Critical metals and rare earth elements

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Mines and Money 2010
Outline

• Critical raw materials
• Introduction to the rare earth elements
• Economic importance and applications
• Characteristics of the market:
  - Geological factors
  - Technical factors
  - Commercial factors
• Global production
• The impact of Chinese policy on supply
• Global response to the supply challenge
• The supply-demand balance
• Developing new capacity
• Hurdles to developing new capacity
• Outlook
Critical raw materials

• Increasing vulnerability in the supply of specific minerals
• Definitions: critical (strategic) minerals, technology minerals, minerals for emerging technologies
• Critical minerals:
  - High supply risk (concentration production)
  - High impact of supply restriction (critical to the economy)
  - Compounded by low substitutability/recycling rates
• Geopolitical-economic framework

<table>
<thead>
<tr>
<th>Antimony</th>
<th>Indium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beryllium</td>
<td>Magnesium</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Niobium</td>
</tr>
<tr>
<td>Fluorspar</td>
<td>PGMs (Platinum Group Metals)</td>
</tr>
<tr>
<td>Gallium</td>
<td>Rare earth elements</td>
</tr>
<tr>
<td>Germanium</td>
<td>Tantalum</td>
</tr>
<tr>
<td>Graphite</td>
<td>Tungsten</td>
</tr>
</tbody>
</table>

Source: EU Study, 2010
What are the rare earth elements (REE)

- 17 chemical elements on the periodic table: the 15 lanthanides, plus scandium (Sc) and yttrium (Y)
- Average concentration crust 150-220 ppm (Cu 55 ppm, Zn 70 ppm)

**Light REE**
La: Lanthanum
Ce: Cerium
Pr: Praseodymium
Nd: Neodymium
Pm: Promethium
Sm: Samarium
Eu: Europium

**Heavy REE**
Gd: Gadolinium
Tb: Terbium
Dy: Dysprosium
Ho: Holmium
Er: Erbium
Tm: Thulium
Yb: Ytterbium
Lu: Lutetium
Economic importance

- 17 elements = hundreds of applications
- Unique properties
- Not currently substitutable in many applications

**Chemicals**
- Unique electron configuration

**Catalytic**
- Oxygen storage and release

**Magnetic**
- High magnetic anisotropy and large magnetic moment

**Optical**
- Fluorescence, high refractive index

**Electrical**
- High conductivity

**Metallurgical**
- Efficient hydrogen storage in REE alloys
Source: Lynas Corporation Ltd, 2010
Scale of the market

- Production REO 2009: 126,230 tonnes\(^1\)
- Value of the REO market: ~US$1.25 billion (before downstream processing)
- Significant potential for market growth (linked to technological change)

\(^1\)USGS, 2010

Source: British Geological Survey
REE market – geological factors

- Geology strongly influences supply and prices
- Rare earths relatively abundant but rarely concentrated
- Naturally occur together
- Relative abundance of REE within and among deposits is highly variable
  - LREE typically 80-99% most deposits
- Many REE minerals – few commercially important:
  - bastnäsite (76% REO – Ce, La, Y)
  - monazite (71% REO – Ce, La, Nd)
  - xenotime (61% REO – Y, HREE)

Source: Oakdene Hollins, 2009
Diverse range of minerals deposit types

Primary deposits:
- Carbonatite-associated
- Alkaline igneous rock-associated
- Iron REE deposits (Fe-Ox-Cu-Au)
- Hydrothermal deposits

Secondary deposits:
- Marine placers
- Alluvial placers
- Paleoplacers
- Lateritic deposits
- Ion-adsorption clays
REE market – technical factors

• REE ores are mineralogically complex

• Must be recovered as a group → separated (chemically similar therefore expensive)

• Dirty ores for clean technologies – ores commonly contain radioactive minerals (environmental approvals challenging)

• Deposits vary significantly in composition (processing route – project specific)

• Deposits complex to evaluate – pilot studies required

• Coupled production - frequently produced as by-products e.g. Bayan Obo (Fe), iloparite, Russia (Ti), Canada (U)
REE market – commercial factors

• Not a single commodity - 17 elements with unique properties and specific applications

• Matching geological ratios to demand is a challenge
  - Potential oversupply of LREE
  - Variable pricing: HREE more expensive

• Non-exchange traded (analogies to industrial minerals):
  - Specialist REE trading companies
  - Reliability of price information
  - Chemicals not conventional commodities (varying purity, customer specific)

• Used in small quantities – demand is inelastic
China dominates REE production

• China’s – 95% global REE production, 30% ‘reserves’*
• Limited reliable production data for individual countries and elements
• Geographic concentration of ‘reserves’ is characteristic of critical metals

<table>
<thead>
<tr>
<th>Country</th>
<th>Production 2009</th>
<th>‘Reserves’*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>REO (tonnes)</td>
<td>World %</td>
</tr>
<tr>
<td>Australia</td>
<td>0</td>
<td>5 400 000</td>
</tr>
<tr>
<td>Brazil</td>
<td>650</td>
<td>48 000</td>
</tr>
<tr>
<td>China</td>
<td>120 000</td>
<td>27 000 000</td>
</tr>
<tr>
<td>CIS</td>
<td>2500</td>
<td>19 000 000</td>
</tr>
<tr>
<td>India</td>
<td>2700</td>
<td>3 100 000</td>
</tr>
<tr>
<td>Malaysia</td>
<td>380</td>
<td>30 000</td>
</tr>
<tr>
<td>USA</td>
<td>-2</td>
<td>13 000 000</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>22 000 000</td>
</tr>
<tr>
<td>Total</td>
<td>126 230</td>
<td>90 000 000</td>
</tr>
</tbody>
</table>

*Reserves - that part of the reserve base which could be economically extracted or produced at the time of determination (USGS, 2010)

1Ore output: 129 400 tonnes
2USA produces 3000 tonnes REO - reprocessing stockpiles Mountain Pass
3Chinese deposits declined to 27 000 000 million tonnes at the end 2009 or 30% World total, from 43 million in 1996 (Ministry Foreign Trade)
Impact Chinese policy on REE supply

• “The Middle East has oil, and China has rare earths” Deng Xiaoping

• Key issues and motivation:
  - No incentive to support overseas supply chains
  - Attracting downstream industry (employment creation)
  - **Maximise benefit to the Chinese economy** – continue to drive Chinese policies to limit REE production and exports

• Policy objectives - improve resource management & conservation, exploitation efficiency, environmental protection:
  - Production quotas
  - Export quotas
  - Export taxes

© NERC A Source: Chinese Ministry of Commerce
Developments Chinese REE industry

• Increased regulation and rationalisation of the sector:
  - Restructuring and consolidation
  - Crackdown on informal production & environmental protection
  - Creation of a unified pricing scheme for LREE
  - Stockpiling resources
• Future policy is unclear:
  - “China to reduce rare earth export quotas” China Daily, 18 Oct. 2010
  - “China will not significantly cut rare earth exports in 2011”, China Daily, 03 Nov. 2010
• Interest in acquisition of overseas REE resources
  - e.g. Arafura Resources
• Opportunities for western companies in China:
  - Processing joint ventures
  - Special REE research funds
Global response to the supply challenge

- Supply is volatile and demand is set to rise
- Policies and programmes e.g.:
  - Various Acts including - Rare Earths and Critical Materials Revitalization Act (Sept, 2010)

- Japan: Guidelines for securing national resources (2008)
- Ministry of Economy, Trade and Industry release a new REE policy (*October, 2010*)
- Agreements with Mongolia to develop REE projects
- US-Japan roundtable on rare earth elements (*Nov. 2019*)

- South Korea: reducing dependence Chinese REE supplies, revising policy

- Inquiry strategically important metals *Science & Technology Committee* (Nov. 2010)


- Challenge export policies?
- Establishing stockpiles?
- Joint ventures – miners/industrial consumers
Supply-demand balance

- 2010 global demand forecast: 136,100 tonnes REO\(^1\) (2009 production 126,230 tonnes)
- 2015 - variable demand balance across the REE: cerium, lanthanum, neodymium, europium, terbium, dysprosium\(^2\)

### Global rare earth element demand (tonnes per annum) ±15%

<table>
<thead>
<tr>
<th>Application</th>
<th>Consumption REO</th>
<th>Increase 2008-2015 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2008(^2)</td>
<td>2015(^2^*)</td>
</tr>
<tr>
<td>Catalysts</td>
<td>25 000</td>
<td>30-34 000</td>
</tr>
<tr>
<td>Glass</td>
<td>12 000</td>
<td>13 000</td>
</tr>
<tr>
<td>Polishing</td>
<td>15 000</td>
<td>20-22 000</td>
</tr>
<tr>
<td>Metal alloys</td>
<td>22 250</td>
<td>50-55 000</td>
</tr>
<tr>
<td>Magnets</td>
<td>26 250</td>
<td>45-50 000</td>
</tr>
<tr>
<td>Phosphors and pigments</td>
<td>9000</td>
<td>12-14 000</td>
</tr>
<tr>
<td>Ceramics</td>
<td>7000</td>
<td>8-10 000</td>
</tr>
<tr>
<td>Other</td>
<td>7500</td>
<td>10-12 000</td>
</tr>
<tr>
<td>Totals</td>
<td>124 000</td>
<td>190-210 000(^*)</td>
</tr>
</tbody>
</table>

\(^1\)Lynas Corporation Ltd, 2010
\(^2\)Industrial Minerals Company of Australia Pty Ltd, 2010

* Forecast
The race to develop non-Chinese rare earth resources

- No shortage of global ‘reserves’ (~90 million tonnes REO) → issue bringing new production online in time
- Many projects but few mines (251 REE projects, 165 companies, 24 countries)

1 USGS, 2010
2 www.techmetalsresearch.com
Hurdles to developing new capacity

• Urgency for new producers:
  - Long start-up times (>7 years\(^1\))
  - “...rebuilding a U.S. rare earth supply chain may take up to 15 years”\(^2\)
• Limited technical knowledge to develop projects
• REE ore mix – LREE vs. HREE-dominant projects
• High production costs
• Restricted opportunities for market entry – offtake agreements
• Project financing:
  - Capitally intensive (>US$40/kg annual capacity\(^3\))
  - Access to debt market (early stage, unfamiliarity to investors)
  - Potential future market size?
  - Potential REE bubble?
  - Evaluation and valuing REE deposits

\(^1\)USGS, 2010
\(^2\)GAO-10-617R Rare Earth Materials in the Defense Supply Chain
\(^3\)Industrial Minerals Company of Australia Pty Ltd, 2010
REE outlook

• China will remain the **dominant REE supplier** short-medium term

• Future **supply will be tight**, particularly for the **HREE**

• Projects outside China need to be developed rapidly to **reduce supply risk:**
  - New projects will come on stream over the next 5 years

• **Caught out by REE** – need to predict future supply problems:
  - Consider **other critical metals**
  - Improved data is required on production
  - International collaboration necessary (USA/Japan/EU)

• **Raw materials security diplomacy** will be of growing importance

• **Recycling, substitution** and resource efficiency increasingly important
Sources of reference and acknowledgements

- Abigail Walters (co-researcher, BGS)
- U.S. Geological Survey
- U.S. Government Accountability Office
- Congressional Research Service
- Company websites
- Lynas Corporation Ltd.
- Industrial Minerals Company of Australia Pty Ltd.
- metal-pages.com
- techmetalsresearch.com
- EU study, 2010
- Chinese Ministry of Commerce
- Oakdene Hollins
- Clint Cox, The Anchor House