GLOBALIZATION AND SUSTAINABILITY OF THE RARE EARTHS

Karl A. Gschneidner, Jr.
Ames Laboratory, U.S. Department of Energy and Department of Materials Science and Engineering
Iowa State University
Ames, Iowa 50011-3020, USA

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QUIZ

How many rare earth items did you handle or observe this morning since you got up and came to class?

None?
One?
Two?
Three?
Four or More?
THE RARE EARTH ELEMENTS
IMPACT EVERYONE

Many times a day
car
TV
cell phone
i-pod
computer
electronic displays

They can’t be avoided, except . . .
THE ONLY WAY TO AVOID THE RARE EARTHS

Pack-up a sleeping bag

Head for the deep woods or a cave in the desert

But don’t bring your cell phone or lighter flint
ACKNOWLEDGEMENT

Some of the slides for this presentation were taken from talks presented by the following persons at recent conferences or workshops on the rare earth crisis

Dudley J. Kingsnorth  Industrial Minerals Company of Australia, Pty. Ltd.
James B. Hedrick  U.S. Geological Survey – retired
Mark A. Smith  Molycorp Minerals
Yasushi Watanabe  Geological Survey of Japan
GLOBALIZATION
REE PRODUCTION TRENDS

Monazite-placer era | Mountain Pass era | Chinese era → ?

Source: USGS Fact Sheet 087-02 updated with recent USGS Minerals Yearbook

In 2010 China produced (mined) 97% of the rare earths utilized in commerce
REE MINERAL RESERVES

88 million metric tons of contained rare-earth oxide (REO)

- China: 30.9%
- Malaysia: <1%
- Others: 25.2%
- CIS: 21.8%
- United States: 14.9%
- India: 1.3%
- Australia: 6.0%

Enough rare earths for >600 years at current production levels

Enough rare earths for >69 years at a 10% growth rate per annum
## RESERVES
*(in percent)*

<table>
<thead>
<tr>
<th>Country</th>
<th>1980&lt;sup&gt;a&lt;/sup&gt;</th>
<th>1992</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>3</td>
<td>6.1</td>
<td>6.0</td>
</tr>
<tr>
<td>China</td>
<td>70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>51.3</td>
<td>30.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>India</td>
<td>4</td>
<td>2.7</td>
<td>1.3</td>
</tr>
<tr>
<td>CIS</td>
<td>2</td>
<td>0.5</td>
<td>21.8</td>
</tr>
<tr>
<td>Malaysia</td>
<td>--</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>USA</td>
<td>20</td>
<td>15.0</td>
<td>14.9</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>24.4</td>
<td>25.2</td>
</tr>
</tbody>
</table>

Total (M metric tons) | 26 | 84 | 88

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<sup>a</sup>In 1970 it was 75%.

<sup>b</sup>The actual tonnage of the known Chinese reserves increased by almost 300% from 1980 to 2010.
China: RE Export Transition

- 1970s: Rare earth mineral concentrates.
- 1980s: Mixed rare earth chemical concentrates.
- Early 1990s: Separated rare earth oxides and metals.
- Late 1990s: Magnets, phosphors, polishing powders.
- 2000s: Electric motors, computers, batteries, LCDs, mobile phones.
PROBLEMS FOR USA

Military Security
All US weapon systems depend on rare earths – especially \( \text{Nd}_2\text{Fe}_{14}\text{B} \) permanent magnets in electric motors, computers, guidance systems

Energy Security
Electric motors and batteries, wind turbines, petroleum refining, optical displays, fluorescent lighting, oxygen and electrical sensors (automotive engines)

U.S. Teenager; Yourself
i-pods, cell phones, TVs, automobiles (gasoline, catalytic converters)
ORE SOURCES AND MINING OPERATIONS

Operational in 2011/12
Operational by 2015/16 (HRE)
124,000 metric tons of contained rare-earth oxide (REO)

Black market: 10 to 15% of reported production, mostly smuggled out of China*

*“... This region of southern China, long plagued by gangsters who illegally mine some of the world's sought-after industrial metals. The gangs reap profits that can rival drug money, while leaving pollution and violence in their wake.”
THE RARE EARTHS MARKET TODAY

• Estimated demand in 2010: 124,000t REO
• Average price: US$63/kg REO; January 2011
  - Mixed RE oxides $15/kg REO
  - Ce $60/kg REO
  - Y, La $70/kg REO
  - Nd, Pr $89/kg REO
  - Dy $290/kg REO
  - Eu, Tb $620/kg REO
• Total value: US$ 15 billion pa
• Constraints on Chinese exports are creating opportunities for non-Chinese projects
• Many non-Chinese rare earths projects being evaluated
# U.S. MINES

Expected Dates for the Beginning of Mining

<table>
<thead>
<tr>
<th>Location</th>
<th>Company</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain Pass, California</td>
<td>Molycorp^a^</td>
<td>2010</td>
</tr>
<tr>
<td>Carbonatites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bokan Mountain, Alaska^b</td>
<td>Ucore Uranium (Canada)</td>
<td>2014</td>
</tr>
<tr>
<td>Peralkaline Igneous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bear Lodge, Wyoming</td>
<td>Rare Element Resources</td>
<td>2015</td>
</tr>
<tr>
<td>Carbonatites</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemhi Pass, Idaho</td>
<td></td>
<td>&gt;2015</td>
</tr>
<tr>
<td>Vein deposit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pea Ridge Mine, Missouri^b,c</td>
<td></td>
<td>&gt;2015</td>
</tr>
<tr>
<td>Fe mine, by-product</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineville, New York^b</td>
<td></td>
<td>&gt;2015</td>
</tr>
<tr>
<td>Fe mine, by-product</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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^a Mined 3000 tons in 2010, full production (20,000 tons) in 2012; 40,000 tons by 2014

^b Deposits listed in green print are heavy rare earth deposits

^c Iron mine being reopened in 2012.
Applications For Rare Earth Elements

**Catalysts**
- Petroleum refining
- Chemical processing
- Catalytic converter
- Diesel additives
- Industrial pollution scrubber

**Electronics**
- Display phosphors (CRT, PDP, LCD)
- Medical imaging phosphors
- Lasers
- Fiber Optics
- Optical temperature sensors

**Ceramics**
- Capacitors
- Sensors
- Colorants
- Scintillators

**Glass**
- Polishing compounds
- Optical glass
- UV resistant glass
- Thermal control mirrors
- Colorizers/Decolorizers

**Metal Alloys**
- Hydrogen storage (NiMH batteries, Fuel cells)
- Steel
- Lighter flints
- Aluminum/Magnesium
- Cast iron
- Superalloys

**Magnets**
- Motors
- Disc drives & disk drive motors
- Power generation
- Actuators
- Microphones & speakers
- MRI

**Other**
- Water Treatment
- Fluorescent lighting
- Pigments
- Fertilizer
- Medical Tracers
- Coatings
SUSTAINABILITY

Substitution

Recycling
4f ELECTRON ENERGY LEVELS
(In the absence of a crystal field)
SUBSTITUTION

Difficult, if Not Impossible

Most critical applications – phosphors, magnets
  Depend on the 4f electronic levels (each lanthanide is different) and crystal environment
  
  Eu – red phosphor: TV and color displays
  Tb – green phosphor: TV and color displays
  Nd – lasers
  Nd, Sm, Dy – permanent magnets
  Er – fiber optics
  La, Y, Gd – absence of 4f level – optical & electronic

Applications of unseparated rare earths
  Depend upon the valence state and average atomic size of the rare earths in the mixture
  
  petroleum cracking catalysts
  alloy additives – Mg, Al, cast iron

Mixed valence applications
  CE(III)-CE(IV) – glass polishing, UV resistant glass, catalytic converters
SUBSTITUTION – YES or NO EXAMPLES

YES

Mischmetal for La in Ni metal hydride batteries
Rouge (Fe oxides) for CeO$_2$/Ce$_2$O$_3$ in glass polishing
(However Ce is not in short supply – excess)

PARTIAL SUBSTITUTION

Pr for Nd in NdFeB magnets; 4Nd atoms per 1Pr in original ore
Y – high temperature superalloys – used for ~30 years
Al, Cr, could be utilized instead of Y

NO (People have been looking – but no luck)

Eu – red color in TV; used for ~50 years, yet no substitute
Nd – permanent magnets; used for ~27 years, , yet no substitute
Sm – permanent magnets; used for over 30 years, , yet no substitute
Ce – 3-way catalytic converters (automotive exhaust) – used for ~30 years – yet no substitute
RECYCLING - PHOSPHORS

Phosphors in fluorescent lighting Y, Eu, Tb
Lamps also contain Hg

Government needs to require all fluorescent lamps be returned to a recycle center – remove Hg (and recover REs) – to keep Hg out of the waste stream, land fills

Some recycling research going on presently in USA CFC and long tubes
Today all car batteries have to be returned to centers to remove the lead.

Should be able to use these centers to recover the La or mixed rare earths, and the Ni

Ni is a carcinogen
RARE EARTH MAGNETS

Dell Laptop Computer

Spindle magnet on steel bracket – weight of magnet = 6.5 g each (two)
Speaker magnet – 1 g each (two)
Hard Drive Magnet
2.0 wt.% of hard drive
RECYCLING - MAGNETS

URBAN MINING

Recovering permanent magnets from computers (hard drives), cell phones, etc.

Hard drive: \( \text{Nd}_2\text{Fe}_{14}\text{B} \) magnets – 2.0 wt.%
- recycle the magnet to recover the Nd – 0.5 wt.%
Hitachi found it takes a worker 5 minutes to get a magnet out of the hard drive (12 units/hr.)
Hitachi developed a mechanical method to extract 100 units/hour

Cell phone:
- Speaker magnet: \( \text{Nd}_2\text{Fe}_{14}\text{B} \) – 0.06 wt.%
- \textbf{Not economical}; unless recycled for another material(s) – then perhaps economical

For comparison: Best known RE ore source is Mountain Pass Mine:
- 6-8% REO or 1.5 to 2.0% Nd+Pr
Speaker Magnet of Cell Phone
0.06 wt.% of cell phone
RECYCLING - FUTURE

Design objects for end-of-life re-utilization of energy critical components

So it is an easy and cost effective way to remove rare earth magnets, La-Ni metal hydride batteries, etc.
About 10 years from initial start to having rare earths come out of the mine.
THE OUTLOOK FOR 2015
(Dudley Kingsnorth, IMCOA)

• Supply will be tight.
• ‘Balance’ will still be an issue; so prices for Nd, Tb, and Dy will remain strong.
• Potential large surplus of Ce. Chinese have raised prices and controlled exports.
• China will not ‘starve’ the ROW of rare earths.
• Several new projects should be on-stream
• Demand: 190-210,000tpa RWO – will be met.
WILL THE CHINESE CUT THE PRICE OF RARE EARTHS IN THE FUTURE?

NOT LIKELY – BECAUSE

South China clays will be depleted in 10 to 15 years.

Chinese economy is growing so fast they will need all of Chinese rare earths by 2015 at the latest.

Chinese do not want to use their vast, but finite, resources to supply the rest of the world (ROW) high tech products.
GSCHNEIDNER’S FORECAST

USING
Dudley Kingsnorth projections
Published information from non-Chinese companies planning on mining RE ores

PREDICTION
There will be a 13% surplus of REO on the market between 2015 and 2020
Because of over production, weak companies will go out of business, the strong will survive.
DILBERT’S SOLUTION

Not Recommended – odds are against you
INDUSTRY

Strong US Government Support
Molycorp started RE mining January 2, 2011
beneficiation, separation

IT IS HAPPENING – 2010 House Bill H.R.6160 (Died, No Senate action)
– 2011 House Bill H.R.618 (Revised version of H.R. 6160)

Future near-term action of support
• Premanufacture RE materials
  Nd, La, RE compounds
• Manufacturers of intermediate products
  magnets, batteries, phosphors, catalysts, etc.
• Manufacturers of commercial products containing rare earths
  electric motors, batteries, cell phones, monitors, CF lamps
• Loan guarantees in H.R. 618 (also in the 2010 H.R. 6160)

President Obama’s 2012 Budget
• New Energy Innovation Hubs – three, one of which is
  critical materials and rare earth elements (EERE)

Companies
Vertically integrate
  full spectrum of RE processing and manufacture

Alliances
companies involved in the supply train (mining to products)
Training students

- undergraduate, graduate, post-doctorate
- chemistry, chemical engineering, materials science & engineering, physics, electrical engineering

Research projects funding
NSF, DOE, DOD, NIST

National Research Center for Rare Earths and Energy
- Educational institution with a strong tradition on REs
- Link with industry and national laboratories
- Subsidiary branches at other universities
SUMMARY
GLOBALIZATION

The rare earth deposits are everywhere in the world.

No country has a stranglehold (in theory).

Some deposits are more economically viable:
- amount RE in ore body
- infrastructure (transportation, power, water)

Rare earths are utilized everywhere:
- more so in developed world
- less so in third world countries
SUSTAINABILITY

Difficult
Amounts of rare earths in a given product is small
recovery or recycling may not be economically feasible

Solutions
Strive to reduce amount of REs in the product
Improve the efficiency of the various processes in the manufacture of a product
Find alternate non-rare earth materials to replace the rare earth components
Design products so that at the end-of-life the critical materials (e.g. REs) are more easily recovered for recycling
FINAL EXAM

How many rare earth items did you handle or observe this morning since you got up and came to class?

None?
One?
Two?
Three?
Four or More?