Material Scarcity
-- in Search of Solutions --

Endangered Elements
- Metals and Phosphorus -
The Elements

- solar panels
- catalysts
- batteries
- magnets
- lights
- food & life

- Serious threat in next 100 years
- Rising threat from increasing use
- Limited availability future risk to supply
- Abundant element
- Formed by radioactive decay
- Insufficient information
China dominates the rare earth metals

NRC-Handelsblad January 16, 2010

Hybrid cars, flat screens, and solar panels contain rare (earth) metals. Most are obtained from China and unstable regions. **The Western world is vulnerable.**

Europa afhankelijk van rest van de wereld voor kritische metalen

De taartdiagrammen geven het aandeel aan van de totale wereldproductie

Magnets: Nd, Dy, Tb, Sm
Solar Cells: Pr, Yt, Yb
Phosphors: Eu, Y, Tb, Ce
Catalysts: Ce, Rh, Pt, Pd
Batteries: La, Li, …
Electronics: Ni, Ta, Ga, In, Ge
Optics: Ge, Ta, La
Lasers: Y, Er, Ho, Dy, Tb, …
Without rare earth metals, no car

NRC-Handelsblad January 22, 2010

Just like many other Novel Technologies

Nd, Dy, La

Eu, Y, Ho

Gd

Neodymium

500 g
Toyota Prius
Mercedes S 400

200 kg
Windturbine 16m
War on Unobtanium

Scarcity of Minerals
A strategic security issue!

The Hague Centre for Strategic Studies 02 | 01 | 10
EU Critical Materials List

- China major producer
- US study

Supply Risk vs. Economic Importance

- Commodities: Lithium, Neodymium, Antimony, Germanium, Tungsten, Cobalt, Tantalum, Graphite.
# Scarcity of Minerals

## Chinese share of world production

### Rare earth metals

- Gallium: 83%

### China's Rare Earth Element Export Quotas

<table>
<thead>
<tr>
<th>Year</th>
<th>Export Quotas (Tonnes Rare Earth Oxides)</th>
<th>Annual Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>65,609</td>
<td>-</td>
</tr>
<tr>
<td>2006</td>
<td>61,821</td>
<td>-6%</td>
</tr>
<tr>
<td>2007</td>
<td>59,643</td>
<td>-4%</td>
</tr>
<tr>
<td>2008</td>
<td>56,939</td>
<td>-5%</td>
</tr>
<tr>
<td>2009</td>
<td>50,145</td>
<td>-12%</td>
</tr>
<tr>
<td>2010</td>
<td>30,258</td>
<td>-40%</td>
</tr>
<tr>
<td>2011</td>
<td>30,184</td>
<td>-0.24%</td>
</tr>
</tbody>
</table>

(Source: Kingsnorth 2010 and Scott 2011)

## China keeps rare earth metals for itself

(NRC – Dutch Newspaper)

<table>
<thead>
<tr>
<th>MINERAL</th>
<th>SHARE</th>
<th>EXPORT QUOTA (2010)</th>
<th>MAIN APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dysprosium</td>
<td>99%</td>
<td>Full export ban</td>
<td>Permanent magnet</td>
</tr>
<tr>
<td>Lanthanum</td>
<td>95%</td>
<td>ca. 9,000 tonnes</td>
<td>NiMH battery</td>
</tr>
<tr>
<td>Neodymium</td>
<td>95%</td>
<td>ca. 5,000 tonnes</td>
<td>Permanent magnet</td>
</tr>
<tr>
<td>Antimony</td>
<td>87%</td>
<td>57,500 tonnes</td>
<td>Semiconductors</td>
</tr>
<tr>
<td>Tungsten</td>
<td>84%</td>
<td>14,300 tonnes</td>
<td>High-performance cutting tools</td>
</tr>
<tr>
<td>Gallium</td>
<td>83%</td>
<td>-</td>
<td>Semiconductor</td>
</tr>
</tbody>
</table>

(Export Quotas: Tonnes Rare Earth Oxides)
Scarcity of Minerals - China

Global Production of Rare Earth Oxides, 1950 – 2000

Bayan Obo Mine, Inner Mongolia
the largest worldwide
Scarcity of Minerals - non-China

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Resource (million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayan Obo</td>
<td>1,460</td>
</tr>
<tr>
<td>Kvanefjeld Greenland</td>
<td>215</td>
</tr>
<tr>
<td>Mountain Pass</td>
<td>20</td>
</tr>
<tr>
<td>Nechalacho</td>
<td>65</td>
</tr>
<tr>
<td>Mt Weld</td>
<td>12</td>
</tr>
</tbody>
</table>

Source: IMCOA 2009

Relative Abundance of Rare Earth Elements

World Reserves in million tons (USGS 2012)

<table>
<thead>
<tr>
<th>Country</th>
<th>Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>13</td>
</tr>
<tr>
<td>Australia</td>
<td>1.6</td>
</tr>
<tr>
<td>China</td>
<td>55</td>
</tr>
<tr>
<td>CIS</td>
<td>19</td>
</tr>
<tr>
<td>India</td>
<td>3.1</td>
</tr>
<tr>
<td>Other countries</td>
<td>22</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>114</strong></td>
</tr>
</tbody>
</table>
Rare Earths & Precious Metals

Scandium, Ytrium, and the Lanthanides

Economic Importance

Global Precious Metals Reserves
Precious, Rare Earth, and Major Industrial Metals

WGI Worldwide Governance Indicator vs Hersfindahl-Hirschman Index

\[ \sum (\text{market share})^2 \] of 50 largest firms

Above 2500 means highly concentrated
EU Critical Materials for Energy

Rare earth prices vs. gold and silver

EU Metal Need in 2030 as % of 2010 World Supply

Critical Metals in strategic energy technologies
Assessing Rare Metals as supply-chain bottlenecks in low-carbon energy technologies

14 critical metals
US DOE 2011 Critical Materials List (16)

Short-Term (present–2015)

Medium-Term (2015–2025)

R Reduce the use
R Recycle for re-use
R Replace - substitute

All Energy Related - PV coatings, magnets, batteries, phosphors