A cleantech resource crisis?

Will rare earth and lithium availability thwart cleantech growth?

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A large number of metals critical to clean technologies are mined from the ground. Will they always be available? And inexpensively? The Cleantech Group looks at two important cleantech inputs – rare earth elements and lithium – and whether the West has become complacent in securing supplies, and the implications.

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Contents

Acknowledgments

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Umicore is a materials technology group. It generates approximately 50% of its revenues and spends approximately 80% of its R&D budget in the area of clean technology, such as emission control catalysts, materials for rechargeable batteries and photovoltaics and precious metals recycling. Umicore's ambition is to develop, produce and recycle materials in a way that fulfills its mission: materials for a better life.
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Summary

Will the scaling up of cleantech lead to short-term REE and lithium bottlenecks, or perhaps long-term availability problems?

Where will opportunities be created?

Mined compounds such as rare earth elements (REE) and lithium have become crucial inputs in certain clean technologies. REE are used in technologies such as wind turbines, electric vehicle motors, fuel cells and energy efficient lighting. Lithium-ion has become the battery of choice for electric vehicle makers, turning lithium into a strategically important metal as the world begins to electrify its automobile fleet.

Given that China is in control of 97 percent of global REE production, and that Chile and Australia produce 70 percent of the world's lithium, there is growing concern that the transition to a clean economy could ultimately create a global dependency on these materials instead of oil.

China has already restricted the amount of REE available for export by 40 percent in the last 7 years. Similarly Bolivia – which possesses 50 percent of the world's minable lithium deposits – is not ready to produce any lithium and is providing strong disincentives to foreign investors. For both of these metals, there are long time lags in generating new sources of supply, which is leading some to believe that we are about to face long-term supply availability issues which will significantly hinder the cleantech revolution.

Japanese corporations and the government have already been acting vigorously to this concern by developing strategies for securing lithium supplies and REE from non-Chinese sources. However, the U.S. and the EU are only now beginning to wake up to the issue, and will need to subsidize local mining and refining operations so as to hedge against China's monopoly on REE.

Along with this potentially large risk to clean technology industries are great opportunities for investors, corporations and technology developers. REE and lithium can be recycled, reducing the need to mine new material. Recycling projects are already underway in this area and will become essential once wind turbines and electric vehicles reach the end of their lifecycles, providing large quantities of material to be recycled.

Similarly, stakeholders may be able to benefit from governments' renewed interest in securing supplies of these materials by negotiating subsidies, government guaranteed loans and tax credits. This is already happening in Japan.

Key Takeaways

In summary, the main findings, detailed further in the document:

- The lack of non-Chinese REE mines ready for commercial production means that China is going to remain the monopoly supplier of REE for at least the next five years, giving it a strategic advantage as the cleantech sector goes to scale.
- Investors and governments must follow Japan's lead in attempting to secure REE supplies. If they continue to stand idle as China looks to cut rare earth exports and take control of non-Chinese mines, they could soon be locked out of the REE market, with their ability to produce many cleantech products at the mercy of the Chinese.
- Whereas the price of lithium and REE are increasing rapidly, they still account for a fraction of a percent of the total cost of electric vehicle batteries and wind turbines, respectively. Therefore, the two markets for these materials appear able to tolerate a substantial increase in prices without impacting overall competitiveness.
- Bolivia's lack of lithium mining experience, strong disincentives to foreign investors and poor climate conditions at its deposits make lithium production there less economical than at other major producer's mines. Nevertheless, there is likely to be room for foreign investors and mining firms to profitably develop Bolivia's vast lithium deposits.
- Whereas availability of input materials may prove to be a minor inconvenience to the cleantech industry, it is unlikely to be a major hindrance to the march of cleantech. Nevertheless, investors and technology developers must consider more carefully how much of a threat their input supply chains could cause to the competitive advantage of mass-scale production of their products and hedge those risks if necessary.

Rare Earth Elements

REE are a collection of 17 elements that exhibit a particular set of chemical properties. The term "rare" is actually a historical misnomer, as most of them are found in relatively high concentrations in the earth's crust. The term arises from the uncommon oxide-type minerals from which they were first isolated.

Symbols and Names of the REE

La	Lanthanum	Dy	Dysprosium
Ce	Cerium	Ho	Holmium
Pr	Praseodymium	Er	Erbium
Nd	Neodymium	Tm	Thulium
Pm	Promethium	Yb	Ytterbium
Sm	Samarium	Lu	Lutetium
Eu	Europium	Y	Yttrium
Gd	Gadolinium	Sc	Scandium
Tb	Terbium		

Cleantech applications

REE are widely used in cleantech and high-tech products

The strong magnetic and conductive properties of REE have made them increasingly attractive to scientists who have created an array of popular high-tech and cleantech products requiring them. The table below shows the cleantech applications for the various REE, however, they are also used in the production of many high-tech products such as MRI machines and guided missiles[1 2].

Rare earth applications in clean technologies

Cleantech application	REE used	Additional information
Electric vehicle motors	Neodymium	A Toyota Prius motor contains 1 kilogram of neodymium.
Fluorescent lamps	Europium & Terbium	Terbium prices quadrupled from 2003 to 2008, peaking at $895 per kilogram, before slumping in the global economic crisis to $450 per kilogram.
Fuel cells	Terbium & lanthanum	Terbium is used as a crystal stabilizer of fuel cells which operate at elevated temperatures. Lanthanum is used as a catalyst[3].
Hybrid vehicle motors	Dysprosium	It improves vehicle performance and lowers car weight resulting in reduced fuel consumption. Dysprosium can make magnets in electric motors lighter by 90 percent. Dysprosium prices have climbed nearly sevenfold since 2003, to $117 per kilogram.
Nickel-metal hydride batteries	Lanthanum	A Toyota Prius battery contains 10 to 15 kilograms of lanthanum.
Permanent magnet direct drive wind turbine generators	Neodymium	Wind turbines can use 700 to 1200 kilograms of neodymium (NEO) magnets per MW. A permanent magnet direct drive wind turbine generator contains 175 to 420 kg of pure neodymium per MW. Other types of turbines contain less or even no neodymium.

Source: Cleantech Group analysis

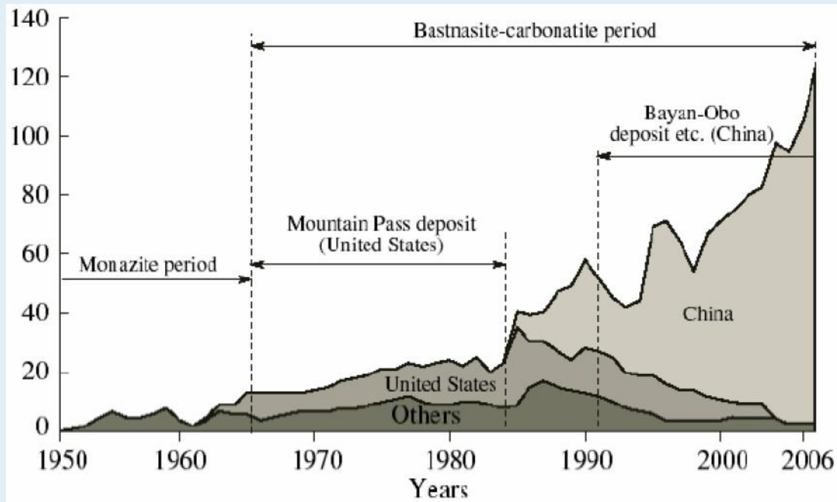
1 http://pubs.usgs.gov/fs/2002/fs087-02/fs087-02.pdf
2 http://www.arafuraresources.com.au/energy_prod.html
3 http://www.arafuraresources.com.au/energy_prod.html

Why is the cleantech industry concerned

China produces 97 percent of today's REE

Nearly all of China's REE production comes from the Bayan-Obo mine in Inner Mongolia, China. The remainder comes from small and sometimes illegal mines in the south of the country.

Global REE Production



Source: The U.S. Geological Survey

REE, even though abundant in the earth's crust, don't have a tendency to be concentrated in exploitable ore deposits. Economically viable concentrations of REE are known to exist in only a handful of places, mainly in China, the U.S., Australia, Canada, South Africa and Greenland.

Historically in the U.S., refined REE products were produced primarily at the Mountain Pass plant in California. However, the mine shut down in 2002 after China flooded the rare earths market in the 1980s and 1990s and caused world prices to drop by half. Now, the U.S. imports 100 percent of its REE supplies.

China's monopoly in the production and processing of REE has raised concerns in the rest of the world, which is now devoid of entire supply chains vital to clean technologies. In other words, the fear is that the transition to a clean economy will ultimately lead to a global dependency on REE for energy instead of oil.

REE demand will grow significantly

Global REE demand could grow by 8 percent to 11 percent over the next 3 years. Demand is expected to increase by 10 percent to 15 percent per annum in China, 3 percent to 5 percent in Japan, and 2 percent to 4 percent in the rest of the world[4].

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[4] http://www.ggg.gl/Assets/Rare%20Earth%20Industry%20Overview.pdf

In context: How much neodymium will cleantech require over the next decade?

The most important REE to the cleantech industry is neodymium. It is primarily used to make magnets for wind turbine generators and for electric vehicle motors. Neodymium production is estimated to be 36,000 metric tons annually in 2012[5]. By 2020, this value is estimated to be significantly higher as new REE mines come online and start generating significant yields.

Wind turbine generators
The Global Wind Energy Council predicts, under its most ambitious scenario, that total wind energy capacity could reach 1,081 GW in 2020[6]. Given that total installed wind capacity was 121 GW in 2008[7], this would require 960 GW of new capacity by 2020.

Although it is difficult to estimate exactly how much neodymium this will require – because it depends heavily on what type of turbines are used – an upper limit estimate puts the demand into perspective.

Neodymium quantities used in wind turbine types

		Type of Turbine	
		Gearbox	**Direct Drive**
Generator Type	**Permanent magnet**	Contains 80 to 100 kg per MW of Neo magnets equating to 20 to 35 kg per MW of pure neodymium	Contains 700 to 1,200 kg of Neo magnets per MW equating to 175 to 420 kg per MW of pure neodymium
	Doubly-fed induction	Contains no neodymium	Contains no neodymium

Source: Cleantech Group analysis

The vast majority of commercial turbines use gearboxes[8]. Permanent magnet direct drive turbines only make up a small proportion of total wind turbines sold. If we assume that all wind turbine sales to 2020 will be permanent magnet gearbox turbines, then installing 960 GW of capacity would require 19,200 to 33,600 metric tons of neodymium over the next decade.

The wind industry itself hasn't raised much concern regarding a neodymium shortage, but instead is more concerned about the rising prices of other raw materials such as steel (used in towers, gearboxes and rotors), copper (used in generators) and concrete (used in foundations and towers)[9].

Electric vehicle motors
Two million electric-vehicle and plug-in hybrids are expected to be sold from 2010 to 2015[10], which would require 2,000 metric tons of neodymium for the motors over the five year period.

Nissan CEO Carlos Ghosn estimates that electric vehicle sales could make up 10 percent of global vehicle demand in 2020. This is one of the more optimistic estimates in the market and equates to approximately 5.4 million electric vehicle sales in 2020[11] and would therefore require 5,400 metric tons of neodymium.

A concern with electric vehicle motors is that, unlike wind turbine generators, there is no current commercial alternative to using neodymium.

Conclusion
Based on a projected neodymium production of 36,000 metric tons annually in 2012, and more beyond that, the market should be in a position to supply the requirements of known clean technologies over the next decade.

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[5] http://www.ggg.gl/Assets/Rare%20Earth%20Industry%20Overview.pdf
[6] http://www.gwec.net/fileadmin/images/Logos/Corporate/GWEO_A4_2008_lowres.pdf
[7] http://www.gwec.net/index.php?id=13
[8] http://www.gwec.net/fileadmin/images/Logos/Corporate/GWEO_A4_2008_lowres.pdf
[9] http://www.gwec.net/fileadmin/images/Logos/Corporate/GWEO_A4_2008_lowres.pdf
[10] http://www.pwc.com/en_US/us/technology/assets/pwc-cleantech-revolution.pdf
[11] http://www.bcg.com/documents/file36615.pdf

REE prices have already been rising sharply

REE prices have already risen significantly over the past three years, driven by the steep growth in demand for neodymium magnets used in wind turbines and electric vehicle motors. Recently the price of neodymium has been about $25 per kilogram, four times as much as in 2003. Similarly dysprosium – which is used to make these magnets lighter – is now selling for more than $150 per kilogram, a tenfold price increase over 2003.

There are significant time lags in generating additional REE supply

Whilst countries other than China have promising reserves, and some REE mines are in the development pipeline, it will take several years for any of them to produce significant quantities. As of January 2010, the Cleantech Group is aware of the following non-Chinese REE mines under development.

Many non-Chinese mines are at various stages of development but are unlikely to produce significant quantities in the next 5 years

Non-Chinese REE Projects Under Development

Mining Company	Mine Under Development	Status
Arafura Resources	Nolans Project, Australia	Arafura is finalizing commercial agreements and plans to be producing in 2012. The mine is estimated to contain 850,000 metric tons of REE[12] with a particularly high concentration of neodymium[13] which makes it highly desirable. In September 2009, Arafura shareholders approved a $23 million investment from Chinese company East China Exploration (ECE). This has given ECE a 25 percent interest and will enable Arafura to progress with its feasibility study.
Avalon Rare Earths	Thor Lake Rare Metals Project, Canada	The development is still in its early stages, and the pre-feasibility study is due to be completed in Spring 2010[14], after which planning for the full feasibility study and environmental permitting process is needed[15]. There is no indication as to when the mine will start producing.
Great Western Minerals Group (GWMG)	Hoidas Lake Project, Canada	GWMG's goal is to provide 10 percent or more of the U.S. demand for REEs by 2011. The company is finalizing process design, engineering, and environmental work in order to complete a final feasibility study[16]. The development is thought to have a particularly high neodymium content, which would make it desirable[17].
Great Western Minerals Group (GWMG) & Rareco	Steenkampskraal Mine, South Africa	In January 2009, GWMG entered into an option agreement with Rareco to refurbish, re-commission, and operate the abandoned Steenkampskraal mine. The agreement allows GWMG the right to acquire exclusive access to 100 percent of the REE mined there. Yet even though the mine has a very high grade of REE deposits, it is estimated that the amount of recoverable REE in the mine is very small – approximately 30,000 metric tons[18].
Greenland Minerals and Enery	Kvanefjeld Project, Greenland	The REE deposits at Kvanefjeld are supposedly large and are said to contain a relatively high proportion of the more valuable heavy REE.
Lynas	Mt. Weld Project, Australia	Lynas had to suspend work in February 2009 because China Nonferrous Metal Mining Group terminated its proposed $505 million investment after Australia's Foreign Investment Review Board said it could not take a stake in Lynas of greater than 50 percent. The Chinese company had planned to take a 51.6 percent interest. Consequently, Lynas completed a A$450

[12] http://www.arafuraresources.com.au/nol_res.html
[13] http://www.arafuraresources.com.au/nol_reo_dist.html
[14] http://avalonraremetals.com/_resources/presentation/Corporate-Presentation-09-11-27.pdf
[15] http://pr-canada.net/index.php?option=com_content&task=view&id=133853&Itemid=65
[16] http://www.gwmg.ca/projects/hoidas-lake
[17] http://www.gwmg.ca/rare-earths/faq
[18] http://www.gwmg.ca/projects/Steenkampskraal_Mine

		million (US$404 million) equity offering in October 2009 and is attracting the interest of institutional investors such as Morgan Stanley.
MolyCorp Minerals	Mountain Pass, California	MolyCorp has resumed processing old, stockpiled ore to remove the REE from it, and hopes to resume excavating and processing new ore from the mine in 2011. Its goal is to produce 20,000 metric tons a year by January 2012.
Neo Material Technologies	Pitinga mine, Brazil	Neo signed a development agreement with Brazil-based mining firm Mineracao Taboca in April 2009 giving Neo exclusive access for two years to the Pitinga mine to investigate the REE commercial production potential[19]. Mitsubishi has also signed an MoU with Neo to fund up to $2.5 million of its development of the Pitinga mine and also committed to a minimum participation of 20 percent in other new REE facilities that Neo decides to construct and operate anywhere outside China. In return, Mitsubishi is to have the right to purchase no less than 20 percent of the annual output of separated REE from such plants[20].
Thorium Energy	Lemhi Pass, Idaho and Montana	The project is still looking at samples and conducting feasibility tests[21].
Toyota, Sojitz, and the Vietnamese government	Dong Pao, Vietnam	The joint venture aims to begin commercial mining operations as early as 2011, supplying about 5,000 metric tons of REE a year for 20 years.
U.S. Rare Earths	Diamond Creek, Idaho	U.S. Rare Earths has recently conducted surveys on the mineral content of the mine. It showed that the mine contains a high concentration of neodymium[22].

Source: Cleantech Group analysis

China is acting strategically by restraining exports

China has reduced REE exports by 40 percent over the past 7 years and further reductions are planned

In July 2009, the Chinese Ministry of Industry and Information Technology (MIIT) released a draft report called *Rare Earths Industry Development Plan 2009-2015*. The report proposes a total ban on shipments overseas of terbium, dysprosium, yttrium, thulium and lutetium as well as a combined export quota of 35,000 metric tons annually on neodymium, europium, cerium and lanthanum for the next six years. China has already reduced the amount of REE available for export by some 40 percent over the last seven years.

This is significant. Japan's REE consumption alone is over 40,000 metric tons per year and relies completely on imports. China's draft proposal will need to be approved by the state council, China's highest governing body, before it can be formally enacted. There has been no indication yet as to when legislators will vote on the plan.

The MIIT has also announced intentions in 2010 to further strengthen the protection of resources and establish a rare metal reserve system.

At current REE prices, it is questionable whether non-Chinese mines will be profitable

China can produce REE at a third of the cost when compared to the West making non-Chinese mines uncompetitive

The rest of the world cannot compete with China on price. Lax environmental standards, low labor costs and questionable legality of some of its mines mean that it can mine REE at a third of the cost when compared to the rest of the world. This will make it difficult for foreign companies to carve out a return on investment from any REE mining venture that doesn't contain significant quantities of the more valuable elements.

Additionally, there is minimal value in developing a REE mine to extract the metals unless it is accompanied by a refining operation to separate the individual REE from one another and the ability to produce the end product necessary. Any investment must be over the entire supply chain or have access to such a supply chain in order to be useful.

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[19] http://www.magnequench.com/assets/content/ir/ir_press/a303/a376/Neo_Press_Rel_15April09.pdf
[20] http://www.magnequench.com/assets/content/ir/ir_press/a303/a406/Neo_Press_Rel_21July09.pdf
[21] http://www.thoriumenergy.com/index.php?option=com_content&task=view&id=42&Itemid=67
[22] http://www.businesswire.com/portal/site/home/permalink/?ndmViewId=news_view&newsId=20091222005157&newsLang=en

The U.S. and EU are yet to take significant action in securing REE supplies

Because China has been the sole producer of REE for the past decade, it consequently possesses a near monopoly on the entire supply chain. In fact, one of the reasons that Australia rebuffed a recent attempt by China Non Ferrous Metals to acquire Lynas' Mt. Weld mine was that the investment would have created only 90 jobs in Australia, while ensuring far more jobs in China refining the metals and producing the end product[23].

Additionally, because Chinese REE mining companies are government owned and therefore not audited by independent third parties, they have easy and rapid access to capital for acquisition financing through stated-owned banks that is guaranteed by the government[24]. Because of their determination to secure foreign REE supplies, they are willing to out-bid listed foreign mining companies worried about what would happen to their share prices if they overpay. Therefore, it seems as if only foreign government intervention can prevent China from obtaining complete dominance in the REE market – as in the case with the Mt. Weld mine.

How have stakeholders been responding

Governments are developing strategies to secure REE supplies

Japan
In July 2009, the Japanese government created a *"Strategy for Ensuring Stable Supplies of Rare Metals"* based on four pillars:[25]

- Securing overseas resources via Japanese support of mining developments in foreign countries
- Developing a new recycling system for REE through research and development of recycling technology and creating a recycling-oriented society
- Developing alternative materials by promoting research and development activities leading to nanotechnology-based practical applications of alternative materials
- Developing a strategy to flexibly increase or release reserves of some rare metals which are to be stockpiled based on supply and demand trends

United States
There is a bill before the U.S. government called the *Rare Earths Supply-Chain Technology and Resources Transformation Act of 2009 (RESTART ACT)*[26]. It was set up for the purpose of restarting domestic REE production. A report for the Secretary of Defense that assesses REE supply and demand in the U.S. is due by April 2010. The U.S. military is particularly concerned about the continued availability of REE for military applications. However, the U.S. government is yet to take specific cleantech-related action in securing REE supplies, which, if not done, could also arguably be of national security concern.

European Union
In June 2009, the European Union and the U.S. called for the World Trade Organization (WTO) to intervene regarding China's export restrictions on raw materials after they failed to persuade China to reduce its export tariffs and raise quotas on materials such as REE[27].

Additionally, scientists from the German Federal Institute for Geosciences and Natural Resources (BGR), which advises the German government, have warned that the imposition of REE export limits could "lead to serious bottlenecks"[28]. Wind turbines are the biggest consumer of neodymium, and Germany has over 25 GW of wind capacity installed.

The U.S. has established a non-profit organization aimed at securing REE supplies

The Rare Earth Industry and Technology Association (REITA) is a Colorado non-profit formed in September 2009 dedicated to the establishment of a sustainable domestic REE industry and technology base to meet the growing need for REE for green energy, defense, high-tech and homeland security applications[29]. REITA is to pool the capabilities of its members and offer a platform for communication, business networking and industry unity.

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[23] http://www.jackliftonreport.com/
[24] http://www.cs-re.org.cn/en/modules.php?name=News&file=article&sid=24
[25] http://www.meti.go.jp/english/press/data/20090728_01.html
[26] http://www.usmagnetmaterials.com/wp-content/uploads/2008/05/Restart-Act-Final-10-09.pdf
[27] http://english.sina.com/china/p/2009/0623/250585.html
[28] http://www.spiegel.de/international/business/0,1518,658977,00.html
[29] http://www.reitausa.org/default.asp

Japanese automakers are investing in REE mine developments in Vietnam and Brazil

Companies exposed to REE scarcities are exploring non-China sources of supply

Japan is the second largest consumer of REE, and consumes 25 percent of global REE production (China consumes 60 percent)[30]. As Japan isn't a supplier of REE, it is seen as the major destination for REE produced by non-Chinese projects.

Japanese automakers stand to lose the most from a REE supply squeeze, which is why it has been aggressively looking for alternative supplies. For example, Toyota is looking for alternative supplies in Vietnam. Toyota and the Vietnamese government plan to launch a joint venture to start developing a major REE site in Vietnam in 2010. The venture is expected to begin commercial operations as early as 2011, supplying 5,000 metric tons of REE for 20 years.

Similarly Mitsubishi signed an MoU with Canada-based Neo Material Technologies in July 2009 to help fund the development of the Pitinga mine in Brazil and other potential mines outside of China.

Developing REE alternatives and new methods of REE extraction

REE alternatives

If the price of REE increases enough, it may become economical for automakers to transfer to less common types of motors that don't require REE, such as wound-rotor motors[31]. For example, **Contitech** favors this method over neodymium.

New methods of REE extraction

Researchers at the University of Leeds have discovered a way to extract rare earth oxides from industrial waste streams. The research team initially developed a patented industrial process to extract higher yields of titanium dioxide and refine it to over 99 percent purity. They then discovered that they could also extract significant quantities of rare earth metal oxides as co-products of the refining process[32].

There are several REE recycling methods that can be explored

There are potentially three REE recycling extraction methods, none of which are fully developed commercially and all of which have drawbacks either in terms of yielding pure metals, in cost, or both[33] [34].

- **Aqueous based technology**: Produces mixed metal oxides or fluorides which are then as expensive as the original ore to refine.
- **Electro-slag refining**: Works well for large clean pieces of scrap but less well for contaminated or fine shavings of metal. In addition, the transition metals often get pulled across into the end product which then requires extensive further refining to access the REE.
- **Liquid metal extraction**: Can accept multi-metal inputs and distinct metal outputs, but has not been developed commercially for REE. However, has worked for silver extraction from lead ores, so the basic technology is understood.

The high cost of recycling small volumes of REE will mean REE prices will have to increase significantly before REE recycling becomes economically viable.

Wind turbine production is gravitating towards China

It's not anticipated that China will deny REE to the rest of the world, but foreign companies might need to move wind turbine manufacturing facilities to China in order to gain access to the vast quantities of REE. Additionally, Chinese wind turbine manufacturers have a local strategic advantage and can expand their operations quickly.

This gravitation of wind manufacturing to China is already underway. As the Cleantech Group noted in its 2009 year-end press briefing, the largest cleantech IPO in 2009 was wind power provider China Longyuan Electric Power Group, which raised $2.23 billion in 4Q09[35]. Additionally, global clean energy investment in 2009 was resilient despite the recession because of buoyant

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[30] http://www.ggg.gl/Assets/Rare%20Earth%20Industry%20Overview.pdf
[31] http://pepei.pennnet.com/display_article/257024/17/ARTCL/none/none/1/Power-from-thin-air/
[32] http://www.leeds.ac.uk/news/article/291/valuable_rare-earth_raw_materials_extracted_from_industrial_waste_stream
[33] http://agmetalminer.com/2009/07/16/recycling-of-rare-earth-metals-faces-challenges/
[34] http://www.osti.gov/bridge/purl.cover.jsp?purl=/10190438-P7QwV3/webviewable/
[35] http://cleantech.com/about/pressreleases/20090106.cfm

investment in Asia, particularly in the wind sector in China. Overall, China wind new-build asset finance investment in 2009 was $21.8 billion, up 27 percent on the previous year[36].

REE outlook

The lack of non-Chinese REE mines ready for commercial production means that China is going to remain the monopoly supplier of REE for at least the next five years, giving it a strategic advantage as the cleantech sector goes mainstream.

Expect REE prices to rise, but for demand to remain strong, at least for wind applications. Why? A permanent magnet gearbox wind turbine requires up to 35 kilograms of neodymium per MW. At $25 per kilogram presently, this costs $875. However, the cost of installing a MW of wind (including grid connection, foundations and control systems) is over $1 million per MW[37], meaning that the neodymium makes up less than 0.1 percent of total turbine cost. Therefore, wind turbine demand is likely to be almost perfectly inelastic to the price of neodymium.

China's reduction in REE export quotas and interest in acquiring foreign REE mines is a signal that it plans to use its dominance to assist its own manufacturing industries at the expense of other countries and that it doesn't consider itself to be under any obligation to supply REE to anyone but itself. It is likely that this will cause tension in the cleantech sector, particularly between Japan and China as Japanese automakers such as Toyota and Nissan roll out their electric vehicles in 2010-2012 and Japan's electronics sector continues to expand rapidly. If Japan's REE mining ventures in Vietnam and Brazil aren't successful, it may find its production capabilities at risk with a lack of essential REE.

The West needs to follow in Japan's footsteps and take more substantial steps in securing REE supplies

Japan's proactive long-term stance on REE has not been matched by the European Union and the United States. Complacency and short-term thinking may come back to haunt them soon in two politically sensitive sectors: cleantech and the military. If it continues to stand idle as China invests in further REE projects abroad, it may soon be locked out of the REE market completely, leaving its ability to produce many cleantech products totally at the mercy of the Chinese. Therefore, it needs to act vigorously by subsidizing local REE mining and refining operations so as to hedge against China's dominance.

Corporations, investors and technology developers may be able to benefit from governments' renewed interest in securing REE supplies by negotiating subsidies, government guaranteed loans and tax credits for securing domestic supplies, as is already happening in Japan.

[36] http://www.newenergyfinance.com/free-publications/press-releases/
[37] http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Economics_of_Wind_Main_Report_FINAL-lr.pdf

Lithium

Lithium is the world's lightest metal and is soft enough to be cut with a knife. It is a good conductor of both heat and electricity and is highly reactive.

Cleantech applications

Lithium is the principal component in lithium-ion batteries, which are now the battery of choice for electric vehicle makers. No other metal is better at holding a charge and dissipating heat with as little weight, making lithium the best known element for making powerful batteries.

Why is the cleantech industry concerned

Global lithium deposits are concentrated in only a few countries

Over 70 percent of the world's economic lithium deposits are found in an area known as the Lithium Triangle, which is where the borders of Chile, Argentina and Bolivia meet. It is bounded by three Salars (salt flats)[38].

- Salar de Atacama – Chile
- Salar de Hombre Muerto – Argentina
- Salar de Uyuni – Bolivia

Bolivia possesses 50 percent of the world's lithium deposits, but is yet to produce

Global Lithium Production and Reserves[39]

Country	2008 Lithium Production (metric tons)	Reserves	Reserve Base
US	Withheld	38,000	410,000
Argentina	3,200	Not Available	Not Available
Australia	6,900	170,000	220,000
Bolivia	0	0	5,400,000
Brazil	180	190,000	910,000
Canada	710	180,000	360,000
Chile	12,000	3,000,000	3,000,000
China	3,500	540,000	1,100,000
Portugal	570	Not Available	Not Available
Zimbabwe	300	23,000	27,000
World Total (rounded)	27,400	4,100,000	11,000,000

Source: USGS

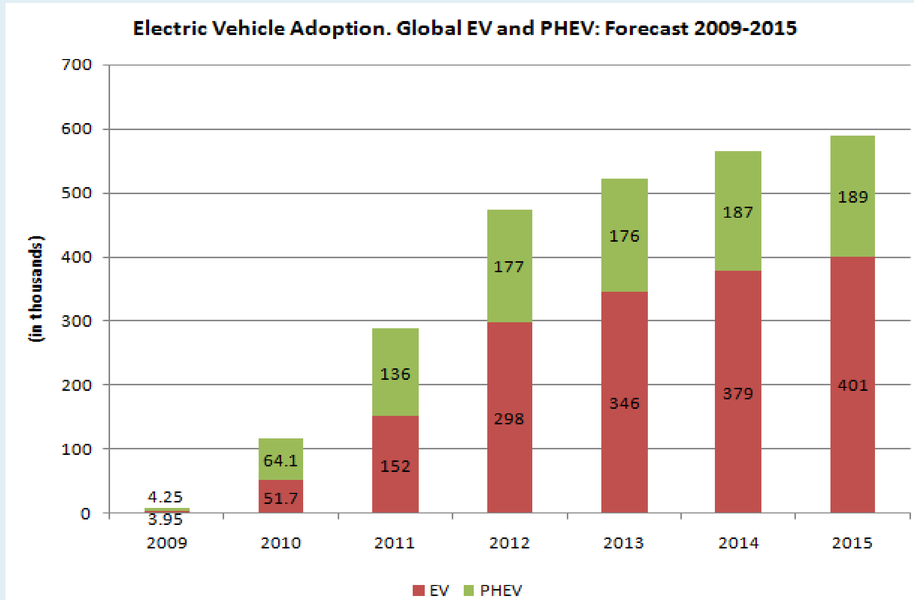
Reserves—That part of the reserve base that could be economically extracted or produced at the time of determination. The term reserves need not signify that extraction facilities are in place and operative.
Reserve Base—That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics.

Lithium demand will rise fast partly to accommodate EV battery demand

At least 32 pure electric or plug-in hybrid vehicles are set to launch in the next 3 years

We are at a tipping point where electric vehicles are about to penetrate the automobile market. To date, at least 25 pure electric vehicles and seven plug-in hybrid electric vehicles have been announced to launch in 2010-12[40]. Global market demand for PHEV and EVs is expected to reach 600,000 in 2015, according to PricewaterhouseCoopers (see following illustration). Nissan has estimated that electric vehicle sales could reach 5.4 million in 2020.

[38] http://www.meridian-int-res.com/Projects/Lithium_Microscope.pdf
[39] http://minerals.usgs.gov/minerals/pubs/mcs/2009/mcs2009.pdf
[40] http://www.pwc.com/en_US/us/technology/assets/pwc-cleantech-revolution.pdf



Source: PricewaterhouseCoopers Autofacts

A lithium shortage is not expected in 2015, however, it could develop later on if electric vehicles heavily penetrate the automobile market and production isn't significantly increased

In Context: Will there be enough lithium to satisfy imminent demand?

Existing lithium-ion batteries for EVs require approximately 0.3 kg of lithium metal equivalent per kWh of battery[41]. Using assumptions that a small PHEV with a 20 mile electric range would require a 5-kWh battery, and a full EV would use a 24-kWh battery like the forthcoming Nissan Leaf, a total of 3,170 metric tons of lithium – or 12 percent of today's total yearly production – could be required to satisfy forecasted EV and PHEV demand in 2015.

Lithium demand for batteries *outside* the automotive sector is expected to increase by 25 percent a year, and lithium demand for other purposes is to rise by 3 percent to 4 percent annually. Based on these projections, and the lithium required to satisfy forecasted EV sales in 2015, total lithium demand may reach approximately 42,000 metric tons in 2015[42].

On the supply side, lithium production is expected to reach 44,000 metric tons in 2015, almost exactly matching demand, suggesting no catastrophic lithium shortage in the next five years.

However, it is possible that pressure on lithium resources could arise once electric vehicles become more widely adopted by 2020, assuming lithium remains the material of choice for automotive batteries. Supplying the estimated 5.4 million EVs in 2020 with 24-kWh batteries would require 39,000 metric tons of lithium for automotive EV applications alone.

As a result of this, three steps will need to be taken:

- Existing lithium mines will need to increase production
- New lithium mines will need to be developed, and
- A commercial lithium recycling infrastructure will need to be in place.

[41] http://www.meridian-int-res.com/Projects/Lithium_Problem_2.pdf
[42] http://www.meridian-int-res.com/Projects/Lithium_Microscope.pdf

Bolivia's ambition to become a major lithium producer is encouraging but is likely to encounter difficulties

Given that Bolivia possesses 50 percent of the world's lithium resources but doesn't yet produce any, it has the potential to become a major lithium producer in the future. However, there are two major factors that are likely to hinder its ability to become one:

1. **The climate conditions at Salar de Uyuni in Bolivia aren't conducive to extracting lithium at a low cost.**

Three main conditions make a lithium deposit commercially viable:

- The lithium deposit mustn't be contaminated with too much magnesium, as the process of removing it is expensive
- The lithium deposit must be in a climate where natural evaporation occurs. This will concentrate the watery solution where lithium chloride deposits are normally found, and
- The lithium must be concentrated in a small area to make extraction easier.

Uyuni's higher level of rainfall and cooler climate means its evaporation rate is just under half that of the Salar de Atacama in Chile. Achieving the necessary concentrations is further complicated because the lithium in the Uyuni brine is spread thinly – approximately 10 times as thin when compared to the Salar de Atacama – over a larger area. Finally, Bolivia's deposits contain a high ratio of magnesium to lithium in the brine. These conditions make extracting Bolivia's deposits much less economical than those in Chile and Argentina.

Bolivia's deposits aren't the most economical to extract

Lithium Triangle Deposit Parameters

	Chile Salar de Atacama	**Argentina** Salar de Hombre Muerto	**Bolivia** Salar de Uyuni
Average altitude (km)	2.3	4.3	3.7
Evaporation rate (mm/y)	3,200	2,300	1,500
Approximate area (sq. km)	3,000	565	8,000
Li concentration (by weight)	0.150%	0.062%	0.035%
Magnesium:Lithium ratio*	6.4	1.4	18.6
Average rainfall (mm/y)	10-15	55-70	20-50

*Lower is better

Source: STRATFOR from multiple sources

2. **The Bolivian president wants to nationalize the lithium market**

Leftist Bolivian President Evo Morales believes that the nation's lithium deposits will bring Bolivia social and economic prosperity, and is therefore not open to foreign investment that will take the financial benefits of the lithium resources away from Bolivians and into the hands of foreign mining companies.

Nonetheless, Morales has said that foreign investment partners are welcome, as long as they use the lithium in Bolivia. In other words, partners must build battery factories and possibly EV assembly lines in Bolivia. This attitude is providing a strong disincentive for foreign investment and is problematic in terms of scaling up global lithium production quickly because Bolivia has an anemic economy and lacks the experience required to produce lithium.

The project cost of commercially producing lithium in Bolivia is high relative to what it would cost Chile and Argentina to expand existing production. It is estimated that the Bolivian government will need to spend $400 million on the necessary facilities to extract lithium carbonate. Then $800 million will be required to develop the capacity to produce lithium and, finally, Bolivia would need to develop the capacity to manufacture lithium batteries, for which there is no cost estimate. On the other hand, Chile and Argentina are said to be able to add 25 percent more capacity with a $40 million to $50 million investment.

Despite the disincentives, foreign companies are still attracted to the Bolivian deposit due to its enormity. The state-run Bolivian mining corporation Comibol has sent a sample of lithium brine to France-based Bollore Group, Japan-based Sumitomo, and South Korea-based Korea Resource (KORES) to study the mineral composition of the salt flats. Following this, in September 2009, Bollore made a $1.2 billion investment offer to develop Bolivia's lithium resources, including building a lithium battery factory and Bolivia said that it still expects to keep at least a 60 percent ownership of the resources.

Subsequently, in October 2009, Comibol revealed its plan to invest $400 million on a lithium carbonate plant at Salar de Uyuni and its intention to produce 12,000 metric tons of lithium a year in 2013. However, other sources think that a more realistic assessment might be 2,000 metric tons in 2015 and 5,500 metric tons in 2020 if everything goes according to plan[43].

How have stakeholders been responding

Stakeholders are exploring new lithium sources

Alternative methods of lithium extraction will only become profitable if the price of lithium increases significantly

Currently the brine salt flats in South America are providing the majority of global production because the brine extraction process is the cheapest way to produce lithium. However, an increase in the price of lithium will make other extraction methods – from clays, pegmatites or possibly the sea – competitive and profitable. Lithium extraction from clays costs about $4,200 to$4,500 per metric ton to produce, whilst brine extracted lithium costs around $1,500-2,300 per metric ton.

Until 1997, the U.S. was the world's leading producer of lithium. However, the brine-based extraction method used by the Lithium Triangle caused a number of the traditional pegmatite and clay facilities to cease production due to the higher cost of extraction, including mines in Greenbushes, Australia; Kings Mountain, North Carolina; and Pervomaisky, Russia.

Future potential lithium resources exist in areas such as Osterbotten, Finland; Jiajika, China; Hector Clays, California; Searles Lake, Los Angeles; the Great Salt Lake, Utah; the Salton Sea, California; The Smackover Oilfield Brines, Arkansas; Bonneville Salt Flats, Utah and the Dead Sea, Israel[44].

Alternatively, scientists at Saga University in Japan estimate that global seawater contains an estimated 230 billion metric tons of lithium, and it is currently conducting research in extracting lithium from the sea. However, current technology is not economically competitive, and would get much less so as energy prices rise, and is not expected to be mature enough to produce lithium at significant quantities in the short term. Moreover, California-based **Somibol** is pursuing the extraction of lithium from hot geothermal waste-water at a plant at the top of the active San Andreas fault.

Lithium recycling

There are already several locations worldwide that have the capacity to recycle lithium, however the global infrastructure is still in its infancy. It is likely that this market will grow – and the economics will improve – in tandem with the EV market once there is more recoverable material in the system.

It is expected that most of the lithium from electric vehicle batteries will be recycled, but not until the first set of electric vehicles finish their life cycle

Historically, automotive batteries boast some of the highest recycling rates for any product. In the U.S., 99 percent of lead acid automotive batteries were recycled in 2006. There seems no reason to suggest that lithium-ion batteries for electric vehicles will not follow a similar trend, with or without government regulation.

Keeping existing lithium in the energy cycle reduces the need to mine more lithium. However, given that a lithium battery is expected to have an average lifetime of 10 years in an electric vehicle, any meaningful augmentation of the lithium supply from recycling will not occur until 10 years after large scale production of the batteries for cars has begun.

Nonetheless, anticipating the burst in EV adoption, many companies are realizing that battery recycling will become more economical and are getting involved in projects as they anticipate the quantities of lithium available for recycling to increase.

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[43] http://www.meridian-int-res.com/Projects/Lithium_Microscope.pdf
[44] http://www.meridian-int-res.com/Projects/Lithium_Microscope.pdf

Lithium recycling will reduce the need to extract new lithium resources

Global Lithium-ion Recycling Projects

Companies Involved	Project Information
Better Place	Better Place is evaluating both second life applications for used batteries and is working with automakers, battery vendors and recyclers on emerging technologies for recovering and recycling most (95 percent) of the materials in batteries that are no longer operational.
EnerDel & Itochu	These companies are partnering to develop a secondary market for lithium-ion batteries by selling them to community or grid storage systems once they have outlived their usefulness in vehicles. EnerDel is expected to supply advanced battery systems for a residential electricity grid to be installed in an apartment building near Tokyo.
Nippon Mining & Metals (NMM)	NMM is expected to develop a plant to extract cobalt, nickel, lithium and manganese from used lithium-ion batteries and to recycle cathode materials used in the lithium-ion batteries. NMM aims to launch into commercial scale operation in 2011.
Nissan & Sumitomo	Nissan and Sumitomo have said that they will establish a joint venture to recycle lithium-ion electric car batteries which would enable Nissan to lower the prices of its zero-emission vehicles by taking into account the resale value of their batteries. The recycled batteries are expected to be used to store energy received via photovoltaic solar panels or to store back-up power. The lithium-ion batteries Nissan uses retain 70 percent to 80 percent of their residual capacity, even after their average lifetime of 10 years in an electric car.
OnTo Technology	The United States Council for Automotive Research's (USCAR) Vehicle Recycling Partnership (VRP), composed of DaimlerChrysler, Ford Motor and General Motors, awarded a contract to OnTo Technology to research and develop ways to recycle nickel-metal hydride (NiMH) and lithium-ion batteries in May 2007. No information on the results is available.
Recupyl Battery Solutions	Recupyl Battery Solutions is scheduled to open a battery recycling centre in Michigan in 2Q 2010 to focus on recycling EV batteries. Recupyl has already created several plants in Poland, Singapore, Spain, the United Kingdom, France and in other countries.
Renault, French Atomic Energy Commission (CEA) and the French Strategic Investment Fund (FSI)	These three organizations are anticipated to create a joint venture for EV batteries that will address the full lifecycle of the batteries, including recycling, after they have been used in vehicles.
Reva & ZEM Energy	Reva and ZEM Energy have signed a deal to create a second life programme for lithium-ion batteries used in the Indian auto firm's electric vehicles. The aim of the deal is to identify a suitable use for the batteries once they can no longer be used in an electric vehicle.
Toxco Waste Management & Tesla	Tesla and Toxco have been working closely to implement a recycling plan[45]. The goals of the plan have been stated as: 1. Maximize the amount of materials that can be reused 2. Maximize the amount of materials that can be recycled, and 3. Minimize energy consumption utilized during the transportation and recycling process. Toxco has the only lithium battery recycling facility in North America and was the recipient of a $9.5 million grant from the Department of Energy in August 2009[46].
Umicore	Umicore is expected to invest €25 million in an industrial-scale recycling facility for end-of-life rechargeable batteries in Belgium. It is expected to become operational in the first half of 2011 and its initial annual capacity will be 7,000 metric tons. The investment is to enable Umicore to deal with the expected growth in the availability of end-of-life lithium-ion, lithium-polymer and nickel-metal hydride rechargeable batteries[47].

Source: Cleantech Group Analysis

[45] http://www.teslamotors.com/blog4/?p=66
[46] http://www.toxco.com/docs/Toxco%20DOE.pdf
[47] http://www.investorrelations.umicore.com/en/newsPublications/pressReleases/2009/URS_recyling_EN.pdf

Technology developers are exploring alternative battery chemistries

Several alternatives to lithium-ion batteries are in the development pipeline but all are at early stages. A few companies are looking at metal-air batteries that will supposedly be able to dramatically outperform the best lithium-ion batteries.

For example, Arizona-based **Fluidic Energy** is working on the development of a metal-air ionic that will supposedly have up to 11 times the energy density and cost approximately a third as much as the top lithium-ion technologies. Additionally, Swiss-based **ReVolt** are aiming to release a zinc-air battery this year for use in hearing aids, and later for cell phones. Eventually much larger batteries are planned for electric vehicles.

Lithium outlook

Lithium prices are rising, but won't impact EV battery costs significantly

Raw lithium accounts for under a 0.5 percent of the total cost of an EV battery

Lithium still remains inexpensive, but prices are rising. In 2009, the cost of lithium metal equivalent was $1.2 per kilogram – almost tripling 2006 values. To put this cost in perspective, a Nissan Leaf 24-kWh battery is estimated to contain around 7 kilograms, which currently costs under $10. Given that an EV car battery can cost the consumer between $3,000 to $10,000, the cost of the raw lithium accounts for under 0.5 percent of the total battery cost.

Therefore, the cost of lithium is not a major driver of cost in battery manufacturing, and the market will be able to tolerate significant increases in the cost of lithium without unduly impacting competitiveness. Although the overall price of the batteries must come down for electric vehicles to be adopted widely, this is heavily dependent on improving battery manufacturing processes and reductions achieved from economies of scale[48].

Rising costs will eventually create new opportunities

Per the Cleantech Group's analysis in this report, it seems as if there will be enough lithium to support industry growth at least until 2015. However, lithium production may not be able to support mass adoption of electric vehicles in 2020, creating opportunities for investors, corporations, technology developers and mining companies to extract new sources of supply, recycle lithium content from old batteries or develop alternative ways to store energy for vehicles.

The strategic value of Bolivia's reserves has been over-hyped

It is likely that Chile and Argentina will continue to dominate global lithium production in the short to medium term, and that it will be difficult for Bolivia to achieve its goal of becoming a major lithium producer in the next five years.

Additionally, if Bolivia continues to provide strong disincentives to investors, investors will look elsewhere for lithium. In January 2010, a Toyota affiliate entered into a joint venture with Australian mineral-exploration company, Orocobre, to develop a lithium mine called Salar de Olaroz in Argentina. Toyota plans to take a 25 percent stake in the project and provide $4.5 million for a feasibility study as well as a low-cost Japanese government loan to fund at least 60 percent of the project's development. In December 2009, Magna International and Mitsubishi made a $10.5 million equity investment in Toronto-based Lithium Americas to help develop another lithium deposit in Argentina.

SQM – the Chilean lithium producer – currently sells its lithium for about three times what it costs to produce due to strong demand. Therefore, there may be margin enough for foreign investors to help Bolivia profitably extract its lithium deposits despite the vast expense and the poorer conditions they have.

Bolivian President Morales is determined to harness the country's vast lithium deposit in order to bring social and economic prosperity to his nation. Eventually the country will enter production, and another lithium supplier in the world is good news for the electric vehicle industry. However, claims that Bolivia is the "Saudi-Arabia of lithium" because of the size of its deposits ignores the deeper underlying subtleties of lithium production.

[48] http://action.pluginamerica.org/o/2711/images/World-Lithium-Resource-Impact-on-Electric-Vehicles-v1.pdf

Conclusion

Cleantech investors and technology developers are not as aware of input resource availability as much as they should be. From an investor's point of view, it would not only be wise to diversify in terms of clean energy generation methods, but also to diversify in terms of input materials used to build those technologies. And technology developers must consider how an unforeseen threat in their input supply chains could affect mass-scale production of their products, and hedge those risks if necessary.

However, even though availability of these inputs should be an issue that the entire cleantech community is aware of, no imminent shortage of REEs or lithium will be expected to cause panic or thwart a cleantech revolution as it reaches scale this decade.

Indeed, while lithium reserves may not be able to power all 800 million gasoline powered cars on the road today, to do so would be untenable from an energy dependency point of view. Nor are lithium ion battery-powered electric vehicles the only clean transport option. Biofuels, fuel cells, other battery chemistries and alternative e-mobility business models are also at various stages of development.

A similar story can be told for REE used in permanent magnet wind turbines. No, there is not enough REE in the world to entirely power the global economy with wind turbines. Other clean energy generation technologies such as solar, bio-energy, geothermal and marine are also vital.

Watch carefully for the intervention of governments in markets for the raw materials like REE and lithium used in clean technologies. Commercial opportunities will be created.

Learn more – resources, links, references

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REE

Rare Earths at the crossroads
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Lithium

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Recycling of Advanced Batteries for Electric Vehicles
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Advanced Batteries for Electric-Drive Vehicles
http://mydocs.epri.com/docs/public/000000000001009299.pdf

Other Useful Sources of Data

The U.S. Geological Survey
http://www.usgs.gov/

Roskill
http://www.roskill.com/

The Jack Lifton Repot
http://www.jackliftonreport.com/

The U.S. Magnet Materials Association (USMMA)
http://www.usmagnetmaterials.com/

The Rare Metal Blog
www.raremetalblog.com

International Lithium Alliance
www.lithiumalliance.org

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