. Geological Survey, *2011 Mineral Commodity Summary for Lithium*.

¹² United States Geological Service, *2011 Mineral Commodity Summary for Lithium*.

Lithium is used in a variety of products, including ceramics and glass (31%), batteries (23%), lubricating greases (9%), air treatment (6%), primary aluminium production (6%), continuous casting (4%), rubber and thermoplastics (4%), pharmaceuticals (2%), and other uses (15%).¹³ “Other” uses include alloys, constructions, dyestuffs, industrial bleaching and sanitation, pool chemicals, and specialty inorganic chemicals.

Most cellular phones and laptop computers are powered by lithium batteries, as are many heavy-duty power tools. Laptop sales increased 23% in between 2006 and 2007, and another 25% in between 2007 and 2008. Sales of laptops and cell phones are not expected to drop.¹⁴ Lithium-ion battery production represented 75% of the global portable rechargeable battery market worldwide in 2009.

Lithium batteries are likely to be the fastest growing application for lithium, especially as battery technology continues to improve, opening up new applications. Companies such as IBM¹⁵ are investing to advance lithium battery technology, and as better lithium batteries become available demand is expected to rise. Technological advances continue in utilizing batteries for: individual and public transportation; power grid storage for peak period relief; power storage for green energy applications; and many others.

One of the largest potential battery markets for lithium is batteries in hybrid and electric vehicles (including busses and other forms of public transportation). The large batteries required for these vehicles use far more lithium than the smaller batteries used for laptop computers or power tools. If lithium battery technology improves enough for these vehicles to become more feasible and cost efficient, then they may begin to represent a higher percentage of the total vehicle market. If even 50% of the vehicle market becomes hybrid or electric within the next 30 years, the required increase in lithium output would be substantial. Projections are provided within the report. While demand is expected to increase, overcapacity conditions by the year 2020 are anticipated with new projects under development.¹⁶

¹³ United States Geological Service, *2011 Mineral Commodity Summary for Lithium*

¹⁴ Meridian International Research, (May 2008), *The Trouble With Lithium 2*

¹⁵ Technology Review India, (June 11th, 2009), *IBM Invests in Battery Research*, <http://www.technologyreview.in/energy/22780/>

¹⁶ TRU, *Long-range supply-demand forecast for global lithium 2020*, Presentation at : 3rd Lithium Supply & Markets Conference Toronto January 20, 2011. Available <http://trugroup.com/Lithium-Market-Conference.html>.

1.3.1 Presence in Canada

There are no lithium mines or brine based lithium extraction facilities currently operating in Canada. Most of the lithium projects in Canada are in exploration phases. Canada Lithium has completed an independent mineral resource assessment on their Quebec Lithium project, and it is currently undertaking an environmental assessment. The Quebec Lithium project was the facility closest to operation identified in Canada. The following is a short list of companies exploring lithium mining opportunities in Canada. A more complete list with further details is provided in the body of the report:

- Canada Lithium Corporation;
- Channel Resources Inc.;
- International Lithium Corporation; and
- Rock Tech Lithium.

1.4 Rare Earths and Lithium Mining and Processing Methods

Outside of China, rare earths are nearly always mined from hard rock deposits. Rare earth elements have been found in monazite sands, but all of the Canadian projects identified through research have planned to harvest rare earths from hard rock resources (usually bastnasite deposits). The mining and ore production processes for rare earths bear many similarities to other forms of mining. The process by which different rare earth elements are separated from one another is the most unique (and complicated) part of bringing rare earth elements to market.

Lithium mining is conducted either through mining hard rock (spodumene) deposits, or through extracting lithium from brines using solar evaporation techniques. Brine based lithium extraction is said to be far more cost effective than hard rock mining. One area in Canada has been found to have lithium-containing brines that could potentially be exploited, and three different companies are exploring opportunities in that area. Several spodumene lithium projects are also planned in Canada.

1.4.1 Rare Earth Mining and Processing Methods

Rare earth element mining is generally very similar to other forms of mining, as hard rock must be extracted from the ground. For example, strip mining is practiced at the Molycorp Mountain Pass facility. A number of different methods, all of which are commonly used in other forms of mining/beneficiation, are then used to upgrade the rock to an ore. These processes include screening, the use of wet gravity equipment, electrostatic or electromagnetic separation and many others.

The upgrading of ore to make concentrate involves attacking the ore chemically. This may include roasting, salt or caustic fusion, high temperature sulphation, and acid leaching as required to decompose the minerals in a given concentrate and allow the rare earth elements to be dissolved. The leach solutions can then be processed using selective precipitation, solvent extraction, or ion exchange processes to remove most of the impurities and produce higher-grade intermediate chemical compounds suitable for refining.

1.4.2 Lithium Mining and Processing Methods

In spodumene mining, the mining process itself is fairly basic. The product extracted from the mines generally undergoes a flotation beneficiation process in order to produce a concentrate. The lithium concentrate then most commonly undergoes one of two processes, the soda ash process or the sulphuric acid process. In both of these processes, the first step is calcination, where the alpha spodumene concentrate (5% Li_2O content) is transformed into more reactive beta spodumene by heating to $1,100^\circ\text{C}$. After calcination the two processes diverge. These processes are both fairly complicated, and are discussed in detail in the body of this report.

The process used to obtain lithium carbonate from brine is known as the lime soda evaporation process. The brine is pumped out of the ground and into a series of shallow ponds, where it is left to evaporate for 12 to 18 months. Different salts crystallize out at different times and as this happens the solution becomes more concentrated. Boron, which concentrates with the lithium, is removed using an extraction process. Then the product is treated with a base (such as lime) to remove magnesium. Then, the initial volume of water is reduced, at which point the concentrate is treated with soda ash to precipitate out insoluble lithium carbonate.

1.5 Substances of Environmental Concern in Rare Earth and Lithium Mining and Processing

There are many different possible pollutants or contaminants that could result from rare earths mining, beneficiation, concentration and separation processes. Information on potential environmental concerns are identified from Avalon Rare Metals' environmental assessment report¹⁷ and a chemical analysis of the tailings from Molycorp's Mountain Pass facility, which are summarized below and detailed later in this report. One of the main pollutants of concern identified in the rare earth elements industry is thorium.

¹⁷ The environmental assessment process is ongoing.

Spodumene based lithium mining is very similar to other types of mining, and would have many of the same pollutants (taking into account the properties of the host mineral). Solar evaporation techniques, on the other hand, are relatively environmentally benign.

1.5.1 Substances of Concern for Rare Earths

Rare earth element mining is similar to other kinds of mining, and has similar pollutants and/or effluents associated with it, including magnetic fractions and tailings. Nearly all by-products or waste materials from rare earth processing are naturally radioactive due to contained thorium.

Thorium disposal and radiation are the main concerns that could shut down or delay the Lynas Corporation plant in Malaysia.¹⁸ Thorium disposal also caused the shut down of a Mitsubishi rare earth element plant in Malaysia in 1992. The company has since needed to spend an estimated \$100 million to clean up the site.¹⁹ Additionally, thorium radiation from improper disposal has been cited as a major reason the Chinese have slowed production and tried to increase environmental oversight for rare earth element mining and processing. How to properly capture and dispose of thorium remains a challenge in the industry.

1.5.2 Substances of Concern for Lithium

Canada Lithium is currently conducting an environmental assessment for a spodumene lithium mine in Quebec. As of the writing of this report, there was no direct data from this project available. However, literature reviewed during this study indicates that spodumene lithium mining has no unique pollutants or effluents common to the process. The nature of pollutants and effluents released from this type of mining depends largely upon the host mineral.

Chemetall in Nevada is currently practicing lithium extraction from brine. Information and permits obtained from the Nevada Department of Environmental Protection and Chemetall found permit requirements were fairly unique due to the fact that the lithium extraction processes were being conducted in a closed hydro geologic system. This system allowed little to no pollutants or effluents to be released to any water sources other than the brine itself. However, the permits did identify the following effluents being released from the facility:

- salt;
- semi-solid calcium sulphate and magnesium hydroxide sludge;
- semi-solid magnesium hydroxide and calcium carbonate sludge;

¹⁸ International Business Times, (March 16th, 2011), *Thorium: Rare Earth Liability or Asset?*, <http://www.ibtimes.com/articles/123268/20110316/thorium-rare-earth-liability-or-asset.htm>

¹⁹ NY Times, (March 8th, 2011), *Mitsubishi Quietly Cleans Up Its Former Refinery*, <http://www.nytimes.com/2011/03/09/business/energy-environment/09rareside.html>

- spent liquor and plant waste waters (emergency eyewash supply, floor washing etc.);
- calcium carbonate solids; and
- CaCO₃ solution.

Further information on the Chemetall facility and their permits can be found in the body of the report.

1.6 Effectiveness of the *Metal Mining Effluent Regulations* to Address Identified Substances

Canada's *Metal Mining Effluent Regulations* (MMER) are Regulations under the *Fisheries Act* that impose limits on the maximum concentrations in effluent of substances that are referred to in the Regulations as "deleterious substances". The substances that are regulated are arsenic, copper, cyanide, lead, nickel, zinc, total suspended solids and radium 226. The MMER also require that the effluent not be acutely lethal to rainbow trout, and that mines undertake environmental effects monitoring activities to assess the impacts of the mine effluent on fish, fish habitat and the use of fisheries resources.

It is also worth noting that the regulations require owners/operators of tailings impoundment areas (TIAs) that are listed in Schedule 2 to develop and implement fish habitat compensation plans. These plans must be approved by Fisheries and Oceans Canada and must be structured to ensure that they offset any impacts on fish habitat that would occur in conjunction with the development of the TIA.

Rare earth elements mining and lithium mining are not currently being practiced in Canada, and the MMER were not specifically designed to manage the environmental aspects of these mining processes. As a result, the *Metal Mining Effluent Regulations* do not specifically regulate all of the individual substances of concern that might be released from the mining or processing of rare earth elements and lithium. However, any substances not specifically listed on the MMER would be covered under the general prohibition of subsection 36(3) of the *Fisheries Act*, which prohibits the deposit of deleterious substances into waters frequented by fish.

1.6.1 Effectiveness of the MMER for Rare Earths

Thorium (and to a lesser extent uranium) is the most common and problematic pollutant identified in this study resulting from rare earth element mining and processing. The MMER do not currently identify thorium or uranium as "deleterious substances" and as a result do not directly address their release to the environment. This means that the general prohibition of deposit under subsection 36(3) of the *Fisheries Act* currently applies to these substances. It is also important to note that because thorium and uranium are considered naturally occurring radioactive material (NORM) and their release is not

associated with the nuclear fuel cycle, they are not regulated by the Canadian Nuclear Safety Commission (CNSC). As a result of this, the regulation of NORM material is currently under provincial jurisdiction.

Release guidelines, which include uranium and thorium, have been established by Health Canada under “The Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials” (Health Canada, 2000). These guidelines are included later in the report, and should be considered in the context of developing recommended limits to be proposed to provincial jurisdictions. Also contained later in this report are other potential matters of concern regarding pollutants released from rare earth elements mining and processing.

1.6.2 Effectiveness of the MMER for Lithium

Lithium extraction from brine resources is not covered by the MMER. This is the case because, under the MMER “mine means hydrometallurgical, milling, or mining facilities that are designed or used to produce a metal, a metal concentrate or an ore from which a metal or metal concentrate may be produced or any facilities, including smelters, pelletizing plants, sintering plants, refineries and acid plants, where any effluent from the facility is combined with the effluent from hydrometallurgy, milling or mining.”²⁰ While extracting lithium from brine is carried out in order to produce a metal, the process associated with the extraction and subsequent processing of brine does fall under the scope of activities that are subject to the MMER.

It is worth noting that the uneconomical by-products from brine facilities are often pumped directly back into the ground, similar to the process followed by oil and gas facilities that use brines.

As there are currently no brine based lithium extraction facilities in Canada, it is not entirely clear what regulations these facilities may fall under. These facilities are more similar to brine based petroleum facilities than to the metal mining facilities that are covered under the MMER. Alberta’s Energy Resources Conservation Board (ERCB) has regulations that cover the petroleum industry in that province, and while they were not reviewed in this report, they should potentially be considered when developing any regulations for brine based lithium extraction facilities.

²⁰ *Metal Mining Effluent Regulations*

2. Introduction

2.1 Background

Composed mostly of members of the periodic table's lanthanide series, rare earths are similar in abundance as more familiar elements such as copper, nickel or zinc, while even the least abundant naturally occurring rare earths are 200 times more common than gold.²¹ However, rare earth elements (REE's) are only found in commercially viable amounts in select instances. Overall there are 17 rare earth elements - lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, terbium, thulium, ytterbium, lutetium, scandium and yttrium.

China produces approximately 97% of the global supply of rare earths. The largest global producers at present are Baotou Steel and Rare Earth Co., both located in China. However China reduced its export quotas for rare earths by 35% for the first half of 2011 versus 2010, attributing this reduction to its desire to preserve ample reserves. At that time, China also cautioned that it had not decided on the quotas for the second half of 2011. As a result of these decisions by the Chinese government, a host of mining companies have advanced plans to open or reopen mines that can produce rare earth elements in economic quantities. Several of these proposed rare earth mines are located in Canada.

Lithium is a metal that occurs naturally in pegmatitic minerals, ocean water and some brines and clays. It is used in heat resistant glass and ceramics, alloys, and within lithium and lithium-ion batteries. As with rare earths, lithium is fairly common (roughly as common as lead or nickel) but is generally found in such low concentrations that it is not economically feasible to extract. The main commercially viable concentrations of lithium occur in the Salar de Uyuni area of Bolivia, with similarly large deposits in Chile and Argentina.

The majority of businesses attempting to extract lithium from Canada are planning on mining spodumene deposits. This process is generally far more expensive than extracting lithium from brines as is practiced in the salt flats of South America. While there are Canadian businesses that are planning to extract lithium from brines, the process used in these operations does not fall under the scope of activities that are subject to the MMER.

The study was undertaken in the context of the expanding global market demand for rare earth elements and for lithium and the potential for associated implications for the

²¹ CNBC News, (Nov 5, 2010), *How Are Rare Earth Elements Used?*, http://www.cnbc.com/id/40027130/How_Are_Rare_Earth_Elements_Used

Canadian mining industry. While Environment Canada has considerable experience with the management of the environmental aspects of a broad range of metal mines, there are currently no lithium or rare earth element mines operating in Canada. This drives the need to ensure that the current requirements of the *Metal Mining Effluent Regulations* are adequate for these industries.

2.2 Purpose of this Report

This report provides background information on the rare earth elements and lithium mining industries with a particular emphasis on the management of their environmental aspects. The report considers these industries within Canada and internationally, examining their current state and the potential for future development in Canada. This report provides information to support Environment Canada's planned evaluation of the *Metal Mining Effluent Regulations* with the intention of identifying any unique environmental aspects that need to be considered for these industries.

2.3 Methodology

The methodology used to prepare this report involved:

- literature and Internet searches; and
- consultations with rare earth and lithium industry representatives and government regulatory experts.

Useful information was identified in: environment permits for facilities in the United States (i.e., Molycorp, Chemetall); the environmental impact assessment report for Avalon Rare Metals²²; and a variety of market and scientific literature sources, as referenced in the report.

²² The environmental assessment process is ongoing.

3. Rare Earths and Lithium Mining

3.1 Introduction

Rare earth element mining and processing is not usually linked with lithium mining and processing. As the two commodities are quite distinct and have experienced very different trends in Canada and internationally, they are discussed separately below.

3.2 Rare Earth Elements

The rare earth elements are defined by the International Union of Pure and Applied Chemistry as the 15 lanthanoid elements (with atomic numbers of 57 through 71) in addition to scandium and yttrium. All of these elements except for scandium are commonly found together, however, depending upon the actual mining site in question, they can occur in different amounts. The rare earth elements are separated into light rare earth elements (LREEs) and heavy rare earth elements (HREEs). The distinction between the two tends to be based on the specific configurations of electrons within each rare earth element atom. However, this has been diluted somewhat by industry which categorizes the first five lanthanoids as LREEs.

Figure 2: The Rare Earth Elements

57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.5	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97	39 Y 88.906
Light rare earths				Heavy rare earths										
La - Lanthanum				Eu - Europium				Er - Erbium						
Ce - Cerium				Gd - Gadolinium				Tm - Thulium						
Pr - Praseodymium				Tb - Terbium				Yb - Ytterbium						
Nd - Neodymium				Dy - Dysprosium				Lu - Lutetium						
Sm - Samarium				Eu - Europium				Y - Yttrium						

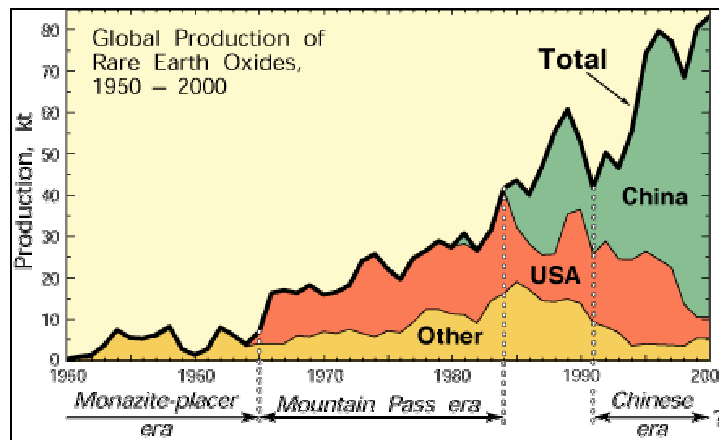
Figure 2.2 Sub-groups of the rare-earth metals, per industry (not scientific) norms
(sources: TMR, industry sources).

Source: Technology Metals Research, LLC, Critical Rare Earths, Global Supply and Demand Projections and the Leading Contenders for New Sources of Supply

*Please note that Scandium is considered a rare earth element, but is not categorized as either a heavy or light rare earth, and therefore not included in the above figure.

Rare earth metals were first commercialized when the incandescent lamp mantle industry was established in 1884. Some of the first countries commercially producing rare earth elements at this time were Sweden and Norway, followed by Brazil, India, and the United States leading up to and just beyond 1900.²³ In roughly 1965 the Mountain Pass mine in California (currently owned by Molycorp) began to supply the majority of rare earth metals produced globally. This remained the case until the early 1990s, when China began flooding the market with rare earth elements at prices that considerably undercut those from the Mountain Pass Mine or anywhere else on earth. Theories abound as to why they were able to do this, however industry sources have indicated that the ionic clay deposits in China allow for very inexpensive extraction in comparison with any other deposits in the world.²⁴ Within a fairly short period of time this situation resulted in the near collapse of global rare earth element production outside of China. As of 2007, China was thought to produce roughly 95% of the global supply rare earth metals.²⁵

Figure 3: Global Production of Rare Earth Oxides



Source: U.S. Geological Survey, *Rare Earth Elements – Critical Resources Strategy*.

Producers in China had taken over the market and were driving competitors out of business. However, the Chinese have begun to scale back their production. There are several different potential reasons for this. One of the reasons is environmental concerns. Some members of Canadian industry believe that a number of the operations in China have had poor environmental controls in place, and thorium (a by-product from rare earth mining) is radioactive. As a result, China has cited the need to protect their environment

²³ Center for Strategic and International Studies, (December 15th, 2010), *Rare Earth Elements, Geology, Geography, and Geopolitics*, http://csis.org/files/attachments/101215_EnergyHedrick.pdf

²⁴ Personal Interview with Neo Materials, Sept 1st, 2011.

²⁵ CBC News, (June 21st, 2007), *Rare Earths: An Abundance of Riches in the Hands of a Few*, <http://www.cbc.ca/news/background/tech/rare-earths.html>

and people as a primary reason why production of rare earth elements in China has been substantially reduced. At the same time, China has begun to develop stockpiles to reduce the impact of industry shutdowns and natural disasters. Along with these two factors, China has also recognized that rare earth elements are a strategically important resource and that if business as usual practices continued they could run out of their supply in roughly 30 years.²⁶ The above factors have resulted in diminishing export quotas from China, as shown below.

**Table 4: Trend in Chinese Rare Earth
Export Quotas**
(Tonnes Rare Earth Oxide)

Year	Rare Earths Export Quota	Percent Change*	Global Demand	Rest-of-World Demand
2004	65,609	0%	90,000	57,000
2005	65,609	0%	98,000	47,000
2006	61,821	-6%	110,000	52,000
2007	59,643	-4%	120,000	54,000
2008	56,939	-5.5%	124,000	52,000
2009	50,145	-12%	-	-

*Cumulative average reduction in quotas (2005-2009) is 6-7% per annum.

From 2009, therefore 2009 demand not yet known.

Source: Industrial Minerals Company of Australia, *Meeting Demand in 2014: The Critical Issues*, <http://www.reitaglobal.org/storage/The%20Road%20to%20Commercial%20Rare%20Earths%20Production%20IMCOA.pdf>

With demand continuing to increase and supply shrinking, the market has begun to open up to new competition. However, the Chinese have by and large dominated the market for such a long period of time that the development of the industry lags far behind the Chinese worldwide. Even in the U.S., the Mountain Pass mine and processing facility lags far behind the Chinese insofar as development, capacity, and production costs. The Mountain Pass mine only began processing ores again in 2007,²⁷ after having been shut down due to environmental and regulatory problems with their main wastewater pipeline.²⁸ Currently, there are bastnasite concentrates and other rare earth intermediates being sold from mine stocks at Mountain Pass, but mining has not resumed.²⁹

²⁶ Industrial Minerals Company of Australia, *Meeting Demand in 2014: The Critical Issues*, <http://www.reitaglobal.org/storage/The%20Road%20to%20Commercial%20Rare%20Earths%20Production%20IMCOA.pdf>

²⁷ U.S. Geological Survey, *2011 Mineral Commodity Summary for Rare Earths*

²⁸ U.S. Geological Survey, *Rare Earth Elements – Critical Resources Strategy*

²⁹ U.S. Geological Survey, *2011 Mineral Commodity Summary for Rare Earths*

Table 5: World Mine Production of Rare Earths
(tonnes)

	2009	2010
China	129,000	130,000
India	2,700	2,700
Brazil	550	550
Malaysia	350	350
United States	-	-
Australia	-	-
Other Countries	NA	NA
Canada	-	-
World Total (Rounded Down)	133,000	133,600

Source: U.S. Geological Survey, 2011 Mineral Commodity Summary for Rare Earths

3.2.1 Rare Earths Mining in Canada

Rare earths prospecting and land purchasing in Canada have increased dramatically since China has begun to limit exports of their products. However, at this time there is still no rare earth elements mining in Canada. This situation is likely to continue for some time, as establishing a rare earths mining and separation process can take between 5 and 12 years and cost between \$500 million and \$1 billion.³⁰ The table below lists projects and companies exploring rare earth element mining possibilities in Canada.

³⁰ Industrial Minerals Company of Australia, *Meeting Demand in 2014: The Critical Issues*, <http://www.reitaglobal.org/storage/The%20Road%20to%20Commercial%20Rare%20Earths%20Production%20IMCOA.pdf>

Table 6: Rare Earth Element Mining In Canada
(Many companies have multiple project sites, not all are listed)

Company	Site Location
Avalon Rare Earths	Thor Lake, Northwest Territories
	Separation Rapids, Kenora, Ontario
	East Kemptville, Yarmouth County, Nova Scotia
	Lilypad Lakes, Pickle Lake, Ontario
Cabot Corporation, Tantalum Mining Corporation of Canada (TANCO)	Tanco Mine, Bernic Lake, Manitoba
Great Western Minerals Group	Hoidas Lake, Saskatchewan
Canada Rare Earths	Abitibi region, Quebec
Bolero Resources Corp.	“Carbonatite Syndicate” mine, 80 km north east of Prince George, British Columbia
	“Charge” Mine, Northern British Columbia
Quest Rare Minerals Ltd.	Strange Lake, Quebec/Labrador
Search Minerals Inc. (Alterra)	Port Hope Simpson Labrador
	Red Wine Property, Churchill Falls Labrador
	Strange Lake, Quebec/Labrador
Silver Grail Resources Ltd.	Dease Lake, British Columbia, Major Hart site
Canadian International Minerals Inc.	Carbo, British Columbia (50k east of Bear Lake)
	Dead Horse Creek, Ontario
	Prairie Lake, Ontario
GeoMega	Montveil, Abitibi Region of Quebec
Matamec	Temiscamingue, Quebec
Pele Mountain Resources	Elliot Lake, Ontario
Rare Earth Metals Inc.	Springer Township, Ontario
	Clay Howells, Ontario
	Coldwell, Ontario
	Labrador, Canada
Rare Earth Industries	Mt. Bisson, British Columbia
	Northern British Columbia

Source: Cheminfo Services Research

While the list is not exhaustive, it is believed to cover the majority of the current Canadian industry. Many of these companies are much further from actual implementation than others. There are fewer than 10 main players.³¹ Some of these players are briefly described below.

³¹ Personal Interview with REE World Trade Association, August 29th, 2011.

- **Avalon Rare Metals Inc** is a Canadian company focused on developing rare earth element projects in Canada. Their main deposit of concern is the Nechalacho project off of Thor Lake in the Northwest Territories. The deposit has high concentrations of “heavy” rare earth elements, and is therefore extremely valuable. However, the project faces some serious challenges. As the site is remote, access to electricity and transportation infrastructure has not yet been developed; both of these amenities are required in order to run rare earth element processing facilities. Good transportation infrastructure is required in order to ship product, and to transport the multiple acids necessary for the separation process to the separation facility. The separation process also requires a great deal of electricity, which naturally poses additional problems for such a remote site. Avalon Rare Metals, therefore, has a great deal of potential pending the resolution of some key infrastructure issues. Avalon has, however, done a great deal of research and exploratory work, including an environmental assessment that is currently underway (available from the Mackenzie Valley Review Board website³²). This environmental assessment does explore the option of locating the separation plant closer to the current infrastructure than the mine site thus partially overcoming some of the infrastructure challenges.
- **Quest Rare Minerals Ltd.** is a Canadian company with its rare earth holdings in northern Quebec/Labrador (Strange Lake). They face similar challenges to Avalon Rare Metals in that their facility would require access to power and transportation infrastructure before it could be economically feasible. However, like Avalon they are considered to be relatively far ahead in their exploration process.³³
- **Matamec Explorations Inc.** is a Canadian company with its rare earth holdings in a Eudialyte deposit in the Temiscamingue region of Quebec. Matamec has been working with SGS mineral services in Lakefield, Ontario to develop a new “dry” method for concentrating rare earth element oxides. The process uses dry permanent magnetic separation in addition to Matamec’s proprietary leaching method.³⁴ At this time, Matamec does not intend to separate individual rare earth elements, and instead intends to sell their concentrated rare earth oxides as an end product.³⁵ Matamec has also recently signed a memorandum of understanding with Toyota Tsusho Corp (the trading arm of Toyota Motor Corp) to fast track the development of their Canadian Kipawa rare earths deposit.³⁶

³² Mackenzie Valley Review Board Website.

http://www.reviewboard.ca/registry/project_detail.php?project_id=87&doc_stage=5

³³ Personal Interview with REE World Trade Association, August 29th, 2011.

³⁴ RareMetalBlog.com, (March 8th 2011), *Matamec Yields Overall Recoveries of Rare Earths of About 81% from Eudialyte Zone of the Kipawa Deposit*,

³⁵ Personal Interview with Matamec Explorations, December 7th, 2011.

³⁶ Domain-B.com, (December 16th 2011), *Toyota’s Trading Arm to Form Rare Earth JV with Canada’s Matamec*, http://www.domainb.com/companies/companies_t/Toyota_Motor_Corp/20111216_canada_matamec.html

- **GeoMegA** owns a property in the Abitibi region of Quebec, and is also a Canadian company. Their rare earth element holdings are in a carbonotite deposit that houses primarily light rare earth elements, as opposed to the heavier and more valuable heavy rare earth elements.
- **Rare Earth Metals Inc.** is a Canadian company with a few different rare earth projects in Canada. None of the projects have gone beyond the exploration phase. Rare Earth Metals currently has exploratory projects underway in Alberta, Ontario and Newfoundland and Labrador.
- **Rare Earth Industries** Rare Earth Industries is a Canadian company with its rare earth holdings in Northern B.C. and the United States. There are very few individuals in Canada that have a good working knowledge of how a separation plant or facility would work, however the Director and president of Rare Earth Industries has participated in the construction of two rare earth separation facilities in China and possesses the necessary knowledge. Additionally, the company is currently working on acquiring a European business that has developed a completely dry separation technique.³⁷
- **Great Western Minerals Group Ltd** is a Canadian business with two projects in Saskatchewan and one in New Brunswick. In addition, they are currently preparing a mine in South Africa. While the South African mine is likely fairly close to going into production, the company's Canadian projects are expected to start mining in 2015-16 at the earliest.³⁸ While the company does not currently have any separation plants, they own both Great Western Technologies Inc (US) and Less Common Metals (UK), which both develop alloys using rare earth elements. They are also working with an undisclosed Chinese company on building a rare earth separation facility in South Africa.³⁹

There are several other Canadian companies involved in the rare earths elements industry, however the companies not mentioned in the table and descriptions above most often have their actual facilities abroad (e.g. Tasman Metals Ltd., Neo Material Technologies).

³⁷ Personal interview with Rare Earth Industries, August 30, 2011

³⁸ Personal interview with Great Western Technologies Inc., December 9, 2011.

³⁹ *ibid*

3.3 Lithium Mining

Lithium can be extracted in one of two ways, either through evaporating brine containing the element or through mining spodumene deposits. Global production of lithium was estimated to be 25,350 tonnes excluding U.S. production in 2010,⁴⁰ a 34% increase over 2009 production.

Table 7: Global Lithium Production (2010)
(tonnes)

Country	Production
Chile	8,800
Australia	8,500
China	4,500
Argentina	2,900
Brazil	180
Zimbabwe	470
United States	Unavailable
World Total	25,350

Source: U.S. Geological Survey, *2011 Mineral Commodity Summary for Lithium*.

The chemical grade of lithium carbonate produced from brine and spodumene is not suitable for use in batteries - in order to be used in batteries it must be purified to at least 99.95%. The production figures above reflect a non-purified lithium useable for all of the other products outlined below in the markets section. Purifying lithium to a battery grade product requires several reaction and recrystallisation steps and in some cases having the product pass through an ion exchange resin. Process losses of up to 30% occur.⁴¹

Several brine operations are under development in Argentina (and three in Canada) while spodumene mining operations are under development in Finland, Australia, Canada and elsewhere. Lithium deposits have been identified all over the world in countries such as Afghanistan, Austria, France, Ireland, India, Mozambique, Spain, Sweden and Zaire, but economic conditions have not favoured development in these areas.⁴² Roughly 70% of the world's lithium deposits are located in what is known as the "lithium triangle" where the borders of Chile, Bolivia and Argentina meet.⁴³

⁴⁰ United States Geological Service, *2011 Mineral Commodity Summary for Lithium*.

⁴¹ Meridian International Research, (May 2008), *The Trouble With Lithium 2*

⁴² United States Geological Service, *2011 Mineral Commodity Summary for Lithium*

⁴³ Meridian International Research, (May 2008), *The Trouble With Lithium 2*

3.3.1 Lithium Mining in Canada

The lithium mining industry in Canada is mainly based on spodumene mining, with only three identified brine based operations under exploration. As of 2007, one lithium mine was operating in Canada,⁴⁴ the Tantalum Mining Corporation of Canada (TANCO) mine at Bernic Lake, Manitoba. This facility produces high grade spodumene concentrate for the ceramic and glass industry along with caesium and tantalum. Other identified exploratory and junior lithium mining operations known to exist in Canada are shown in the table below.

Table 8: Exploratory and Junior Lithium Mining Activities in Canada

Company	Site Location
Cabot Corporation	TANCO mine at Bernic Lake, Manitoba
Canada Lithium Corp	La Corne Township, Quebec
Channel Resources Inc.	Fox Creek, Alberta (Brine)
First Lithium Resources	Goldslith Site, Manitoba
	Valleyview Project, Alberta (Brine)
International Lithium Corporation	Thunder Bay, Ontario
	Georgia Lake, Ontario
	Great Slave Lake, Northwest Territories
	Dryden, Ontario
Lithium 1	James Bay, Quebec
Mineral Hill Industries Ltd.	Lacorne Township, Quebec
	Figury Township, Quebec
	Landrienne Township, Quebec
	Landrienne/Lacorne Townships, Quebec
Nemaska Exploration	Whabouchi, Quebec
North Arrow Minerals	Pheonix Project, Northwest Territories
	Torp Lake Project, Nunavut
Petro Horizon Energy Corp	Brazil Lake, Nova Scotia
Rock Tech Lithium	Georgia Lake, Ontario
	Sibley Basin, Ontario
	James Bay, Quebec
	Lacorne, Quebec
	Saint Urbain, Quebec
Sirios	Pontax Project, Quebec
Ultra Lithium Plus	Berland River, Alberta (Brine)
	Armstrong, Ontario

Source: Cheminfo Services Research

⁴⁴ Natural Resources Canada, *Mineral and Metal Commodity Review 2007*

Three sites in the table above are brine based extraction projects: Ultra Lithium Plus's Berland River project, First Lithium Resources Valleyview Lithium Project and Channel Resources Inc. Fox Creek Project. All of these projects are in Alberta, roughly 200 kilometres west of Edmonton. It is unclear exactly how close these sites are to one another, but they appear to be in nearly identical locations. The sites are situated over oil and gas pools hosted in the Devonian age Beaverhill Lake and the southern Woodbend (Leduc) carbonate reef complexes. The water brines spatially associated with these oil and gas pools contain high concentrations of sodium and calcium chloride as well as concentrations of lithium, potassium, boron and bromine. It is this combination of different valuable substances that makes the brines potentially viable for commercial extraction and refining.

As stated before, extracting lithium from brine is a far less capital-intensive method of getting lithium than traditional spodumene mining. The three brine sites discussed above may have some additional advantages. There are currently petroleum product companies operating in the same area, and when extracting their products they also extract brine, which they currently inject back into the aquifer after separating it from their petroleum products. While nothing is certain, and no deals have been reached at this point, there is always the potential that these petroleum product companies could significantly cut down on brine disposal costs by simply passing it along to these three lithium brine ventures. None of the brine operations have gone beyond an initial exploration phase, no environmental assessments have been completed, and no permitting has been undertaken. None of the brine based lithium extraction projects are near operation.

There are currently various processing techniques that are either already used or are in development for extracting lithium from brines. Most techniques currently require an evaporation period of 18 to 24 months before the concentrated brine can then be processed, but certain closed circuit techniques are also under investigation.

Aside from the TANCO mine and Canada Lithium's Quebec Lithium project, spodumene based lithium mining and extraction in Canada seems to be by and large further from operation than the brine operations. Currently, only junior mining interests have scouted different sites and conducted some testing, no construction has been started, and no permitting has been undertaken. As this is the case, and as building a spodumene mining and refining facility would be a very time consuming and capital-intensive venture, it is reasonable to assume that new spodumene lithium mining is likely many years off. However, Canada Lithium Corporation's La Corne Township project is essentially a redevelopment of a previously used mine, and fairly detailed study and planning has gone into the project (including a full environmental assessment that is still being worked on).

3.4 Global Markets for Rare Earths and Lithium

The global markets for rare earth elements and lithium are competitive. New and important technological applications in military, energy and environmental sectors depend upon these resources, and the demand for both lithium and rare earth elements has been steadily climbing for years. This trend is expected to continue. The following sections provide details on the global supply and demand trends for rare earth elements and lithium.

3.5 Rare Earths

The 17 rare earth elements are used in a diverse range of technological applications. As they have been deemed to be strategically important for defence by the United States government⁴⁵, the demand for rare earth elements is likely to continue to grow. As outlined elsewhere in this report, this demand continues to grow despite supply limitations from China, the country that currently produces over 95%⁴⁶ of the world's rare earth elements.

3.5.1 Background and Uses

Applications for rare earths include: phosphors in liquid crystal displays, light emitting diodes (LED), and compact fluorescent lamps (CFL). They are also used as important elements in permanent magnets (used for permanent magnet motors and wind farm operations), and in batteries.⁴⁷ Some rare earths are used as fluid cracking catalysts for oil refining, in automotive catalytic converters, as parts of glass polishing compounds, and as elements in alloys. In addition, rare earth elements are used in a variety of technologically complex defense applications, such as missile guidance systems and laser based targeting equipment.⁴⁸ It should be noted that there are very strong national security concerns in the United States in regards to these materials, and that trade associations such as the U.S. Magnetic Materials Association exist entirely to “promote domestic production of the entire supply chain of materials used in magnet systems production to serve our nations defense needs.”⁴⁹

⁴⁵ Congressional Research Service, (2011), *Rare Earth Elements: The Global Supply Chain*

⁴⁶ CBC News, (June 21st, 2007), *Rare Earths: An Abundance of Riches in the Hands of a Few*, <http://www.cbc.ca/news/background/tech/rare-earths.htm>

⁴⁷ Technology Metals Research, LLC, *Critical Rare Earths, Global Supply and Demand Projections and the Leading Contenders for New Sources of Supply*

⁴⁸ Congressional Research Service, (September 30th 2010), *Rare Earth Elements, The Global Supply Chain*

⁴⁹ US Magnetic Materials Association website, <http://www.usmagneticmaterials.com/>

Rare earth elements are generally split into light (more common) and heavy rare earths. Different rare earth elements have varying end uses. The following table shows the most common end uses for several of the rare earths.

Table 9: Rare Earth Elements: Selected End Uses

Light Rare Earths (more abundant)	Major End Use	Heavy Rare Earth (less abundant)	Major End Use
Lanthanum	hybrid engines, metal alloys	Terbium	phosphors, permanent magnets
Cerium	auto catalyst, petroleum refining, metal alloys	Dysprosium	permanent magnets, hybrid engines
Praseodymium	magnets	Erbium	phosphors
Neodymium	auto catalyst, petroleum refining, hard drives in laptops, headphones, hybrid engines	Yttrium	red color, fluorescent lamps, ceramics, metal alloy agent
Samarium	magnets	Holmium	glass coloring, lasers
Europium	red color for television and computer screens	Thulium	medical x-ray units
		Lutetium	catalysts in petroleum refining
		Ytterbium	lasers, steel alloys
		Gadolinium	magnets

Source: Congressional Research Service, (2011), *Rare Earth Elements: The Global Supply Chain*

3.6 Market for Rare Earths

World demand for REEs was estimated at 136,100 tonnes in 2010,⁵⁰ with global production in 2010 totalling roughly 133,600 tonnes.⁵¹ Global demand is expected to continue to grow, while global supply projections remain unclear. Many REE projects are currently being undertaken, however these projects tend to take over ten years to go from exploratory testing to actual production and require substantial investment and supporting infrastructure.

⁵⁰ Bloomberg.com, (October 25, 2010), *Lynas Says Rare Earths Demand to Grow at 9% a Year*, <http://www.bloomberg.com/news/2010-10-25/lynas-corp-says-global-demand-for-rare-earth-to-expand-at-9-annually.html>

⁵¹ U.S. Geological Survey, *2011 Mineral Commodity Summary for Rare Earths*

Table 10: Global Rare Earth Element Oxide Consumption by Volume/Value in 2008

Use	Value	Volume
Magnets	37%	21%
Phosphors	31%	7%
Ceramics	4%	6%
Other	3%	7%
Catalysts	5%	19%
Glass	2%	10%
Polishing	4%	12%
Metal Alloys	14%	18%

Source: Industrial Mining Corporation of Australia (IMCOA), *Meeting Demand in 2014: The Critical Issues*, <http://www.reitaglobal.org/storage/The%20Road%20to%20Commercial%20Rare%20Earths%20Production%20IMCOA.pdf>

3.6.1 Global Supply and Demand

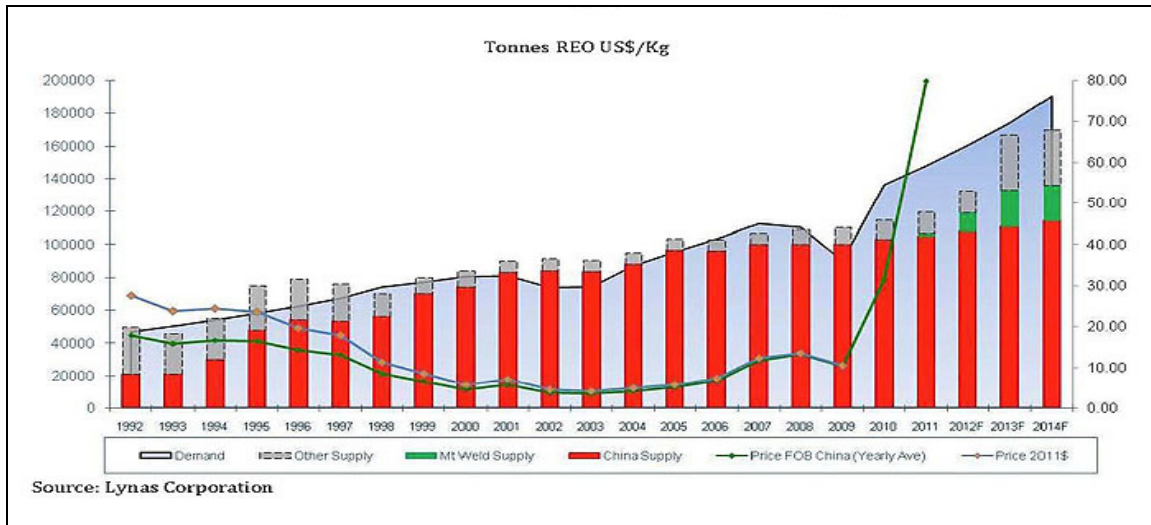
As highlighted briefly above, the supply of rare earth elements is currently being reduced while the possible technological applications for rare earth elements are increasing and the potential market for these elements is growing. China currently represents roughly 60% of global rare earth elements consumption.⁵² Due to the fact that they represent 95% of the global supply and are in the process of cutting their exports, they will likely continue to dominate rare earth element consumption in the short term.

Mine production, especially when it concerns China, only explains a portion of the picture. As detailed above, China has been cutting their export quotas and prices of rare earth elements have been climbing, which has caused the rest of the world to consider entering the sector. This has resulted in a great deal of speculation in regards to what is going to happen to the supply, potential demand and prices of rare earth elements.

The following chart provides projections out to 2014 for supply, demand and pricing:

⁵² Industrial Minerals Company of Australia (IMCOA), *Meeting Demand in 2014: The Critical Issues*, <http://www.reitaglobal.org/storage/The%20Road%20to%20Commercial%20Rare%20Earths%20Production%20IMCOA.pdf>

Figure 4: Projected Supply and Demand of Rare Earth Elements



Source: Lynas Corporation. REO means rare earth oxides

While no two projections for supply and demand are exactly the same, the Industrial Minerals Company of Australia (IMCOA) projections that the US Congressional Research Service use echo the chart above. According to the IMCOA projections, global demand for REEs may reach 185,000 tonnes per year by 2015.⁵³ China's output may reach 140,000 tonnes per year by 2015, while their demand is predicted to rise from 73,000 to 111,000 tonnes by the same date.⁵⁴ Overall, non-China output of REEs will need to be between 45,000 tonnes and 70,000 tonnes annually in order to meet global REE demand. New mine production will make up the difference for some of the REEs, however some forecasts show that there could be shortfalls of other REEs such as dysprosium, terbium, neodymium, europium and erbium.⁵⁵ The Lynas Corporation's Mt. Weld project is expected to produce 40,000 tonnes per year by 2013, and Molycorp's Mountain Pass mine is expected to add 20,000 tonnes to that number.

However, it should be noted that Mountain Pass has had difficulties going into operation, and has been shut down due to environmental difficulties in the past (2002). The US Congressional Research Service report also cites the Avalon Rare Metals Northwest Territories holdings as a potential source in the near term. That project, as noted in this report, has several difficult hurdles to overcome before it can be considered a definite future source of REEs, and the whole project could very well fall through depending on several factors largely outside of the control of those involved in the project (please see

⁵³ IMCOA, (March 2011), *Meeting Rare Earth Demand in the Next Decade*

⁵⁴ *ibid*

⁵⁵ Congressional Research Service, (2011), *Rare Earth Elements, The Global Supply Chain*

section on Canadian REE operations). In summary, while the demand for REEs is certain to grow substantially over the short and long term, the supply of REEs is not nearly as certain.

Another possibility for increasing REE supply is REE recycling. However, until the last few years, rare earth prices have been so depressed (due to the situation in China) that rare earths could not be cost effectively recovered through recycling. While rising prices could be an incentive for stimulating research activity into recycling technology, the majority of REE recycling technologies currently in play are in the research stage and may not reach commercialisation.⁵⁶ It is estimated that less than one percent of REE were recycled from scrap in 2009, and the recycling processes for rare earths are currently quite complex and require both physical and chemical treatments. These recycling technologies are also energy-intensive processes.⁵⁷

3.7 Lithium

Lithium has been called the “holy grail-battery material.”⁵⁸ Technological advances continue to progress in utilizing this metal, and it has potential applications that include individual and public transportation, power grid storage for peak period relief, power storage for green energy applications, and many others. Substantial research dollars from companies such as IBM are being invested in advancing lithium battery technology, and as the technology continues to get better, demand will likely continue to rise.

3.7.1 Background and Uses

Lithium is used in a variety of different products, including ceramics and glass (31%), batteries (23%), lubricating greases (9%), air treatment (6%), primary aluminium production (6%), continuous casting (4%), rubber and thermoplastics (4%), pharmaceuticals (2%), and other uses (15%).⁵⁹ “Other” uses include alloys, constructions, dyestuffs, industrial bleaching and sanitation, pool chemicals, and specialty inorganics. Lithium batteries are likely to be the fastest growing application for lithium, especially as technology continues to improve, opening up new possible applications.

⁵⁶ British Geological Survey, (November 2011), *Rare Earth Elements*

⁵⁷ *ibid*

⁵⁸ Engadget.com, (June 27th, 2009), *Waterproof Lithium Metal-Air Batteries Could Revolutionize Portable Power*, <http://www.engadget.com/2009/06/27/waterproof-lithium-metal-air-batteries-could-revolutionize-porta/>

⁵⁹ United States Geological Service, *2011 Mineral Commodity Summary for Lithium*

3.7.2 Global Supply and Demand

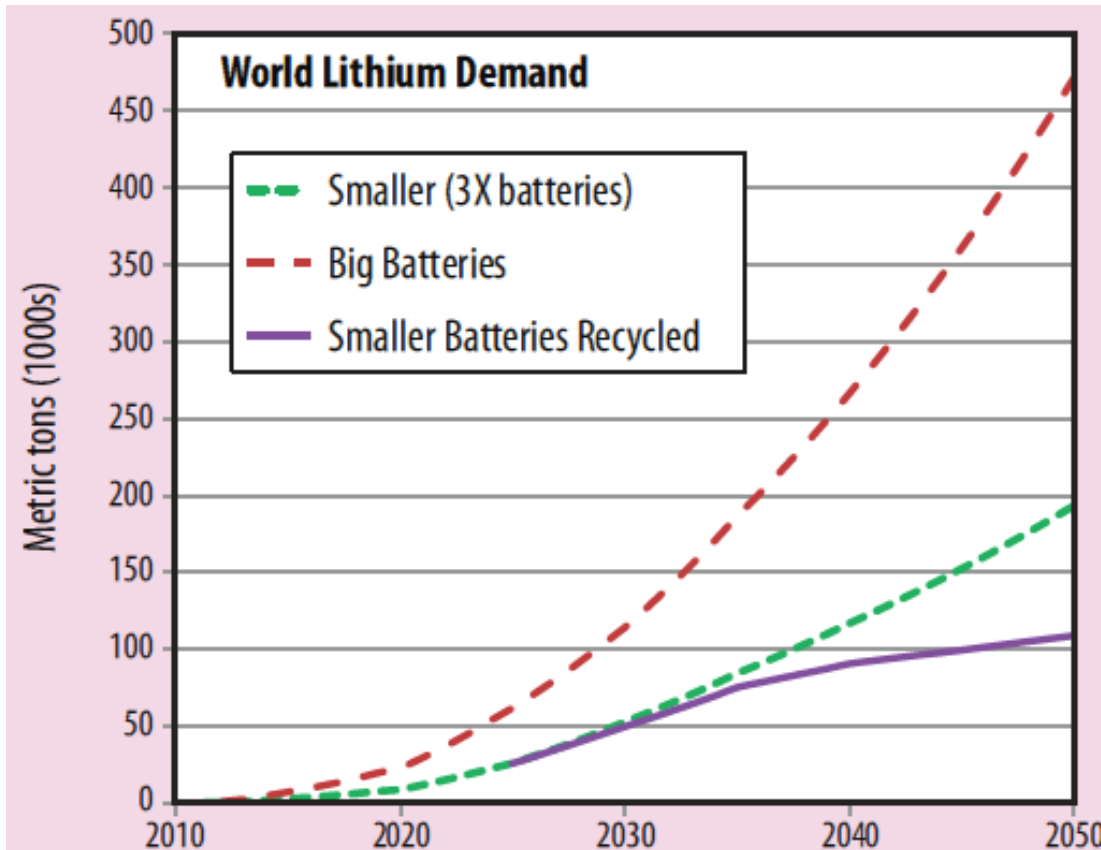
The segment that represents the greatest possibilities for growth for lithium is batteries. Most cellular phones and laptop computers are powered by lithium batteries, as are many heavy-duty power tools. Laptop sales increased 23% in between 2006 and 2007, and another 25% in between 2007 and 2008, and laptop and cell phone sales are not expected to drop.⁶⁰ Lithium-ion battery production represented 75% of the global portable rechargeable battery market worldwide in 2009, and growth is expected to continue. Asia continues to represent the largest part of the market for battery grade lithium consumption, as in 2009 39% of lithium-ion battery production occurred in Japan, 36% in China, and 20% in the Republic of Korea. The amount of lithium consumed globally increased by 20% per year for a few years preceding 2009, indicating that this market will continue to grow quickly. One of the chief determinants of the growth of demand for lithium is the growth of hybrid vehicles.⁶¹

While the laptop sales and cell phone sales above do show significant growth, those batteries are much smaller and require much less lithium than the batteries meant for hybrid (or fully electric) vehicles. There has been a great deal of speculation regarding whether or not world reserves or production could possibly meet the demand posed by lithium batteries for hybrid or electric cars in the coming years. The following figure shows projected demand for small and large batteries up until 2050. Based on assumptions that many vehicles will be either hybrid or fully electric by 2050 (a 90% figure for 2050 is assumed) this table represents possible growth in lithium demand for batteries. As global production totals currently only represent roughly 25,000 tonnes, the possibility that demand could increase to over 500,000 tonnes by 2050 shows that lithium production will need to increase substantially.

⁶⁰ Meridian International Research, (May 2008), *The Trouble With Lithium 2*

⁶¹ US Geological Survey, *2009 Minerals Yearbook, Lithium*

Figure 5: World Lithium Demand for Batteries



Source: US Department of Energy Laboratory, Managed by UChicago Argonne, LLC

However, lithium batteries in their current state of development could not effectively be used in hybrid or electric vehicle applications to the extent shown above. Instead, new technologies are currently under development to increase lithium battery efficiency and storage. For example, lithium metal-air batteries are currently within five years of implementation, and could potentially have over ten times the capacity per kilogram of current lithium-ion batteries.⁶² With substantial investments in the technology coming from IBM⁶³ and other companies, there is potential for these batteries to provide viable solutions to the problems currently stopping lithium-ion batteries from fulfilling more roles (transportation, electric grid), thus substantially increasing demand for lithium.

62 Technology Review India, (June 26th, 2009), *Waterproof Lithium Air Batteries*, <http://www.technologyreview.in/energy/22926/page1/>

63 Technology Review India, (June 11th, 2009), *IBM Invests in Battery Research*, <http://www.technologyreview.in/energy/22780/>

While demand is certainly rising, information on possible supply increases is somewhat less definitive. The following table shows the world total for base reserves for lithium with individual information on the reserves of a number of specific countries, including Canada.

Table 11: Lithium Reserve Base
(tonnes)

Country	Reserve Base
Bolivia	5,400,000
Chile	3,000,000
China	1,100,000
Brazil	910,000
Argentina	not available
United States	410,000
Canada	360,000
Australia	220,000
Portugal	not available
Zimbabwe	27,000
World Total (Rounded)	11,000,000

Source: Us Department of Energy Laboratory, Managed by UChicago Argonne, LLC

New potential demand for lithium is driving developments. New projects are moving forward in: Australia, Bolivia, Canada, Finland, the Republic of Korea, and Serbia.⁶⁴ Some of these new projects, however, may be more feasible than others. As discussed earlier, brine based lithium extraction is far less expensive than spodumene mining, and as a result lithium mined from spodumene deposits may not be able to compete with lithium extracted from brine. However, if brine based lithium mining is found unable to meet growing demand, then lithium mined from spodumene could potentially become economically viable. Further complicating the picture is current investigation into the possibility of extracting lithium from seawater. In 2009, the government of the Republic of Korea acquired technology to extract lithium from seawater.⁶⁵ In early 2010, the government signed an agreement with POSCO (A Korean company) and the Korea Institute of Geoscience and Mineral Resources to conduct joint research and to build a pilot plant for the commercial production of lithium from seawater (seawater has an

⁶⁴US Geological Survey, *2009 Minerals Yearbook, Lithium*, <http://minerals.usgs.gov/minerals/pubs/commodity/lithium/myb1-2009-lithi.pdf>

⁶⁵ibid

average lithium concentration of 174mg/l or 0.17ppm⁶⁶). Construction of this project is scheduled to be completed by 2014.

Another layer of complexity for world lithium supply going forward involves the potential for lithium recycling. As shown in figure 5 above, some researchers believe that lithium recycling will become increasingly important in the future. As of this time, there is little economic need to recycle lithium-ion batteries, as most batteries only contain small amounts of lithium carbonate as a percentage of weight and the material is still relatively inexpensive.⁶⁷ However, depending upon future supply and demand this situation could easily change.

The technology to recycle lithium is currently being used, in 2009 the US Department of Energy granted \$9.5 million to Toxco (a battery recycling company based in California) to expand one of their plants to recycle lithium.⁶⁸ Toxco's website states that they are currently the only company in the world that is able to recover lithium from any size or type of lithium battery, however, indicating that the technology is not currently widespread.⁶⁹ Chemetall (a company that produces lithium) is also involved in LithoRec, a German public/private research venture to develop viable and cost effective lithium recycling technologies.⁷⁰ Chemetall also expects lithium recycling to increase a great deal after 2030, when it is assumed that there will be more electric cars ending their service life with large lithium batteries that will need to be recycled. While some forecasts exist for potential future lithium recycling operations (Figure 5 being an example) there is no guarantee as to the accuracy of these forecasts.

⁶⁶ Meridian International Research, (May 2008), *The Trouble With Lithium 2*

⁶⁷ MIT Technology Review, (August 12th, 2009), *Lithium Battery Recycling Gets a Boost*

⁶⁸ *ibid*

⁶⁹ TOXCO Website, accessed February 23rd, 2012, <http://www.toxco.com/aboutrecycle.html>

⁷⁰ LithoRec, <http://www.lithorec.de/index.php?id=30&L=0#>

4. Mining and Processing Methods Used for Rare Earth Elements and Lithium

4.1 Rare Earth Elements⁷¹

Several steps are required to take rare earth elements from their deposits to commercially viable product. The deposit (usually bastnasite or monazite) must be mined, and the mineral must then be processed to produce a bastnasite or monazite ore. This ore is then processed further, producing a rare earth oxide that may contain 60-70% rare earth elements, perhaps more. This rare earth oxide is then put through one of many possible separation processes, to obtain commercially viable rare earth elements.

4.1.1 Rare Earths Elements Mining

Rare earth elements mining is by and large very similar to other types of mining. Strip mining is often practiced, and the same types of vehicles and equipment used in the rest of the mining sector are often employed in removing the rare earth bearing materials from the ground. Rare earth elements are found primarily in bastnasite and monazite. Bastnasite deposits in China and the United States currently make up the largest percentage of the world's resources (and is the primary ore type found at the Thor Lake deposit in the Northwest Territories). Monazite deposits in Australia, Brazil, China, India, Malaysia, South Africa, Sri Lanka, Thailand and the United States constitute the world's second largest source of potential supply. Apatite, cheralite, eudialyte, loparite, phosphorites, rare earth bearing (ion adsorption) clays (China only), secondary monazite, spent uranium solutions, and xenotime make up the earths remaining resources. However, undiscovered sources are thought to make up the bulk of the world's resources in rare earth elements.⁷² Rare earth elements are usually found in concentrations that are either heavier in Light Rare Earth Elements (LREEs) or in Heavy Rare Earth Elements (HREEs). While a deposit will almost always contain some of both, the value of the find will lie either in the heavy elements or the light ones. The majority of mining and processing that occurs worldwide (especially outside of China) occurs with LREEs (this includes Mountain Pass).

Bastnasite is a mineral that is found in some kinds of rock including bauxite deposits, carbonatites (a rare carbonate igneous intrusive rock), and rarely in some granites. The Molycorp Mountain Pass facility mines rare earth ore from a bastnasite deposit in an open

⁷¹ US EPA, OSWER, Office of Resource Conservation and Recovery, *Identification and Description of Mineral Processing Sectors and Waste Streams, Rare Earths Chapter*

⁷² US Geological Survey, *2011 Mineral Commodity Summary for Rare Earths*

pit approximately 100 metre deep. Blast holes are generally drilled every 3 to 4 m, and are routinely assayed for total rare earth oxides or other elements by X-ray fluorescence methods. Approximately 300 kilotonnes (kt) per year are mined with a stripping ratio of 5:1. The ore is crushed and blended in stockpiles that contain roughly 40 kt and fed into a mill located close by.

Monazite can occur in hard rocks and be mined in a manner similar to that of bastnasite. However, some monazite deposits occur in heavy mineral sands. These mineral sands are mined by floating cutterhead or bucket wheel dredges that concentrate the heavy minerals on board, and discharge the unwanted tailings back into previously mined areas. Onboard the dredges, wet mills separate the heavy minerals from the lighter weight fraction through a series of wet gravity equipment that may include screens, hydroclones, spirals and cones. Wet mill mixed heavy mineral concentrate is sent to a dry mill to separate the individual heavy minerals and produce a concentrate. Dry mill processing includes a combination of scrubbing, drying, screening, electrostatic, electromagnetic, magnetic, and gravity processes. Gravity methods include the use of jigs, spiral and cone concentrators, and shaking tables. Sizing and preconcentration is commonly performed at the mine site by trommels, shaking screens, and gravity separation. Many dredges have such facilities on board or utilize floating preconcentration plants. Monazite can be separated from zircon by electrostatic methods such as electromagnetic or gravity methods. Some deposits may require acid leach treatment and calcining to eliminate iron oxide or other grain coatings.

4.1.2 Bastnasite and Monazite Ore Processing

The above processes generally accomplish both the removal of rare earth containing materials from the ground, and the separation of some undesired substances from the bastnasite or monazite ores. Recovering rare earth oxides (which can then be separated into distinct rare earth elements) is another process altogether. Different processes are used to recover rare earth oxides from monazite ore and bastnasite ore. These processes can achieve rare earth oxides containing roughly 60-70% rare earths. The following process descriptions are taken from a US EPA Office of Resource Conservation and Recovery Report for rare earths. The report uses the processes applied at Mountain Pass (for the bastnasite extraction description) and a mine from Green Cove Springs, Florida for their description of Monazite mining.

Rare earth metals are recovered as oxides from monazite ore by sulfuric acid digestion. The ore undergoes grinding, spiralling, or other similar operations for the initial coarse purification of the ore. Magnetic separation removes the magnetic ore constituents that can be processed separately or discarded as waste. The refined ore is then digested with sulfuric acid at 200-220°C. Rare earth sulfates and thorium sulfates are then dissolved and removed from the waste monazite solids by filtration. Rare earth elements are then precipitated as oxalates or sulfates. These precipitates undergo caustic digestion or

roasting to form rare earth oxides that are finally recovered by filtration. The resulting filtrate is discarded as waste.

To recover rare earth chlorides from bastnasite ore, the ore is crushed, ground, classified, and concentrated to increase the rare earth concentrations. Tailings produced during these operations are discarded as waste. The concentrated bastnasite undergoes an acid digestion to produce several rare earth chlorides; hydrochloric acid is used to digest the bastnasite. The resulting slurry is filtered, and the filter cake is further digested with sodium hydroxide to produce rare earth hydroxides. This rare earth hydroxide cake is chlorinated, converting the hydroxide to chlorides. Final filtration and evaporation yields the solid rare earth chloride products. The wastes produced include a sodium fluoride filtrate, which can be recovered for further processing, and filter cake that is discarded.

In general, the chemical upgrading of ore to make concentrate involves attacking the ore chemically. This may include roasting, salt or caustic fusion, high temperature sulphation, acid leaching as required to decompose the minerals in a given concentrate and allow the rare earth elements to be dissolved. The leach solutions can then be processed using selective precipitation, solvent extraction, or ion exchange processes to remove most of the impurities and produce higher grade intermediate chemical compounds suitable for refining. The nature of the final product of the chemical upgrading process (and the wastes produced) depends on the exact composition of the mineral concentrate, market demands, and the size of the operation. The output from different chemical upgrading plants can be quite similar in composition. For example, two plants handling quite different feed materials might both make a bulk carbonate precipitate containing about 50% of the heavy rare earth oxides with similar rare earth distributions.⁷³

Flotation is used at Mountain Pass to make a bastnasite concentrate containing about 60% rare earth oxides. This concentrate is either used on site as feed for the chemical separation of rare earth elements, or leached to produce a 70% rare earth oxide concentrate. Rare earth elements are extracted in a concentrated solution of sodium hydroxide at 140 to 150°C. After cooling, hydroxides of rare earth elements and thorium are recovered by filtration, and thorium is separated by selective precipitation or dissolution. At Mountain Pass, bastnasite is calcined to drive off carbonate (as CO₂) and fluorine, and leached with hydrochloric acid to dissolve most of the trivalent rare earth elements. The residue can then be sold as a polishing abrasive.

4.1.3 Rare Earth Elements Separation

While mining rare earth elements is somewhat similar to other types of mining, the separation process is unique, and by industry accounts difficult. As can be seen from the

⁷³ Rare Earth Metal Blog, *Extracting and Refining Rare Earths, Can Some Processes be Centralized?*, <http://www.raremetalblog.com/2010/01/blog-.html>

fact that most rare earth elements occupy the same row of the periodic table, rare earth elements are similar to one another. Dividing rare earth bearing materials into separate elements is therefore a difficult and time-consuming process. While information on all of the possible rare earth element separation technologies is not available (and would be considered confidential information by many businesses) some information on separation steps was acquired for this study. Rare earth hydroxides and chlorides acquired from sulphuric and hydrochloric acid digestion (outlined above) go through further processing to recover individual rare earth metal compounds in the form of fluorides, nitrates, carbonates, oxides, and pure metals. Processes include fractional crystallization, fractional precipitation, solvent extraction, ion exchange, and reduction. The following table Table summarizes the processes and their associated wastes while more detail is provided in the subsequent sections.

Table 12: Rare Earth Separation Processes and Associated Wastes

Separation Process	Associated Wastes
Fractional Crystallization and Precipitation	Waste salts and salt solutions (may contain organic fractions)
Solvent Extraction	Spent solvents
Ion Exchange	Waste solution containing metals, complexing agents such as EDTA. Solution may be acidified, neutral or basic.
Calcium Reduction	Calcium fluoride, calcium chloride slag ⁷⁴

4.1.3.1 Fractional Crystallization and Precipitation⁷⁵

In fractional crystallization, changing the salt concentrations in solution through evaporation or temperature control precipitates one or more rare earths in a mixture. Fractional precipitation involves adding a precipitating agent to selectively remove a metal from solution. These two processes generally produce waste salts and salt solutions requiring treatment and disposal. If organic precipitation is used, then organic containing waste fractions may be produced as well.

⁷⁴ Gupta, Krishnamurthy, *Extractive Metallurgy of Rare Earths*, 2005

⁷⁵ Narayan Thakur, *Rare Earths, Chemistry and Applications*, <http://knol.google.com/k/rare-earths#>

4.1.3.2 Solvent Extraction⁷⁶

To separate individual rare earths in a mixture from each other, an aqueous solution containing rare earth salts is sent counter-current to an immiscible organic stream that selectively extracts one rare earth from the others. Several stages of extractions are needed to separate each rare earth metal. Each organic stream is then scrubbed with an aqueous stream to transfer the rare earth element into an aqueous phase. Since all of the products are aqueous solutions, the spent solvents leave the process as wastes. Solvent extraction can be a fast and continuous process, and as a result has become the most commonly used method of separating rare earth elements.

4.1.3.3 Ion Exchange⁷⁷

Ion exchange produces highly pure rare earths in small quantities. For separating a lanthanide mixture, a cation exchange resin is flushed with a solution such as cupric sulfate to prepare the resin for ion exchange. A solution containing the lanthanides is then passed over the ion exchange resin. The lanthanides displace the cation on the resin surface. This step produces an aqueous waste containing the cation that was exchanged, and small amounts of rare earths. At this stage, the lanthanides have been deposited on the resin as a mixture. To separate individual rare earth elements, a chemical solution containing a complexing agent, such as NH_4^+ -ethylenediaminetetraacetic acid (EDTA), is passed over the resin. The EDTA has a high affinity for rare earths, and the lanthanides are complexed with the EDTA and displaced by NH_4^+ on the resin. Each lanthanide has a different affinity for EDTA, and individual lanthanides can be separated and recovered as a result of these varying affinities. Relative to the amount of product generated, large quantities of waste solutions are generated during the process. The waste solutions may be acidic, basic, or neutral, and will contain the metals displaced from the resin during ion exchange, as well as the complexing agents used.

4.1.3.4 Calcium Reduction

High purity rare earth metals can be produced by the metallothermic reduction of rare earth halides. This process is used when 99.99% purity is required. After converting the rare earths into fluorides, they are reduced to the metallic state through contact with calcium or barium at high temperatures.

⁷⁶ Narayan Thakur, *Rare Earths, Chemistry and Applications*, <http://knol.google.com/k/rare-earths#>

⁷⁷ *ibid*

Ten of the rare earths (lanthanum, cerium, praseodymium, neodymium, gadolinium, terbium dysprosium, holmium, erbium, and lutetium as well as scandium, and yttrium) are produced by calcium reduction. The raw material form of these metals is the metal fluoride. The individual metal fluoride is placed with calcium metal into a reduction vessel where a heat -driven reaction produces pure rare earth metal and calcium fluoride. The metals are further purified by melting in a vacuum to remove impurities. Casting is dependent upon the form in which a buyer wants the metal. Non-contact cooling water is used to cool both the reduction vessels and the melting and casting equipment.

4.2 Lithium

Lithium is harvested either through mining spodumene deposits or through extracting lithium from brine. Mining spodumene deposits is similar to other hard rock mining processes, and will have similar effects on the landscape. There are a few different general methods available to process spodumene, two of which are detailed below. Extracting lithium from brines is generally the preferred method of getting lithium, as it is far more cost effective. While several methods exist for extracting lithium from brines, the ones outlined in the relevant section below remain the most commonly utilized.

4.2.1 Lithium Mining From Spodumene Deposits

The hard rock mining method, where lithium is extracted from spodumene deposits, is far more costly than brine based extraction. Sources accessed during preliminary research have categorically stated that spodumene based lithium mining operations cannot be economically feasible unless other high value elements can be found in the spodumene deposits along with lithium.⁷⁸ However, several of the Canadian exploratory ventures outlined in this report are planning on using non-brine lithium sources, and therefore must believe that this type of extraction could still potentially be profitable. The mining process itself is fairly basic, and the product extracted from the mines generally undergoes a flotation beneficiation process in order to produce a concentrate. The lithium concentrate then most commonly undergoes one of two processes, which are the soda ash method and the sulphuric acid method.

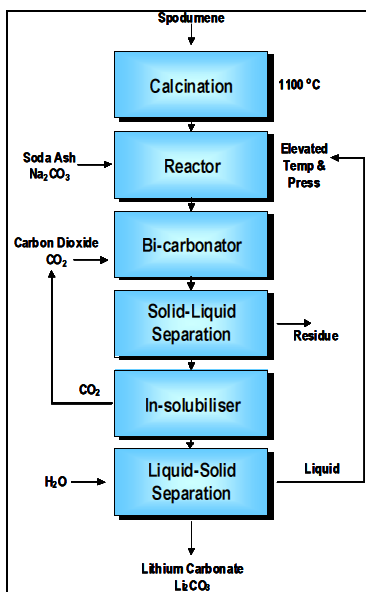
In both methods, the first step is calcination, where the alpha spodumene concentrate (5% Li₂O content) is transformed into more reactive beta spodumene by heating to 1100°C. After calcination the two processes diverge.

⁷⁸ Meridian International Research, (May 2008), *The Trouble With Lithium 2*

4.2.1.1 Soda Ash Process

In the soda ash process, the beta spodumene resulting from the calcination is treated with soda ash at elevated temperature and pressure. The lithium is transformed into lithium carbonate. Once cooled, the slurry is fed to a carbonation reaction treatment with carbon dioxide (again, under pressure) to form lithium bicarbonate, thus increasing the solubility of the lithium content. The solution is then separated to remove solids like aluminum silicate and iron and magnesium salt residues. The liquor is then fed to an evaporator at around 90°C, liberating carbon dioxide and precipitating lithium carbonate. This lithium carbonate is then recovered through filtration, and the liquor is recycled back to the extraction process. The filtered lithium carbonate is further purified using an ion exchange. The following diagram shows the process flow of the soda ash process.

Figure 6: Lithium Extraction from Spodumene Using the Soda Ash Method



Source: Galaxy Lithium Media Release

4.2.1.2 Sulphuric Acid Process

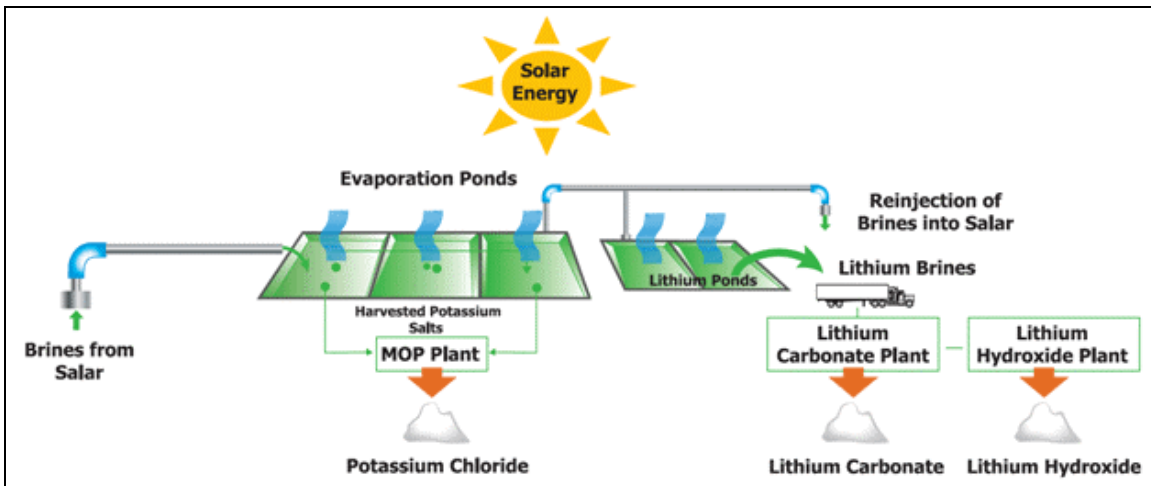
This treatment facilitates extraction of the spodumene into sulfuric acid at 250°C giving lithium sulfate. After solid-liquid separation to remove solids, the solution is treated with sodium hydroxide and sodium carbonate to form sodium sulphate (Glauber salt) and precipitated lithium carbonate. The lithium carbonate product is recovered by filtration

and the lithium sulphate solution is recycled to the front of the process where the Glauber salt is precipitated by cooling.

4.2.2 Lithium Extraction From Brine

The process used to obtain lithium carbonate from brine is known as the lime soda evaporation process. The salty water is pumped out of a main lake and into a series of shallow ponds, where it is left to evaporate for 12 to 18 months. Different salts crystallize out at different times and as this happens the solution becomes more concentrated. Boron, which concentrates with the lithium, is removed using an extraction process. Then the product is treated with a base (such as lime) to remove magnesium. Then, the initial volume of water is reduced, at which point the concentrate is treated with soda ash to precipitate out insoluble lithium carbonate. A basic process diagram is shown below.

Figure 7: Lithium Production From Brine Sources



Source: Rodinia Lithium Website

Some other processes have been developed, but they are not often practiced. German Patent DE 19,541,558 describes a process to reduce sodium from lithium by cooling. US Patent 7,214,355 (from 2007) describes a new method of extracting lithium from brines with fewer processing steps than what is described above, but it is not clear if this process is currently in use. The process is detailed and complex, please see US Patent 7,214,355 for further details.

5. Substances and Parameters of Environmental Concern in Rare Earth Elements and Lithium Mining

5.1 Rare Earth Elements

There are three main potential environmental issues related to mining and processing rare earth elements:

- by-products present in rare earth element deposits;
- thorium present in rare earth element deposits; and
- chemicals used in processing/separation of rare earth elements (and resulting waste chemical management).

These three potential concerns are present at different stages of the mining and separation process, and are expanded upon along with relevant background below.

5.1.1 Rare Earth Element Mining/Beneficiation

Rare earth element mining is quite similar to other kinds of mining, and has similar pollutants and/or effluents associated with it, namely magnetic fractions and tailings. What is important to note, however, is that nearly all by-products or waste materials from rare earth processing are naturally radioactive due to contained thorium. Thorium is often extracted from monazite (and is also found in bastnasite deposits containing rare earths), which also happens to be a strong source of rare earth elements. As thorium is a naturally occurring radioactive element, handling the thorium can be an environmental concern.

Thorium disposal and radiation is the main concern that could shut down or delay the Lynas Corporation plant in Malaysia.⁷⁹ Thorium disposal also caused the shut down of a Mitsubishi rare earth element plant in Malaysia in 1992, the company has since needed to spend an estimated \$100 million to clean up the site.⁸⁰ Additionally, thorium radiation from improper disposal has been cited as a major reason the Chinese have slowed production and tried to increase environmental oversight for rare earth element mining and processing. How to properly dispose of thorium remains a challenge in the industry,

⁷⁹ International Business Times, (March 16th, 2011), *Thorium: Rare Earth Liability or Asset?*, <http://www.ibtimes.com/articles/123268/20110316/thorium-rare-earth-liability-or-asset.htm>

⁸⁰ NY Times, (March 8th, 2011), *Mitsubishi Quietly Cleans Up Its Former Refinery*, <http://www.nytimes.com/2011/03/09/business/energy-environment/09rareside.html>

although thorium is also a potentially important resource. Thorium can be used as fuel in Canadian CANDU nuclear reactors⁸¹ and is used in other industrial applications, leaving a potential for thorium to be used and sold commercially. The options that Canadian industry adopts in regards to thorium disposal or use are likely to depend on regulations, individual site specific factors, and economic/market factors that are likely to be company specific.

5.1.1.1 Avalon Rare Metals Case Study: Projected Air Pollutants and Tailing Effluents

Avalon Rare Metals Inc. is currently working on developing a rare earth element project near Thor Lake in the Northwest Territories. The company is working on an environmental assessment of the Thor Lake property, and has projected environmental releases to both air and water that may result from rare earth element mining and beneficiation processes. It should be noted that this information shows potential releases, and that the facilities projected to release these pollutants or effluents have not yet been built. Actual releases may be different. All of the information provided in this subsection is taken from the Avalon Rare Metals environmental assessment, available at the following Mackenzie Valley Review Board website:

http://www.reviewboard.ca/registry/project_detail.php?project_id=87&doc_stage=5.

5.1.1.1.1 Emissions to Air

Insofar as emissions to air, the environmental assessment covers some criteria (or common) air contaminants (CACs) and greenhouse gases (GHGs). The specific CACs included in the scope of the assessment were:

- nitrogen dioxide (NO₂);
- sulphur dioxide (SO₂);
- carbon monoxide (CO);
- total particulate matter (TSP);
- particulate matter with diameter less than 2.5 µm (PM_{2.5}); and
- dustfall.

⁸¹ Energy Conservation and Management, Issues 13-14, (August 2006), *Investigation of CANDU reactors as a thorium burner*

The GHGs that were included in the scope of the environmental assessment were:

- carbon dioxide (CO₂);
- methane (CH₄); and
- nitrous oxide (N₂O).

Exact numbers for releases from the processes listed in the table below were not available due to the preliminary nature of the study. However, the rankings of major, moderate or minor sources does give some indication as to how much of a given air pollutant might be released. This table covers both the activities to do with the mine, as well as the activities that take place in the flotation plant that turns the ore into a rare earth oxide. For further information on the emissions sources or the methodology employed in assembling the information below, please consult the environmental assessment at the website listed above.

Table 13: Emission Sources at the Nechalacho Mine and Flotation Plant

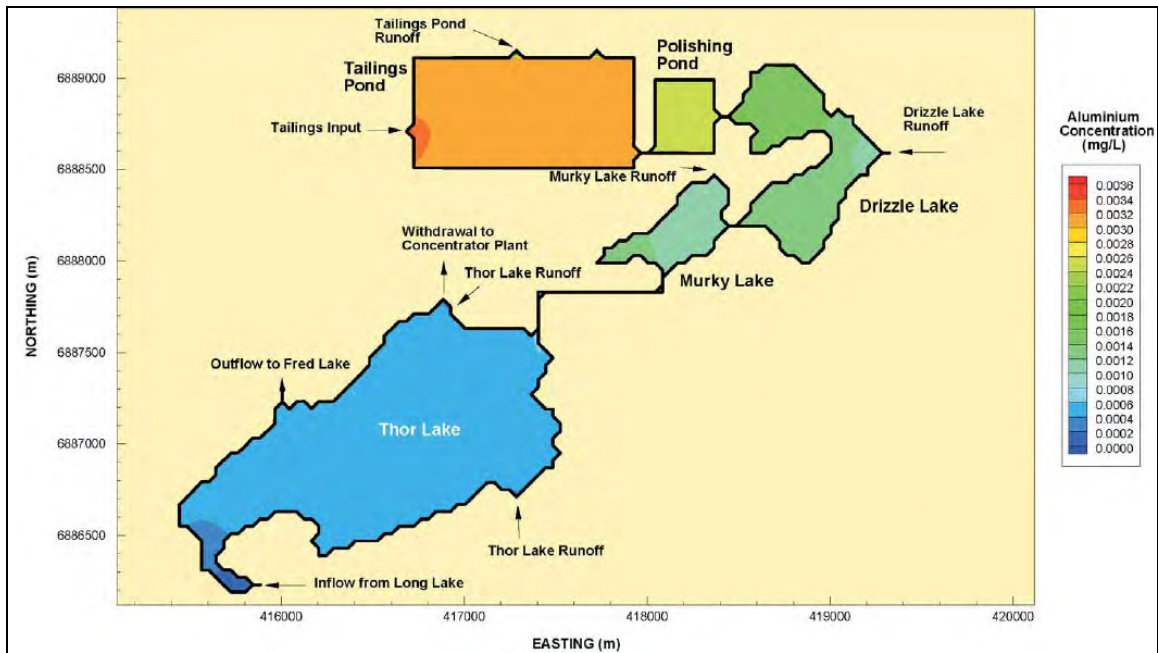
Source	Type of Emissions	Rank	Comments
Underground Mining Activities and Processing	CACs and GHGs	Major	CAC, GHG and fugitive dust emissions from all mining and crushing activities will be concentrated through two ventilation raises
Exhaust from Mine Air Heater Stacks	CACs and GHGs	Major	Mine air heater will heat 300,000 cfm when the ambient temperature is less than 0°C
Exhaust from Diesel Generator Stacks	CACs and GHGs	Major	Six diesel generators will be used to supply all power to the mine and flotation plant
Surface Equipment	GHGs	Major	Fuel combustion in equipment is a large source of GHGs
Transfer and Handling of Ore	CACs	Moderate	Ore transfer and handling is a moderate source of PM emissions
ANFO Explosives	GHGs	Moderate	ANFO explosives are a moderate source of CO ₂ emissions
Fuel Combustion in Vehicles	CACs and GHGs	Minor	Not a continuous source so CACs not modelled but GHG emissions estimated
Fugitive Dust Emissions from Haul Truck/Roads	Fugitive Dust	Minor	Fugitive dust emissions from trucks will be short-term and localized
Waste Incineration	CACs	Minor	Waste incineration is a batch process that will occur only once a day
Fuel Combustion in Aircraft	CACs and GHGs	Minor	Limited effect on ground-level ambient concentrations with infrequent operating hours
Fuel Combustion in Tugs Used to Tow Barges	CACs and GHGs	Minor	Operates only in the summer

Source: Avalon Rare Metals Environmental Assessment

5.1.1.1.2 Emissions to Water

The mining and ore concentration activities (primarily from the flotation/concentration plant) will discharge tailings into a purpose built tailings pond. These tailings will then slowly run to a polishing pond, then into a body of water called Drizzle Lake, then into Murky Lake, and finally into Thor Lake. The following diagram shows both the aluminium concentration expected to be present in these different bodies of water, as well as the structure of the tailings pond and connected water bodies for the planned mining and flotation process tailings. The assessment had diagrams such as this for iron, thorium and uranium. Please note that more metals present in tailings are shown below in table 13.

Figure 8: Avalon Rare Metals Tailings Pond and Surrounding Waters, with Aluminium Concentration Information



Source: Avalon Rare Metals Thor Lake Environmental Assessment

The environmental assessment being conducted by Avalon Rare Metals projected two different kinds of effluents that would be released to this water system through their tailings. One of these is metals, of which the chart above displays aluminium levels. Another type of effluent is nutrients, primarily nitrogen. The amount of metals that are expected to be present in the tailings were shown at what is called a “5 day decant metal concentration in tailings discharge.” This represents what the tailings from the facility

look like after 5 days in the tailings pond, as some of the metals and pollutants decant out of the solution.

Table 14: Five Day Decant Concentrations of Metals In Tailings From Mining and Flotation Plant

Metal	Day 5 Decant Metal Concentration	Metal
Hg	Below detection limit of 0.0001 mg/L	-
Ag	0.00003	-
Al	0.62	-
As	0.0022	0.50
Cd	0.000067	-
Cr	0.0011	-
Cu	0.0023	0.30
Fe	0.570	-
Mo	0.0471	-
Ni	0.0070	0.50
Pb	0.00060	0.20
Se	Below detection limit of 0.001 mg/L	-
Zn	0.007	0.50
U	0.00880	-
Th	0.000694	-
Ra-226	Below detection limit of 0.01 Bq/L	0.37 Bq/L

Note: A '-' indicates that the MMER does not specify limits for that metal.

Source: Avalon Rare Metals Environmental Assessment

The nitrogen released from the flotation plant tailings is also a potential concern, as increased nitrogen in the water can lead to increased phytoplankton growth, upsetting ecosystem balance. The Avalon Rare Metals environmental assessment report did not include information on the actual nitrogen content in the tailings, instead the assessment modelled what the concentration of nitrogen was expected to be in Thor Lake, and what effects this was likely to have on the phytoplankton population. This information was not considered essential to this report, and was not included. For further information, please see the Avalon Rare Metals environmental assessment at the Mackenzie Valley Review Board website.

5.1.1.2 Molycorp Mountain Pass Case Study: Tailings from Mining/Beneficiation

The California Regional Water Quality Board requires detailed information on the waste tailings resulting from the mining of rare earth elements at the Molycorp Mountain Pass



facility. Board Order No. R6V-2010-[Tentative], WDID No. 6B362098001 contains detailed information on the waste tailings generated by the facility, as well as information gleaned from a 33 week study on the paste tailings solids, tailings pond water, and background groundwater at Mountain Pass.

Some explanation is required in regards to exactly what is meant by paste tailings. The Mountain Pass facility employs a thickened, or “paste” technology that dewateres the tailings prior to disposal. The thickening process removes over 75% of the water present in the influent tailings slurry stream from the mill, which is typically comprised of about 65% water. The resulting paste is composed of roughly 85% solids and 15% water. The following table presents the results of a chemical analysis of the paste tailings generated at the Mountain Pass facility. Please note that “amended” paste below has had Portland cement (0.5% by weight) added to it.⁸²

⁸² California Regional Water Quality Control Board Lahontan Region, *Revised Waste Discharge Requirements for Molycorp Minerals LLC Mountain Pass Mine and Mill Operations*, available at http://www.swrcb.ca.gov/rwqcb6/water_issues/available_documents/molycorp/docs/molycorp_wdr.pdf

Table 15: Chemical Analysis of Paste Tailings From the Mountain Pass Facility

Sample		Amended Paste	Unamended Paste	TTL ¹
F	%	0.21	0.23	1.8
Hg	mg/kg	0.5	0.5	20
SiO ₂	%	23	23	-
Ag	mg/kg	< 2	< 2	500
Al	mg/kg	18000	18000	-
As	mg/kg	200	190	500
Ba	mg/kg	7200	3400	10000
Be	mg/kg	4.3	4.3	75
Bi	mg/kg	< 20	< 20	-
Ca	mg/kg	110000	110000	-
Cd	mg/kg	< 2	< 2	100
Ce	mg/kg	7000	7900	-
Co	mg/kg	8.4	8.9	8000
Cr	mg/kg	25	21	2500
Cu	mg/kg	46	47	2500
Fe	mg/kg	28000	30000	-
K	mg/kg	12000	13000	-
La	mg/kg	4900	5400	-
Li	mg/kg	< 70	< 70	-
Mg	mg/kg	23000	23000	-
Mn	mg/kg	3000	3000	-
Mo	mg/kg	< 10	< 10	3500
Na	mg/kg	2600	2300	-
Ni	mg/kg	< 10	< 10	2000
P	mg/kg	270	600	-
Pb	mg/kg	700	1500	1000
Sb	mg/kg	< 20	< 20	500
Se	mg/kg	< 50	< 50	100
Sn	mg/kg	< 50	< 50	-
Sr	mg/kg	8600	9700	-
Th	mg/kg	< 100	< 100	-
Ti	mg/kg	340	350	-
Tl	mg/kg	< 50	< 50	700
U	mg/kg	< 40	< 40	-
V	mg/kg	31	33	2400
Y	mg/kg	52	54	-
Zn	mg/kg	50	58	5000
Ra-226	Bq/g	0.36	0.39	-
Ra-228	Bq/g	0.43	0.44	-
Th-228	Bq/g	0.48	0.47	-
Th-230	Bq/g	0.26	0.3	-
Th-232	Bq/g	0.44	0.49	-
Gross Alpha	Bq/g	7.1	6.8	-
Gross Beta	Bq/g	3.2	3.1	-

¹ - Total Threshold Limit Concentrations as per California Code of Regulations Title 22, Section 66261.24(2)(A)

Source: California Regional Water Quality Board

The following table shows ranges of pollutants found in the paste tailings, the tailings pond water, and the background groundwater over a 33 week period.

Table 16: Pollutant Ranges in Tailings and Groundwater Over a 33 Week Period
(tentative)

Table 1. Waste Characterization – Background Groundwater Quality					
Constituent	Paste Tailings Solids ¹ (mg/L)	Tailings Pond Water ² (mg/L)	Background Groundwater ³ (mg/L)	Title 22 MCL ⁴ (mg/L)	Title 22 ⁵ STLC (mg/L)
TDS	70 – 27,900	7800 - 17,000	372	500	NA
pH (units)	7.2 – 10.99	5.4 – 8.4	7.58	7.5	
alkalinity	49 – 457	NR	232	NA	NA
arsenic	<0.005 – 0.05	0.014 – 0.041	<0.003	0.01	5.0
barium	<0.003 – 1.71	0.068 – 4.7	0.1787	1	100
boron	<0.02 – 0.98	3 – 34	0.24	NA	NA
chloride	<0.2 – 14,000	2600 – 8,600	26.2692	250	NA
Chromium	<0.02 – 0.07	0.028 – 0.034	0.01	0.05	5
fluoride	1.09 – 62.4	35 – 110	0.81	2.0	180
lead	0.002 – 0.65	0.011 – 3.49	ND < 25%	0.015 ⁶	5.0
magnesium	0.66 – 219	<50 – 230	15.8387	NA	NA
manganese	0.005 – 0.7	2.9 – 8	0.06	0.05	NA
Mercury	<0.0001 – 0.0002	<0.0002 – 0.00067	NA	0.002	0.2
nitrate(as N)	0.1 – 563	<1 – 17	3.3327	10	NA
strontium	3.58 – 548	1.5 – 1,600	0.3155	NA	NA
sulfate	5.5 – 1,261	83 – 1,000	46.4545	250	NA
radium total (pCi/L)	<0.54 - < 0.81	0.0 – 2.9	0.8816	5.0	NA
thorium total (pCi/L)	<0.54 - < 1.08	0.1 – 0.65	0.2166	NA	NA
Uranium total (pCi/L)	5.3 -358	6 – 149.85	2.3135	20	NA
Gross Alpha(excluding Radon, Uranium) (pCi/L)	27 – 48.6	41.4 – 531	2.6736	15	NA
Gross Beta (pCi/L)	2.7 – 156.6	21.3 – 445	3.5145	NA	NA
1) Range of concentration values of leached past tailings solids (Modified CAM-WET method) – Molycorp LLC., RWD 2010, Appendix F, Table E2-3 (without regard to amended or unamended tailings material).					
2) Range of concentration values – Molycorp LLC., RWD, 2010 (original data in RWD for Mt Pass Mine and Mill, TRC, 1998)					
3) From fourth quarter 2009 Monitoring Report – mean values from monitoring well 93-1MW					
4) California Code of Regulation (CCR), title 22, sections 64431, 64442, 64449, primary and secondary maximum contaminant levels.					
5) California Department Public Health Action Level.					
6) CCR, title 22, section 66261.24, Table II: Soluble threshold limit concentrations. (STLC for Barium excludes barium sulfate. Milligrams per liter (mg/L); Pico curies/liter (pCi/L).)					
Not reported (NR), not applicable (NA), not detected (ND)					

Source: California Regional Water Quality Board

The tailings described above occur as a result of the specific type of rock encountered at Mountain Pass. Through consultations for this study with rare earth element industry members, it became clear that the exact nature and contained pollutants of concern in the tailings produced at any given mine depend upon what type of rock the rare earths are mined from. While nearly every deposit in Canada is a bastnasite deposit, each bastnasite deposit could potentially be made up of different constituents. As a result, the Mountain Pass tailings may not be representative of the tailings that would result from a mine operating in Canada. While some elements, such as the thorium, would likely be present regardless of mine location there is no guarantee that the volume of thorium contained in these tailings would be consistent with the quantities found elsewhere.

5.1.2 Rare Earth Element Separation Processes

As described above, multi-stage solvent extraction is the most commonly used process for separating rare earth elements from one another. This is largely due to the fact that the process is relatively quick and continuous.⁸³ Additionally, while a multi-stage solvent extraction plant can be very expensive to set up, they are relatively inexpensive (in comparison to some pyrometallurgical processes) to operate.

5.1.2.1 Case Study: Avalon Rare Metals Hydrometallurgical Plant Water Effluents

The Avalon Rare Metals hydrometallurgical plant is designed to take concentrate provided by the flotation plant at the Avalon facility and put it through further purification/concentration steps. The processes employed at the hydrometallurgical plant will include acid baking, caustic cracking, water washing, filtration, caustic regeneration and evaporation, double salt precipitation, solvent extraction and product drying facilities.

5.1.2.1.1 Emissions to Air

As the project has not been constructed, there are no direct measurements for how much air pollution might be caused. As a result, the following table is done in much the same manner as the emissions to air table from the mining and beneficiation section of this report. In order to arrive at these conclusions, the consultants that performed the environmental assessment for Avalon Rare Metals relied on some industry specific emission factors, some US EPA AP-42 emission factors, and some emission factors supplied by the manufacturers of the equipment they were planning on using.

⁸³ US EPA, OSWER, Office of Resource Conservation and Recovery, *Identification and Description of Mineral Processing Sectors and Waste Streams, Rare Earths Chapter*

Table 17: Air Pollutant Sources at the Avalon Rare Metals Hydrometallurgical Plant

Source	Type of Emissions	Rank	Comments
Sulphuric Acid Plant	CACs and GHGs	Major	Large source of SO ₂
Acid Bake Kiln	GHGs	Major	Large source of CO ₂
Product Dryers	CACs	Minor	Product dryers will be equipped with sufficient dust collection to ensure ambient air quality standards are met
Backup Diesel Generators	CACs and GHGs	Minor	Backup power for emergencies only
Limestone Stockpile	Fugitive Dust	Minor	Limestone will be slaked so fugitive emissions should be negligible

Source: Avalon Rare Metals Environmental Assessment

5.1.2.1.2 Effluents to Water

After considering various options (not described) for managing pollutants in water effluents from the potential Avalon Rare Metals facility, it was decided that the preferred option for the tailings would be disposal in a historic open pit, where solids and a controlled amount of water will be stored. Then excess supernatant water from this pit will be pumped into another historic open pit, where it will infiltrate an aquifer.

The proposed tailings from the hydrometallurgical facility will consist of solids from the proposed milling process made up predominantly of gypsum (calcium sulphate - 85%) with some leach residue (approximately 6%) and miscellaneous other solids (approximately 9%). The tailings are expected to be similar to phosphogypsum tailings in terms of void ratio, dry densities and consolidation properties. The following table summarizes the chemical properties of the water component of the tailings solution based on test work completed by SGS in 2011.

Table 18: Hydrometallurgical Solution Analysis Results

Parameter	Unit	*MMER	CH-WT1 PLS +Wash Simulated Hydromet TIs Filtrate
Radionuclide Analyses			
²²⁶ Ra	Bq/L	.37	0.10
²²⁸ Ra	Bq/L		<0.2
²¹⁰ Pb	Bq/L		<0.1
General Analyses			
pH	Units	6.0-9.5	7.73
Alkalinity	mg/L as CaCO ₃		118
EMF	mV		214
Conductivity	µS/cm		13,400
TDS	mg/L		16,800
TSS	mg/L	15.00	--
Cl	mg/L		55
SO ₄	mg/L		11,000
F	mg/L		1.82
TOC	mg/L		53.9
NH ₃ +NH ₄	as N mg/L		91.7
Metal Analyses			
			Diss
Hg	mg/L		<0.0001
As	mg/L	.50	0.0022
Ca	mg/L		393
Cu	mg/L	.30	0.0226
Fe	mg/L		0.150
K	mg/L		86.8
Li	mg/L		2.18
Mg	mg/L		1,530
Mn	mg/L		6.15
Na	mg/L		1,580
Ni	mg/L	.50	0.0701
Pb	mg/L	.20	0.00052
Se	mg/L		0.005
Si	mg/L		2.47
Sr	mg/L		11.2
Th	mg/L		0.002945
U	mg/L		0.0239
Zn	mg/L	.50	<0.002

*Department of Justice Canada. 2002. Metal Mining Effluent Regulations, Fisheries Act SOR-2002-222.

Source: Avalon Rare Metals Environmental Assessment

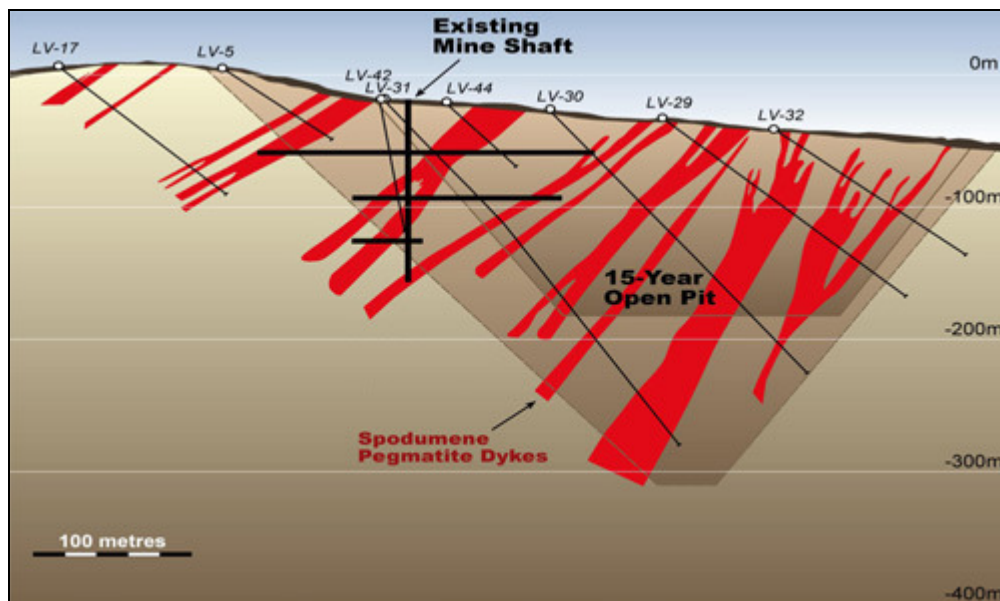
5.2 Lithium

As discussed earlier in this report, lithium is both mined from spodumene deposits and extracted from brine. These two different processes have entirely different waste streams, and will be profiled separately below.

5.2.1 Lithium Mining From Spodumene Deposits

Lithium mining from spodumene (or sometimes other mineral) deposits is quite similar to other forms of mining. Methods can vary, but the example shown below (of a planned lithium mine in Quebec) shows an open pit mine concept.

Figure 9: Quebec Lithium Spodumene Open Pit Mine Plan



Source: Quebec Lithium Website (<http://www.canadalithium.com/s/QuebecLithium.asp>)

As in other types of mining, the beneficiation stage involves the grinding of the hard rock into small particles, and often includes flotation processes. No lithium spodumene mines were found that are currently operating in the United States. The only spodumene mine found that is currently processing the mineral in North America is the TANCO mine in Manitoba. This facility mines and processes the spodumene mineral into powder and then grades it into three products, 7.25%, -200 mesh, and 6.8% concentrates. (Concentrates refer to lithia, or Li_2O , content.) These different spodumene products are sold to producers of lithium carbonate for feedstock, or in mineral form, to the glass and

ceramics industries. The TANCO mine does not have a lithium carbonate plant and does not produce any lithium carbonate.

As described earlier in this report, the ore is then put through a calcination process to form oxides. Calcining is most often followed by either the soda ash process or the sulphuric acid process (also described earlier in the report), although other methods may exist for extracting lithium from spodumene minerals. According to US EPA legislation (detailed in section 5 of the report) total suspended solids (TSS) are a main potential pollutant resulting from lithium carbonate production.

5.2.2 Lithium Extraction From Brine

In order to develop accurate information on pollutants released from the brine extraction process, the Nevada Department of Conservation and Natural Resources Division of Environmental Protection was contacted to obtain permits issued to Chemetall Foote Corporation. Chemetall Foote was actually the first company in the world to develop a lithium brine extraction process, and have been operating their Silver Peak Nevada facility since 1965.⁸⁴ The following description of the process by which subsurface brines are turned into viable commercial lithium carbonate is taken from the Nevada Department of Conservation and Natural Resources, Division of Environmental Protection, Fact Sheet for Permit Number NEV0070005. This description also contains information about the nature of the containment structure designed for the process.

The groundwaters of the Clayton Playa (playa refers to an alkali flat or desert basin) are the “ore” for this facility, averaging more than 139,000 ppm total dissolved solids (TDS). Subsurface brines are pumped, via numerous deep wells, into a series of solar evaporation ponds, where the brines are concentrated over time. Halite (rock salt) is deposited on the pond bottoms early in the series when the saturation point of the sodium chloride is reached. At approximately a third of the way through the concentration circuit, slaked lime treatment results in the production of a semi-solid sludge, consisting primarily of magnesium hydroxide and calcium sulfate, which is deposited in a lime solids pond. Decant and further evaporation of the treated brine results in the continued deposition of salts in the pond bottoms. Where it is economically efficient, the salts are removed from the ponds and stockpiled in one of three piles located adjacent to the pond area. The salts primarily consist of sodium chloride with a minor fraction of potassium chloride and traces of borates and sulfates.

The brine ponds were built directly on top of native clay that has a coefficient of permeability of 1×10^{-6} cm/sec. All pond dikes have a clay slurry core with the same coefficient of permeability. However, the most concentrated brine pond is lined, in

⁸⁴ Nevada Department of Conservation and Natural Resources, Division of Environmental Protection, *Fact Sheet for Permit Number NEV0070005*



addition to the naturally occurring clay, with 0.05 cm (20-mil) polyvinylchloride (PVC). The ponds are designed to operate with a brine depth of 0.3 to 0.6 metres (one to two feet). The resulting freeboard (nominal one foot) will accommodate wave action and accumulation of meteoric waters resulting from more than the 100-year, 24-hour event.

The concentrated brine is fed into the lithium carbonate plant to obtain the final product, lithium carbonate. In the plant, the brine is treated with lime and soda ash to remove any remaining magnesium and calcium, which would interfere with the precipitation of lithium carbonate. This treatment results in the production of a semi-solid sludge composed primarily of magnesium hydroxide and calcium carbonate. This sludge is removed periodically from the treatment tanks and discharged to the playa surface. The polished brine is then heated with steam provided by a fire-tube boiler and the lithium precipitated as carbonate by the addition of soda ash. The lithium carbonate product is then dried and packaged, or used as head feed for the lithium hydroxide facility (see below). The spent liquor is then returned to the pond system via the plant waste ditch, which carries it and other plant waste waters (e.g. pump packing coolant, emergency shower and eyewash supply, floor washing) to the playa surface near the western edge of the pond system.

In the lithium hydroxide facility, lithium hydroxide solution and calcium carbonate solids are produced after adding slaked lime. The calcium carbonate solids are separated by centrifuging, washed and moved to the playa for storage in the pond system. Evaporation of the lithium hydroxide solution produces solid lithium hydroxide monohydrate that is dried and packaged. A portion is further processed into anhydrous lithium hydroxide product.

The process fluids in the lithium carbonate plant are contained in lined steel tanks, which are covered so they are not affected by meteoric events. Fluids in the lithium hydroxide plant are contained in steel and fiber-reinforced plastic tanks, which are contained within the building so they too are not affected by meteoric events. The secondary containment required under Nevada Administrative Code (NAC) 445A.436 is provided for the post-regulation lithium hydroxide plant and lower tank farm (including acid tanks), but not the pre-regulation lithium carbonate plant.

The R-2 pond, which is asphalt-lined, receives process water (CaCO_3 solution) that is pumped to the playa as needed.

The main effluents resulting from the process outlined above include:

- salt;
- semi-solid calcium sulfate and magnesium hydroxide sludge;
- semi-solid magnesium hydroxide and calcium carbonate sludge;
- spent liquor and plant waste waters (emergency eyewash supply, floor washing etc.);
- calcium carbonate solids; and
- CaCO₃ solution.

The basin itself is described in environmental assessments as a closed hydro geologic system, the “Clayton Playa is the terminal discharging point for deeper water circulation through adjacent valleys.”⁸⁵ It seems that pollutants or other substances released into the groundwater simply stay in the basin, with no possibility of polluting groundwater or surface water used outside of the basin. As a result, the Silver Peak lithium facility is exempt from normal Nevada groundwater quality standards. Any regulations regarding lithium extraction from brine may potentially need to take local groundwater and surface water conditions into account.

⁸⁵ Geology and Hydrology of Selected Playas in Western United States, August 2006

6. Effectiveness of the *Metal Mining Effluent Regulation* to Address Identified Substances

6.1 Summary

Canada's *Metal Mining Effluent Regulations* (MMER) are Regulations under the *Fisheries Act* that impose limits on the maximum concentrations in effluents of substances that are referred to in the Regulations as "deleterious substances". The substances that are regulated are arsenic, copper, cyanide, lead, nickel, zinc, total suspended solids and radium 226. The MMER also require that the effluent not be acutely lethal to rainbow trout, and that mines undertake environmental effects monitoring activities to assess the impacts of the mine effluent on fish, fish habitat and the use of fisheries resources.

It is also worth noting that the regulations require owners/operators of tailings impoundment areas (TIAs) that are listed in Schedule 2 to develop and implement fish habitat compensation plans. These plans must be approved by Fisheries and Oceans Canada and must be structured to ensure that they offset any impacts on fish habitat that would occur in conjunction with the development of the TIA.

Rare earth elements mining and lithium mining are not currently being practiced in Canada, and the MMER were not specifically designed to manage the environmental aspects of these mining processes. As a result, the *Metal Mining Effluent Regulations* do not specifically regulate all of the individual substances of concern that might be released from the mining or processing of rare earth elements or lithium. However, any substances not specifically listed on the MMER would be covered under the general prohibition of subsection 36(3) of the *Fisheries Act*, which prohibits the deposit of deleterious substances into waters frequented by fish.

The sections below describe in detail some of the potential concerns and solutions to MMER coverage problems posed by lithium and rare earth element mining and processing activities. First and foremost it should be noted that potential effluents or pollutants depend both on the process employed, as well as the host mineral or brine that the rare earths or lithium is extracted from. The regulations reviewed thus far (and below) from the United States rely on studies of the mineralogy, groundwater, and surface water in order to determine a manner in which a mine may operate without affecting the environmental quality in that specific area. This tactic allows containment systems to be designed to keep specific mining wastes from contaminating the environment, allows for the safe handling or disposal of potentially dangerous wastes generated in potentially

unique or rare situations, and puts little to no burden on facilities that are unlikely to cause pollution that may be detrimental to human or environmental health (Chemetall Silver Peak). A strategy that takes local conditions and site-specific pollutants into account could be advisable.

Beyond this, certain substances of concern have been identified as resulting from rare earth elements or lithium mining and processing. In regards to rare earths, thorium (and to a lesser extent uranium) is perhaps the most common and problematic pollutant identified in this study. The MMER do not identify thorium or uranium as “deleterious substances” and as a result do not address their release to the environment. This means that the general prohibition of deposit under subsection 36(3) of the *Fisheries Act* currently applies to these substances. It is also important to note that because thorium and uranium are considered naturally occurring radioactive material (NORM) and their release is not associated with the nuclear fuel cycle, they are not regulated by the Canadian Nuclear Safety Commission (CNSC) As a result of this, the regulation of NORM material is currently under provincial jurisdiction.

Release guidelines have been established by Health Canada under “The Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials” (Health Canada, 2000). These guidelines give derived release limits for aqueous, solid and air releases for thorium-230, thorium-232, thorium-228, uranium-238 series, and uranium-238 radionuclides. These derived release limits can be found in table 19, entitled: “Diffuse NORM Sources Release Limits.”

Lithium extraction from brine resources is not covered by the MMER. This is the case because, under the MMER “mine means hydrometallurgical, milling, or mining facilities that are designed or used to produce a metal, a metal concentrate or an ore from which a metal or metal concentrate may be produced or any facilities, including smelters, pelletizing plants, sintering plants, refineries and acid plants, where any effluent from the facility is combined with the effluent from hydrometallurgy, milling or mining.”⁸⁶ While extracting lithium from brine is done in order to produce a metal, the process associated with the extraction and subsequent processing of brine does not fall under the scope of activities that are subject to the MMER.

It is worth noting that the uneconomical by-products from brine facilities are often pumped directly back into the ground, similar to the process followed by oil and gas facilities that use brines.

As there are currently no brine based lithium extraction facilities in Canada, it is not entirely clear what regulations these facilities may fall under. It could be that these facilities may be more similar to brine based petroleum facilities than to the hard rock

⁸⁶ *Metal Mining Effluent Regulations*

mining facilities that are covered under the MMER. Alberta's Energy Resources Conservation Board (ERCB) has regulations that cover the petroleum industry in that province, and while they were not reviewed in this report, they should potentially be considered when developing any regulations for brine based lithium extraction facilities.

There are many other pollutants in the effluents of both rare earth and lithium mining or extraction facilities that are not addressed in the MMER. These chemicals may potentially be of no environmental consequence, or present in effluents at levels that are acceptable. However, in the interest of completeness full profiles of the effluents resulting from rare earth element and lithium (spodumene) mining have been included in this report. Additionally, full chemical breakdowns of waste tailings from processing facilities in these sectors and a description of the lithium containing brines in Alberta have been included as well.

6.2 Rare Earth Elements Mining and Separation

Rare earth element mining and processing are not frequently practiced outside of China. However, the Mountain Pass Molycorp facility is currently mining and processing rare earth elements and has obtained permits to do so. Information in this report regarding the wastes and effluents discharged from Mountain Pass have been garnered from these permits. Background on these permits, as well as a brief comparison of the mining waste regulations in California to the requirements of the MMER follow below.

6.2.1 Comparative Analysis of MMER to Applicable U.S. Legislation

As the Mountain Pass rare earth facility in California is currently operating, some comparisons can be usefully drawn between the MMER requirements and the regulations that the Mountain Pass facility must adhere to. Federally speaking, mines in the United States must adhere to the requirements of the Resource Conservation and Recovery Act (RCRA). The RCRA was enacted in 1976, and governs the disposal of solid wastes and hazardous wastes. However, most states have created regulations that are at least as stringent as those of the RCRA (and supersede the RCRA), California included. Therefore in this case it is instructive to refer to California's State Water Resources Board (SWRB) Mining Waste Management Regulations.

The SWRB Mining Waste Management Regulations (Chapter 15: Article 7) are administered by the appropriate Regional Water Quality Control Board (RWQCB) through the issuance of waste discharge requirements (WDRs). These WDRs are applicable to the owner or a waste management unit for the treatment, storage, or disposal of mining waste. Mining waste is defined as including overburden, natural geologic material that has been removed or relocated but not processed, and any solid residues,



sludges, and liquids from the processing of ores and mineral commodities. All of these different waste types are classified as either Group A, Group B or Group C. These groups are defined as follows:

1. Group A —mining wastes of Group A are wastes that must be managed as hazardous waste (please see below), provided the RWQCB finds that such mining wastes pose a significant threat to water quality;

2. Group B —mining wastes of Group B are either:

(A) mining wastes that consist of or contain hazardous wastes, that qualify for a variance (under Chapter 11 of Division 4.5, of Title 22 of the California Code of Regulations), provided that the RWQCB finds that such mining wastes pose a low risk to water quality; or

(B) mining wastes that consist of or contain nonhazardous soluble pollutants of concentrations which exceed water quality objectives for, or could cause, degradation of waters of the state; or

3. Group C —mining wastes from Group C are wastes from which any discharge would be in compliance with the applicable water quality control plan, including water quality objectives other than turbidity.

Hazardous waste is defined as a waste that exhibits characteristics of ignitability, corrosivity, reactivity or toxicity as defined in Chapter 11 of Division 4.5, of Title 22 of the California code of Regulations. Please see http://www.dtsc.ca.gov/lawsregspolicies/title22/upload/oeara_reg_title22_ch11_art3.pdf for further information on how wastes are classified under these regulations. Also, please see http://www.cnsm.csulb.edu/services/safety/documents/hazardous_chemicals.pdf for a full listing of all chemical names and common names for hazardous wastes and hazardous materials under the California Code of Regulations.

Unlike with Canadian federal regulations, there are no emissions limits that are applied to any water-based chemicals or pollutants generated from mining in California. Instead, the system in California is based completely upon establishing a baseline for existing receiving water quality and ensuring that operators or dischargers do not affect that water quality in any way. Tailings ponds or containment areas must therefore be designed to allow for zero contamination of the surrounding surface water or groundwater. Mining wastes must be treated or neutralized whenever feasible in order to minimize the threat to water quality and the need to install waste containment structures, and waste containment

structures must allow for zero releases. Materials used in containment structures must have appropriate chemical and physical properties to ensure that the structures contain waste despite pressure gradients (including hydraulic head and external hydrogeologic forces), physical contact with the waste or leachate, chemical reactions with soil and rock, climatic conditions, the stress of installation or because of the stress of daily operations. The Molycorp permits include a great deal of information on the types of containment structures used for their tailings (provided to Environment Canada electronically), however, these containment structures have been designed specifically for the effluents present at the Molycorp facility, and do not necessarily reflect the best strategy for a different facility.

As noted above, the MMER focus on ensuring that the effluents or pollutants released to the environment fall within certain tolerances. These release tolerances are supported by a series of monitoring requirements designed to ensure that the effluents are not adversely affecting fish, fish habitat or the use of fisheries resources.

The two entirely different approaches taken by the SWRB and Environment Canada regarding mining effluents makes a direct comparison impractical. Additionally, the California regulations do not provide any additional information on what particular substances Environment Canada should potentially be concerned about, as they do not regulate or limit any particular substances. However, using the Molycorp permits and the Avalon Rare Metals environmental assessment, lists of several potential substances of concern can be found earlier in this report.

State environmental bodies as opposed to the US EPA largely oversee mining regulations in the United States, and state regulations outside of those briefly reviewed for California will not be discussed in this report. However, the US EPA does have a few overarching regulations concerning uranium and thorium. The “Uranium Mill Tailings Radiation Control Act” (40CFR192, “Health and Environmental Protection Standards for Uranium and Thorium Tailings”) gives regulations for cleaning up uranium and thorium mill tailings sites. However, the regulation only applies to uranium and thorium mines, and thus does not apply to rare earth facilities.

Beyond this, the US EPA has standards for the clean-up of existing contaminated sites that fall under the “Comprehensive Environmental Response, Compensation, and Liability Act,” a Radionuclides NESHAP under the Clean Air Act, and maximum contaminant levels for beta emitters such as thorium in drinking water.

6.2.2 Substances/Issues of Concern Identified in Rare Earths Mining and Processing

This section lists the “deleterious substances” regulated by the MMER, and refers to the figures containing the substances identified as present in the effluents or tailings from Molycorp or potentially resulting from Avalon Rare Metals future activities. Whether or not these substances are hazardous or dangerous, or should be regulated, is not discussed.

The MMER consider the following substances to be “deleterious substances”, and concentrations of these substances in effluent must meet the discharge limits specified in the Regulations.

Table 19: MMER Deleterious Substances

AUTHORIZED LIMITS OF DELETERIOUS SUBSTANCES				
Item	Column 1 Deleterious Substance	Column 2 Maximum Authorized Monthly Mean Concentration	Column 3 Maximum Authorized Concentration in a Composite Sample	Column 4 Maximum Authorized Concentration in a Grab Sample
1.	Arsenic	0.50 mg/L	0.75 mg/L	1.00 mg/L
2.	Copper	0.30 mg/L	0.45 mg/L	0.60 mg/L
3.	Cyanide	1.00 mg/L	1.50 mg/L	2.00 mg/L
4.	Lead	0.20 mg/L	0.30 mg/L	0.40 mg/L
5.	Nickel	0.50 mg/L	0.75 mg/L	1.00 mg/L
6.	Zinc	0.50 mg/L	0.75 mg/L	1.00 mg/L
7.	Total Suspended Solids	15.00 mg/L	22.50 mg/L	30.00 mg/L
8.	Radium 226	0.37 Bq/L	0.74 Bq/L	1.11 Bq/L

NOTE: All concentrations are total values.
SOR/2006-239, s. 25.

Source: *Metal Mining Effluent Regulations*

For a complete listing of the chemical composition of Molycorp’s paste tailings from their Mountain Pass facility, please see the “Chemical Analysis of Paste Tailings From the Mountain Pass Facility” table earlier in this report. For a breakdown of the pollutants expected to be present in the effluents resulting from processes at the Avalon Rare Metals

facility in the Northwest Territories, please see the “Five Day Decant Concentrations of Metals In Tailings From Mining and Flotation Plant” Table (mining/beneficiation) and the “Hydrometallurgical Solution Analysis Results” Table (concentration).

6.2.3 Potential Areas to Add to or Modify the *Metal Mining Effluent Regulations*

Thorium is a naturally occurring radioactive element, and remains a major environmental concern in rare earths mining and processing. The Lynas Corporation plant currently under construction in Malaysia has been coming under pressure from protesters due to concerns about the effects of the thorium on the local population.⁸⁷ Thorium disposal has already caused the shut down of a Mitsubishi rare earth element plant in Malaysia in 1992, and the company has since spent an estimated \$100 million to clean up the site.⁸⁸ Thorium radiation from improper disposal has been cited as a major reason the Chinese have slowed production and tried to increase environmental oversight for rare earth element mining and processing.

As can be seen from the Molycorp and Avalon Rare Metals information, uranium is also a substance that can occur naturally in small amounts within rare earth element deposits. The MMR specify limits for radium 226 but do not cover uranium or thorium.

Thorium and uranium are considered naturally occurring radioactive material (NORM). The Canadian Nuclear Safety Commission (CNSC) regulations do not apply to NORM (except in the case of the import, export or transport of the material), and therefore jurisdiction over radiation exposure currently lies with the provinces. While Health Canada has developed “The Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials” to address situations where exposure to NORM is not regulated, these guidelines are voluntary.

The guidelines contain suggested release limits for diffuse NORM sources (diffuse being defined as a relatively low concentration within a relatively large volume, as with tailings or other mining waste). The following figure shows these release limits for diffuse NORM sources.

⁸⁷ International Business Times, (March 16th, 2011), *Thorium: Rare Earth Liability or Asset?*, <http://www.ibtimes.com/articles/123268/20110316/thorium-rare-earth-liability-or-asset.htm>

⁸⁸ NY Times, (March 8th, 2011), *Mitsubishi Quietly Cleans Up Its Former Refinery*, <http://www.nytimes.com/2011/03/09/business/energy-environment/09rareside.html>

Table 20: Diffuse NORM Sources Release Limits

Unconditional Derived Release Limits – Diffuse NORM Sources			
NORM RADIONUCLIDE	Derived Release Limit^(a)		
	AQUEOUS^(b) (Bq/L)	SOLID (Bq/kg)	AIR (Bq/m³)
Uranium-238 Series (all progeny)	1	300	0.003
Uranium-238 (U-238, Th-234, Pa-234m, U-234)	10	10,000	0.05
Thorium-230	5	10,000	0.01
Radium-226 (in equilibrium with its progeny)	5	300	0.05
Lead-210 (in equilibrium with bismuth-210 and polonium-210)	1	300	0.05
Thorium-232 Series (all progeny)	1	300	0.002
Thorium-232	1	10,000	0.006
Radium-228 (in equilibrium with Ac-228)	5	300	0.005
Thorium-228 (in equilibrium with all its progeny)	1	300	0.003
Potassium-40	n/a ^(d)	17,000 ^(c)	n/a

Notes:

(a) Pathways Considered:

<p>Aquatic</p> <p>1. Value 10X Guideline for Canadian Drinking Water Quality.</p>	<p>Terrestrial</p> <p>1. External groundshine from soil contaminated to infinite depth. 2. Soil-veg-ingestion/soil ingestion. 3. Inhalation of resuspended material.</p>	<p>Air</p> <p>1. Inhalation at concentration resulting in 0.3 mSv. 2. Exposure factor of 25% assumed.</p>
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Assumptions:

- All radionuclides and compartments in equilibrium.
- Typical values for uptake and transfer factors.
- No allowance for hold-up time.
- 25% "occupancy" factor for solid source (groundshine, soil ingestion, resuspension), 25% 'occupancy' factor for air, and 50% of vegetable intake grown on soil.
- No correction for shielding, surface roughness.

Where more than one long-lived radionuclide is present in a sample, the appropriate sum of the ratios of the activity of each long-lived radionuclide and its corresponding Release limit, must not exceed 1,
e.g., $\frac{\text{Concentration NORM Isotope A}}{\text{Derived Release limit A}} + \frac{\text{Concentration NORM Isotope B}}{\text{Derived Release limit B}} + \dots + \frac{\text{Concentration NORM Isotope N}}{\text{Derived Release limit N}} \leq 1$

(b) Aqueous Release limits ~10x Guidelines for Canadian Drinking Water Quality. Subsequent dilution of the release is assumed. Refer to the Provincial Drinking Water Standard where planned diffuse NORM releases must meet provincial drinking water standards. (See reference 16)

(c) Natural abundance of Potassium 40 in potassium chloride.

(d) No aqueous release limit is needed as potassium content of the body is under homeostatic control, and is not influenced by environmental levels.

Source: The Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials

Beyond naturally occurring radioactive materials, the effluents and potential effluents generated by rare earth element facilities outlined in this report should give Environment Canada any information they require in regards to potential MMER modifications. However, it should also be noted that any pollutants or effluents generated by a rare earths facility will be largely dependant upon the host rock from which the elements are mined, and that any potential permits granted to these facilities (or changes to the MMER) should likely take host mineral composition into account.

6.3 Lithium Extraction

Lithium can be extracted from hard rock spodumene deposits, or from various types of brines (most commonly those naturally occurring in salt flats). Details of these processes are provided in earlier sections of the report, however the ways in which these types of lithium extraction may be covered by the MMER differ considerably. The sections below investigate their respective types of lithium extraction and look at permits or regulations pertinent to lithium extraction operations in the United States.

6.3.1 Lithium Mining From Spodumene Deposits

Lithium mining from spodumene (or less commonly petalite and lepidolite)⁸⁹ is quite similar to other mining processes covered by the MMER. Mine tailings and other pollutants or effluents have been discussed above, and depend at least partially upon the host mineral being exploited. Overall, however, spodumene mining is already practiced in Canada (TANCO mine) and does not present any new challenges to the MMER.

No facilities were found that process spodumene ore into lithium carbonate in Canada or the United States. There is legislation (detailed below) in the United States that deals specifically with lithium carbonate production.

6.3.1.1 *Comparative Analysis of MMER to Applicable U.S. Legislation*

The Code of Federal Regulations has effluent limitation guidelines representing the degree of effluent reduction attainable by the application of the best practicable control technology (BPT) currently available. These effluent limitations have been established for a wide range of different processes, including lithium carbonate production. While there are some exceptions, generally speaking “any existing point source subject to this subpart

⁸⁹ United States Geological Service, Joyce A. Ober, *Lithium*, <http://minerals.usgs.gov/minerals/pubs/commodity/lithium/450494.pdf>

and using spodumene ore must achieve the following effluent limitations representing the degree of effluent reduction attainable by the application of BPT.”⁹⁰

Table 21: US EPA Inorganic Chemicals Manufacturing Point Source Category Effluent Limitations for Lithium Carbonate Production
(40 CFR 415)

Pollutant or Pollutant Property	BPT Effluent Limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Kg/1000 kg of product	
Total Suspended Solids	2.7	0.90
	(1)	(1)

¹: Within the pH range 6.0 to 9.0⁹¹

The only effluents of concern identified from lithium carbonate production by US regulations are total suspended solids, which are also controlled under the MMER. No additional substances or issues of concern were identified as coming from hard rock lithium mining/processing.

6.3.2 Lithium Extraction From Brine

Lithium extraction from brine is a process unlike any covered by the MMER. While there are different methods of extracting lithium from brine (including experimental ones), only the most common method (solar evaporation) will be covered in this report. Details on the solar evaporation process used by Chemetall in the United States have been provided earlier in this report. The State of Nevada Department of Conservation and Natural Resources, Division of Environmental Protection, Bureau of Mining and Reclamation have given Chemetall a Water Pollution Control Permit for their Silver Peak brine facility. This section will examine the requirements of this permit in detail, and compare these requirements to the requirements set out in the MMER, and identify and potential substances of concern arising from solar evaporation lithium extraction.

⁹⁰ US EPA, *Inorganic Chemicals Manufacturing Point Source Category Effluent Limitations for Lithium Carbonate Production 40 CFR 415*, <http://law.justia.com/cfr/title40/40-28.0.1.1.15.html#40:28.0.1.1.15.45>

⁹¹ ibid

6.3.2.1 Comparative Analysis of MMR to Applicable U.S. Legislation

The permit for Silver Peak has requirements for reporting, record keeping and other more administrative requirements that will not be reviewed in this report. However, the requirements of the permit that outline the limits of different pollutants that can be released into the environment will be compared to the requirements of the MMR. The footnotes for the table below show emissions limits for the Silver Peak facility. Please note that “reference values” effectively means emissions limit.⁹² You will note that these profiles have several substances listed on the left for which there are no reference values. This is due to the fact that the Silver Peak facility, due to the low “water quality” of their brines, is exempt from the normal requirements that apply to those substances.

The following table shows the monitoring requirements, as well as the parameters monitored for different elements of the silver peak fluid management system or operations. These elements include water wells, monitoring wells, plant waste streams, brine wells, plant influent and instances of petroleum contaminated soil (PCS) that may occur from spills. (The footnotes are explained on the pages following the table.)

Table 22: Chemetall Lithium Brine Facility Permit Requirements

Identification	Parameter	Frequency
Fresh Water Well (WS)	Profile I ¹ and static water elevation, feet above mean sea level (ft amsl)	Quarterly
Monitoring well adjacent to the R-2 Pond (R-2W)	Profile I ¹ and static water elevation level, ft amsl	Quarterly
R-2 Pond (R-2)	Minimum freeboard, feet (ft)	Quarterly
Lithium hydroxide plant waste stream (HPWS)	Profile II ²	Annually
Lithium carbonate plant waste stream (CPWS)	Profile II ²	Annually
Brine well ³ (BW)	Profile II ² and static water elevation, ft amsl	Annually
Plant influent (PI)	Profile II ²	Annually
PCS Screening Analyses: Each temporary holding pad cell, by PCS source type	VOCs ⁴ , SVOCs ⁵ , TPH ⁶	Prior to removal ⁷
PCS Hazardous Waste Determinations: Each PCS source	Hazardous waste determination ⁸	When required ⁸
PCS Management: Each temporary holding pad, treatment cell, and disposal location, by PCS source type	PCS volume added, volume removed and destination, total volume present (cubic yards)	Quarterly

Source: State of Nevada Water Pollution Control Permit #NEV0070005

⁹² Personal Interview with The State of Nevada Department of Conservation and Natural Resources, Division of Environmental Protection, Bureau of Mining and Reclamation. December 20th, 2011.

Footnotes:

(1) Profile I and the regulatory limits for profile 1 include:

Parameter	Reference Value (mg/L)
Alkalinity, Bicarbonate (as CaCO ₃)	---
Alkalinity, Total (as CaCO ₃)	---
Aluminum	0.2
Antimony	0.006
Arsenic	0.010
Barium	2.0
Beryllium	0.004
Cadmium	0.005
Calcium	---
Chloride	400
Chromium	0.1
Copper	1.0
Fluoride	4.0
Iron	0.6
Lead	0.015
Magnesium	150
Manganese	0.10
Mercury	0.002
Nickel	0.1
Nitrate + Nitrite, Total (as N)	10
Nitrogen, Total (as N)	10
pH (standard units)	6.5 - 8.5
Phosphorus , Total (for non-mining projects only)	---
Potassium	---
Selenium	0.05
Silver	0.1
Sodium	---
Sulfate	500
Thallium	0.002
Total Dissolved Solids	1000
WAD Cyanide (for mining projects only)	0.2
Zinc	5.0

All analyses for the dissolved fraction.

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Profile II and the regulatory limits for profile 2 include:

Parameter	Reference Value (mg/L)
Alkalinity, Bicarbonate (as CaCO ₃)	---
Alkalinity, Total (as CaCO ₃)	---
Aluminum	0.2
Antimony	0.006
Arsenic	0.010
Barium	2.0
Beryllium	0.004
Bismuth	---
Boron	---
Cadmium	0.005
Calcium	---
Chloride	400
Chromium	0.1
Cobalt	---
Copper	1.0
Fluoride	4.0
Gallium	---
Iron	0.6
Lead	0.015
Lithium	---
Magnesium	150
Manganese	0.10
Mercury	0.002
Molybdenum	---
Nickel	0.1
Nitrate + Nitrite, Total (as N)	10
Nitrogen, Total (as N)	10
pH (standard units)	6.5 - 8.5
Phosphorus, Total	---
Potassium	---
Scandium	---
Selenium	0.05
Silver	0.1
Sodium	---
Strontium	---
Sulfate	500
Thallium	0.002
Tin	---
Titanium	---
Total Dissolved Solids	1000
Vanadium	---
WAD Cyanide	0.2
Zinc	5.0

Standard analyses for the dissolved fraction.

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- (2) A different production (brine) well shall be sampled each year.
- (4) Volatile Organic Compounds (VOCs) analyzed by EPA Method 8260B.
- (5) Semi-Volatile Organic Compounds (SVOCs) analyzed by EPA Method 8270D.
- (6) Total Petroleum Hydrocarbons (TPH) analyzed by EPA Method 8015 Modified. If any gasoline-range petroleum is suspected, or if the source-type is unknown, both TPH-P (purgeable) and TPH-E (extractable) are required. Otherwise, only TPH-E is required.
- (7) Each segregated source type of PCS must be sampled separately pursuant to the approved sample collection protocol. For temporary holding pad cells, analyses are required only in quarters when PCS removal from the pad is anticipated. Removal to an approved on-site disposal location is authorized if PCS meets screening levels.
- (8) A hazardous waste determination is required: a) Initially, for each PCS source prior to management under the PCS Management Plan; b) When a PCS waste stream is suspected to have changed character since the last determination; and c) When a hazardous constituent is detected during screening analyses at a concentration suggestive of hazardous waste. Determinations must be performed pursuant to 40 CFR 262.11 using operator knowledge and/or applicable analytical testing methods described in EPA publication SW-846. Operator knowledge must be adequately described and sufficient to justify the determination.

6.3.2.2 Substances/Issues of Concern Identified in Lithium Extraction From Brine

As with other kinds of mining, the potential effluents or pollutants resulting from this process depends upon the “host mineral,” in this case the brine. The following table shows four brine samples taken from the Channel Resources Fox Creek property. While the other two brine operations currently being explored in Canada are in the same area, there is no guarantee that those brines will be similar to the samples shown below.

Table 23: Channel Resources Fox Creek Brine Composition Samples
(mg/L)

Formation	Leduc 3	Swan Hills 4	Leduc 5	Swan Hills 8
Sample Number	RCAH82-475B	RCAH111-676A	D-44	RCAH110-676A
Li	130	130	120	115
Na	43200	54000	42400	39800
K	7500	5100	5000	4300
Mg	1610	2010	979	1630
Ca	18000	15900	27500	13600
Sr	725	630	615	
Ba	5.7	19	4.7	1.7
Cu		0.49	0.57	0.27
Zn		5.9		1.9
Pb	8.5	3.3	4	10
Ag		1.3	1.5	0.92
Fe		0.85	0.89	0.36
Mn	14	14	0.38	9
V		0.8	0.9	0.28
As				
B	2709	260	180	190
PO4	76	24	23	16
NH3	558	637	551	381
SiO2	54	43	88	19
F	6.7	6.2		4.7
Cl	117000	125100	123700	94160
Br	430	426	317	329
I	14	18	18	5
SO4	389	155	239	778
HCO3	365	232	1110	316
(all in mg/L or ppm)				
Salinity (mg/L)	191630	205945	203703	156567
pH	7.15	6.76	8.1	7.34
T (°C)	64	79	113	76

Source: Channel Resources Technical Report on the Lithium Potential of the Fox Creek Property, Swan Hills Area, West-Central Alberta

Any by products or effluent generated by solar evaporation processes that are not economically viable are usually pumped back into the ground. As can be seen above, the brines present in the Fox Creek and Silver Creek properties do not constitute water that

could potentially be useful for either drinking or fish habitat. As the potential uses for the brine (other than lithium/potassium/petroleum product production) are at this point somewhat unclear, and as the composition of this brine is unlikely to negatively effect groundwater quality nearby, it is unclear what possible contaminants (if any) might be of concern for Environment Canada. Therefore, details of effluents released from Silver Peak, and the composition of brines that might be potentially used for lithium extraction have been provided.

6.3.2.3 Potential Areas to Add to/Modify the Metal Mining Effluent Regulation

Lithium extraction from brine is not covered by the MMER in their current form. In addition to this, it is currently unknown what type of form the potential lithium brine facilities in Alberta might take, as all three projects are currently still in the early exploratory phase. These facilities may pump their used brine and by-products back into the ground or make tailings ponds to store potential tailings. Depending upon the goals of Environment Canada, the MMER could potentially need to be changed so that it clearly includes solar evaporation lithium extraction techniques, if required. The Alberta ERCB regulations could potentially be reviewed for further information on viable techniques for managing brine extraction facilities.

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