Solving Critical Materials Challenges –
An Industrial Update for GUIRR

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Imagination at work.  

Acknowledgments: Anthony Ku and Jonathan Loudis
Outline

• Assessing Material Criticality – Industrial Criticality Diagrams
• Industrial Approaches to Criticality Solutions
• Some Examples
  • Sourcing critical materials
  • Reducing manufacturing scrap
  • Material substitutions
  • System substitutions

System Development and Material Engineering technologies are shown to be key approaches to solving critical materials challenges
GE Criticality Diagram - 2008
Impact on operations

- Revenue impacted
- % of world’s use
- Substitutability (specific applications)
- Cost pass-through (specific applications)

Supply and Price Risk

<table>
<thead>
<tr>
<th>World reserves</th>
<th>Political factors</th>
<th>Competing uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-production</td>
<td>Human factors</td>
<td>Price volatility</td>
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</table>
## Development of Defendable Criticality Diagrams

<table>
<thead>
<tr>
<th>Supply Risk scoring</th>
<th>NRC</th>
<th>Yale</th>
<th>DOE</th>
<th>GE</th>
<th>BGS</th>
<th>EU</th>
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<tr>
<td>(Year of assessment)</td>
<td></td>
<td></td>
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<tr>
<td>Physical availability</td>
<td>60%</td>
<td>33%</td>
<td>50%</td>
<td>22%</td>
<td>29%</td>
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<tr>
<td>Reserves/Depletion time</td>
<td>20%</td>
<td>1/6</td>
<td>2/5</td>
<td>1/9</td>
<td>1/7</td>
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<tr>
<td>Companion production</td>
<td>20%</td>
<td>1/6</td>
<td>1/10</td>
<td>1/9</td>
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<tr>
<td>Recycling rate</td>
<td>20%</td>
<td></td>
<td></td>
<td>1/7 Included</td>
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<tr>
<td>Production</td>
<td>67%</td>
<td>40%</td>
<td>33%</td>
<td>56%</td>
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<tr>
<td>Producer concentration</td>
<td>1/6</td>
<td>1/5</td>
<td>1/6</td>
<td>2/7 Included</td>
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<td>Producer stability</td>
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<tr>
<td>Producer governance</td>
<td>1/6</td>
<td>1/5</td>
<td>1/6</td>
<td>2/7</td>
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<tr>
<td>Producer policy</td>
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<td>Price volatility</td>
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<td>1/9</td>
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<tr>
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<td>20%</td>
<td>1/6</td>
<td>1/7</td>
<td>Included</td>
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<tr>
<td>Competing demand</td>
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<td>1/10</td>
<td>1/6</td>
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<td>Impact scoring</td>
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<td>Importance</td>
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<td>50%</td>
<td>75%</td>
<td>50%</td>
<td>100%</td>
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<td>Usage % by population</td>
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<td>% of world’s supply used</td>
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<td>1/4</td>
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<tr>
<td>Substitutability</td>
<td>33%</td>
<td>50%</td>
<td>25%</td>
<td>25%</td>
<td></td>
<td></td>
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<tr>
<td>Performance</td>
<td>1/6</td>
<td></td>
<td></td>
<td>1/4</td>
<td>Included</td>
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<tr>
<td>Availability</td>
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<tr>
<td>Market factors</td>
<td>33%</td>
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<td></td>
<td>25%</td>
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<tr>
<td>Cost pass through</td>
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<td>Emerging uses</td>
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<td>1/3</td>
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</table>
Solutions to Criticality Challenges

**Sourcing** ... ensure supply through diversification, fixed price contracts, forwards, options, etc.

**Manufacturing efficiency** ... reduced waste, recycled waste, advanced manufacturing (i.e. additive)

**Recycling** ... manufacturing shrinkage and end-of-life products, repair, re-manufacturing

**Material re-design or substitution** ... reduce or eliminate at-risk element, use alternate material

**System substitution** ... use an alternate technology to satisfy a customer’s need
GE

- GE uses ~3 Billion lbs of raw material in our products annually
- For manufacturing companies, typically one-half of their Cost of Goods & Services Sold is spent on materials. For GE, translates to ~$40 B/yr
- GE uses at least 75 of the first 83 elements on the periodic table
Example: Rare earth elements

- >90% produced in China
- Prices peaked at 10-20x in mid-2011

Fluorescent lamp phosphors
- Y, Ce, Tb, La, Eu

White LED phosphors
- Y, Ce, Tb, Eu

Industrial motors
- Nd, Dy, Tb

Thermal barrier coatings for gas turbines and aircraft engines
- Y

Scintillators for CT & PET imaging
- Y, Ce, Tb, Gd, Eu, Lu

Generators for 2.5MW+ wind turbines
- Nd, Dy, Tb
Sourcing

Diversifying the supply chain

Revisiting raw material specs

Ku et al., JOM 2014

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Manufacturing efficiency

Recovery and reuse of manufacturing scrap
Substitution

Materials R&D

Alternate system designs

New magnet materials

New phosphor materials

F. Johnson, GE Global Research

Emission Intensity

Wavelength (nm)

400 450 500 550 600 650 700

0 0.2 0.4 0.6 0.8 1 1.2

Triphosphor

RED

GREEN

LEDs for lighting

DFIGs for wind

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Summary

• Criticality diagrams have developed since 2008

• Critical elements change with time – rare earth criticality reduced

• Systems and materials engineering can reduce the criticality risks