Material resources and low-carbon energy technologies

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Contents

• Introduction
• Demand side issues
• Supply side issues
• Unique properties
• Envisaging the future
Objectives

• Provide an overview
  – Demand side
  – Supply side
  – Unique properties
• Build a common understanding
  – What should be expected?
• Learning process (both ways)
• Identify opportunities for collaboration
Introduction
Suppose that...

• In Jan 2004, you happened to spend $500 to buy something looks useless like this:
• In Jun 2008, you put it on the market and got astonishing $11,000 out of it.
• Excited, you decided to invest $100,000 on it.
• Sold it two months later, it became $7,600.
• Which material is this?
  – Rhodium
High-tech metals

• Metals strongly tied to emerging technologies.
• Unique characteristics in supply-demand dynamics.
• Geopolitical influence.
Putting things in perspective

- September 2010: Dispute over Senkaku (Japanese) or Diaoyu (Chinese) islands.
- The Washington Post Oct 30, 2010:
  “China on Saturday assured the United States that it would continue the export of crucial rare-earth minerals that Beijing is believed to have halted as a way to pressure Japan.”
Toyota Forms Task Force on Rare Earth Metals Amid China Export Ban Reports

By Makiko Kitamura and Jason Scott - Sep 28, 2010 8:22 PM PT

Toyota Motor Corp. has set up a task force on rare earth minerals used in hybrid cars amid reports of China’s ban on exports of the materials to Japan.

The carmaker, the world’s largest producer of gasoline-electric vehicles, said it formed the committee, confirming a report in the Nikkan Kogyo newspaper today. Japanese companies are looking to diversify supply with Lynas Corp., a Sydney-based miner of rare earth metals, saying it had signed a contract with an unnamed Japanese customer.

Rare earth minerals such as neodymium and dysprosium are used in electric-motor magnets in hybrid cars, including Toyota’s Prius and Honda Motor Co.’s Insight, and in mobile
What’s the big deal?

REE export (2010)
What’s the big deal?

Million USD

<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>$</td>
<td>$600</td>
<td>$500</td>
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<tr>
<td>$100</td>
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<td>$200</td>
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<td>$300</td>
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<td></td>
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<tr>
<td>$800</td>
<td></td>
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</tr>
</tbody>
</table>

10 Million USD

Li>um

REE export (2010)

Litium (2008)
What’s the big deal?

- REE export (2010)
- Lithium (2008)
- Copper (2007)
What’s the big deal?

- REE export (2010)
- Lithium (2008)
- Copper (2007)
- Aluminum (2007)
What’s the big deal?

Million USD

<table>
<thead>
<tr>
<th>Material</th>
<th>Year</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>REE export</td>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>Lithium</td>
<td>2008</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>2007</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>2007</td>
<td></td>
</tr>
<tr>
<td>Crude oil</td>
<td>2006</td>
<td></td>
</tr>
</tbody>
</table>
In sum...

• High-tech metals, especially REE are hot issue.
• But its economic importance is nowhere near those of the bulk resources (yet).
• The unique supply-demand dynamics and limited substitutability, however, make these metals particularly interesting.
Scope of the discussion

Low-Carbon Energy Technologies
- Photovoltaics
- Wind turbines
- Solid State Lighting
- Batteries
- Fuel cells

Materials
- Rare Earth Elements
- Lithium
- Platinum / Palladium
- Indium / Gallium
- Tantalum
Issues to be discussed

• Demand-side characteristics
• Supply-side characteristics
• Unique properties in supply-demand dynamics
• What should we expect in the future?
• Research priorities
Demand side
## Energy-Materials Nexus

### Clean Energy Technologies and Components

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>PV films</th>
<th>Magnets</th>
<th>Magnets</th>
<th>Batteries</th>
<th>Phosphors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanthanum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Praseodymium</td>
<td>▪️</td>
<td>▪️</td>
<td>▪️</td>
<td></td>
<td>▪️</td>
</tr>
<tr>
<td>Neodymium</td>
<td>▪️</td>
<td>▪️</td>
<td>▪️</td>
<td></td>
<td>▪️</td>
</tr>
<tr>
<td>Samarium</td>
<td>▪️</td>
<td>▪️</td>
<td>▪️</td>
<td></td>
<td>▪️</td>
</tr>
<tr>
<td>Europium</td>
<td>▪️</td>
<td>▪️</td>
<td>▪️</td>
<td></td>
<td>▪️</td>
</tr>
<tr>
<td>Terbium</td>
<td>▪️</td>
<td>▪️</td>
<td>▪️</td>
<td></td>
<td>▪️</td>
</tr>
<tr>
<td>Dysprosium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yttrium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indium</td>
<td>▪️</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Gallium</td>
<td>▪️</td>
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<td></td>
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<tr>
<td>Tellurium</td>
<td>▪️</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt</td>
<td>▪️</td>
<td></td>
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<tr>
<td>Lithium</td>
<td>▪️</td>
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</tr>
</tbody>
</table>

DOE, 2010 (December)

BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA
Triple junction cell (Forbes and Hubbard, 2010)

DOE, 2010

Rare Earth Metals for Lighting and Display

<table>
<thead>
<tr>
<th>Devices</th>
<th>Electrode</th>
<th>Phosphor</th>
<th>Back light</th>
<th>Sealing glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorescent lamp</td>
<td>W</td>
<td>Tb, Eu, Ce, Y, La, Mn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LED lighting</td>
<td>Ga</td>
<td>Eu, Ce, Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crystal</td>
<td>In</td>
<td>Same as LED or fluorescent lamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasma Display</td>
<td>Bi</td>
<td>Eu, Y, Tb, Mn</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dulcos, 2010
Efficiency by means of using materials

Source: Arnold Magnetic Technologies (2010)
http://arpa-e.energy.gov/LinkClick.aspx?fileticket=E8Qu6CDIEdw%3d&tabid=401
Efficiency by means of using materials

Best Research-Cell Efficiencies

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Multijunction Concentrators
- Three-junction (2-terminal, monolithic)
- Two-junction (2-terminal, monolithic)

Crystalline Si Cells
- Single crystal
- Multicrystalline
- Thin Si

Thin Film Technologies
- Cu(In,Ga)Se₂
- CdTe
- Amorphous Si:H (stabilized)

Emerging PV
- Organic cells

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Efficiency by means of using materials

• Typical laptop battery: 5g lithium
• Plug-in hybrid car: 15-20kg lithium
  3,000-4,000 laptops

Picture from: http://www.fastcompany.com/blog/ariel-schwartz/sustainability/
Technologies in question

• Photovoltaics
• Wind turbines
• Solid State Lighting
• Batteries
• Fuel cells
• Display
• Mobile communication
• Semi-conductors
• Catalysts and catalytic converters
• Aviation and turbines
Demand on LCETs

• Demands on Low-Carbon Energy Technologies (LCETs) are growing fast
  – Installed PV capacity: doubling every two years.
  – Wind power: annual growth rate in 2010 reached 31% (doubling in 2.5 years).
  – Lithium battery demand is expected to grow 14 times by 2020.
  – LED market is expected grow at 9.4% per year until 2020.
IEA PV Roadmap (2010)
In sum...

• Enormous, policy-backed pull from the market.
• Demand on high-tech metals will continue to increase accordingly.
• But one should never forget:
  – Demand from other technologies than LCETs
  – Demand from speculation and hedging
Si Technology: The Complexity is Increasing Rapidly

Source: T. McManus, Intel Corp., 2006
How to Invest in Rare Earth Metals
By Jason Hamlin, on September 11th, 2009

Welcome to Gold Stock Bull! Make sure to enter your email for free updates whenever a new article is posted. To view the GSB portfolio, receive trade alerts and get the contrarian newsletter, become a Premium Member.

The following is an excerpt from the Gold Stock Bull Newsletter, which is available to Premium Members along with access to the GSB Portfolio and email trading alerts that are sent out any time we buy or sell. To become a Premium Member and receive full access, click here.

I haven't been nearly as excited about the investment opportunities in a new sector as I am about rare earth metals at the current moment. Demand for rare metals has been exploding and few new mines are coming online in this geographically-concentrated sector.

Rare earth elements or rare earth metals are a collection of seventeen chemical elements in the periodic table, namely scandium, yttrium, and the fifteen lanthanoids. The use of rare earth elements in modern technology has increased dramatically over the past years. For example, dysprosium has gained significant importance for its use in the construction of hybrid car motors. Unfortunately, this new demand has strained supply, and there is growing concern that the world may soon face a shortage of the materials. This is where the investment opportunity unfolds.

The story of rare earth metals is mostly one of China producing and exporting while Japan, America and everyone else is importing. Rare earth metals are vital to new technologies such as iPhones and flat screen televisions, green energy technology such as wind, solar and geothermal and critical to the future of hybrid and electric cars. Rare Earth Elements and Heavy Rare Earths are a strategic choke point held in China's hands as they produce 95% of REEs. Lately China has been tightening the others in their hands, and the political tension is rising. This is a Win-win opportunity.
Supply side
What’s going on

• Price increases, so does the greed.

• China
  – Chinalco invested on Rio Tinto (14 billion, 2008)
  – Established Socomin in Congo (9 billion, 2008)

• Russia
  – Mikhail Khodorkovsky, found guilty  
    (Dec. 27, 2010)
  – Yukos purchased Rosneft (2006)

Average annual price increase rate vs. Price volatility index graph.

- Elements: Cd, Ir, Zn, Cu, Cr, Rg, Tl, W, In, Mo, Rh
- Y-axis: 0% to 120%
- X-axis: 0.00 to 1.20
- Data points for each element.
Supply-side characteristics

• Limited volume of supply
• Dependence on host metals
• Highly elastic response to demand
Limited supply

Ir (Iridium)
## Chinese export limitation on REEs

<table>
<thead>
<tr>
<th>Element</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neodymium</td>
<td>15%</td>
<td>25%</td>
</tr>
<tr>
<td>Lanthanum</td>
<td>0%</td>
<td>25%</td>
</tr>
<tr>
<td>Cerium</td>
<td>0%</td>
<td>25%</td>
</tr>
</tbody>
</table>

- In 2011, REE export quota is likely to reduce to around 30,000 tonne from 35,000 tonne in 2010.
Supply-side responses

- Diversification
- Japan-India coalition for REE development
- US Mountain Pass area expected to re-open (2011)
- Recycling tech

Press-enterprise.com
Key characteristics
Recyclability

- Serious supply risks
- Rapid demand growth
- Serious recycling restrictions

Elements: Pd, Pt, RE, Te, In, Ge, Ga, Ru, Li, Ta
Distribution model for Cu converter

\[ x_i(\text{Me}) \text{ in Cu} = 0.01 \text{ (mol fraction)} \]

\[ p_{O_2} = 10^{-6} \text{ atm} \]

\[ p_{Cu} = 8 \times 10^{-6} \text{ atm} \]

\[ T = 1500 \text{ K} \]

Nakajima, 2010
Recycling of high-tech metals

• Traditional method using smelter promises little hope.
• Solvent extraction, and biological & physical absorption technologies being developed.
Price elasticity

GE renews efforts to reduce Ta usage in superalloys

From: Don Lipkin (GE Global Research): personal communication
**Targeted impact**

<table>
<thead>
<tr>
<th>RISK LEVEL</th>
<th>GE % OF WORLD SUPPLY</th>
<th>IMPACT ON GE REVENUE</th>
<th>GE ABILITY TO SUBSTITUTE</th>
<th>ABILITY TO PASS THROUGH COST INCREASES</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERY HIGH</td>
<td>Extremely significant, &gt;X%</td>
<td>&gt;$Y Bn</td>
<td>Very difficult—Very unique and no substitute expected</td>
<td>Nearly impossible</td>
</tr>
<tr>
<td>HIGH</td>
<td>Very significant, 0.25X% – X%</td>
<td>$0.25 Y – $Y Bn</td>
<td>Difficult—No known substitute; extensive research</td>
<td>Difficult</td>
</tr>
<tr>
<td>MEDIUM</td>
<td>Significant, 0.05X% – 0.25X%</td>
<td>$0.05Y – $0.25Y Bn</td>
<td>Moderate—Possible substitutes known but not tested</td>
<td>Partially possible</td>
</tr>
<tr>
<td>LOW</td>
<td>Low, 0.01X% – 0.05X%</td>
<td>$0.01Y – $0.05Y Bn</td>
<td>Easy—Substitute known but not designed in</td>
<td>Relatively easy</td>
</tr>
<tr>
<td>VERY LOW</td>
<td>Very low, &lt;0.01X%</td>
<td>&lt;$0.01Y Bn</td>
<td>Very easy—Substitute design ready for production</td>
<td>Done automatically</td>
</tr>
</tbody>
</table>

*Duclos, et al. (2010) Mechanical Engineering*
Targeted impact

Area represents annual value
Duclos, et al. (2010) *Mechanical Engineering*
Co-production tree
Co-elements

Interconnected Carrier Metal Cycles

Oxide ores

Sulfide ores

Sulfide and oxide ores

Verhoef et al, 2004
Envisaging the future
Reserves

• Rare earth elements are not “rare”.
• Reserves for other metals such as Lithium are generally abundant as well.
• R&D investments on extraction and recycling technologies just started.
Envisaging the future
## RE Price Changes

<table>
<thead>
<tr>
<th></th>
<th>July 2003</th>
<th>Nov 2010</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dy</td>
<td>27.0</td>
<td>400.0</td>
<td>14.8 x</td>
</tr>
<tr>
<td>Nd</td>
<td>7.0</td>
<td>93.5</td>
<td>13.4 x</td>
</tr>
<tr>
<td>Pr</td>
<td>7.0</td>
<td>85.5</td>
<td>12.2 x</td>
</tr>
<tr>
<td>Sm</td>
<td>11.3</td>
<td>51.5</td>
<td>4.6 x</td>
</tr>
</tbody>
</table>

Prices are FOB China for indicated metal, USD/kg
What to expect

• Short-to-mid term shortage in supply
• Mid-term price shock
• Possible hedging and “false” demand
• Potential bilateral coalition between countries
• Cartelization, nationalism over resources
Priority research areas

• Material-risk-conscious design
  – Reduced use of materials
  – Design for disassembly and recycling
• Recycling technologies
• Collaboration between design and fabrication, material science, industrial ecology and metallurgy.
Thank you!

• Questions, suggestions, comments welcomed.
• Contact: suh@bren.ucsb.edu