Understanding the Rare Earth Element Supply Chain
Identifying Domestic Gaps and Opportunities

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Outline

Global Supply
Domestic Demand
Demand Projections and Value
Understanding the Supply Chain
Challenges for a Domestic Supply Chain
Opportunities for Coal-Based Sources
Filling Domestic Supply Chain Gaps
Global Supply and Demand for REE

Source: USGS
Domestic Rare Earth Use

Source: USGS

2019 Estimated Domestic End Use for Imported REEs

- **Electronics**
- **Renewable Resources & Green Technology**
- **Catalysts**
- **Metal Alloys**
- **Ceramics & Glass**
- **Polishing**
- **Other**

Total U.S Demand for Raw REE
Approx. 13,000 mt/year

Source: USGS
Domestic Demand
Imports of Raw REE by Element

REOs Major End-Use Category

**Lanthanum Oxide (La₂O₃):**
By 2020, the global demand for this oxide is primarily fueled by catalyst related applications (64.5%) and will decrease (62.2%) as the demand for PVC stabilizers in the other end-use categories (3.7% to 11.2%) grows faster than the demand for catalysts.

**Cerium Oxide (Ce₂O₃):**
In 2016 38.6% of the demand was driven by catalyst related applications, 27.4% Glass Polishing Powders and 6.9% by other end uses like PV stabilizers. By 2025, the demand will shift to 38.2%, 26.9% and 12.6% respectively.

**Neodymium Oxide (Nd₂O₃):**
In 2016 80.9% of the demand of Nd₂O₃ was driven from NdFeB permanent magnets. By 2025 this percentage will grow to 85%.

**Yttrium Oxide (Y₂O₃):**
Yttrium demand is primarily fueled by phosphors used on linear fluorescent lamps (LFLs), compact fluorescent lamps (CFLs) and light emitting diodes (LEDs).
Domestic Demand by End Use
REE Embedded in Imported Goods

<table>
<thead>
<tr>
<th>Imported Product</th>
<th>Parts with REES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Light Emitting Diodes (Modules/ Lamps)</td>
<td>Modules/Lamps</td>
</tr>
<tr>
<td>2. Ceramic Capacitors</td>
<td>Capacitors</td>
</tr>
<tr>
<td>3. Headphones</td>
<td>Permanent Magnets</td>
</tr>
<tr>
<td>4. Linear Fluorescent Lamps</td>
<td>Modules/Lamps</td>
</tr>
<tr>
<td>5. Mobile Phones</td>
<td>Vibration Motor, Speakers, Screen (Permanent Magnets/Phosphors)</td>
</tr>
<tr>
<td>6. Laptops</td>
<td>HDD, Speakers, LED display (Permanent Magnets/Phosphors)</td>
</tr>
<tr>
<td>7. Speakers</td>
<td>Permanent Magnets</td>
</tr>
<tr>
<td>8. PVC Stabilizers</td>
<td>PVC stabilizer</td>
</tr>
<tr>
<td>9. Desktop Monitors (Non Cathode Ray)</td>
<td>LED Backlight (Large Screen)</td>
</tr>
<tr>
<td>10. AC and Refrigerator Compressors</td>
<td>Magnetic Pumps</td>
</tr>
<tr>
<td>11. Finished Refrigerators</td>
<td>Magnetic Pumps</td>
</tr>
</tbody>
</table>

Total Units Imported in 2016: 12.6 billion
Percentage of Total Embedded Demand: 20%

Of imported goods containing REE, the top 11 categories of imports (by number of units) contained more than 8,000 metric tons of REE, representing approximately 20%.

Source: Adamas Intelligence
Projected Demand Growth by End Use

Source: Adamas Intelligence
Demand Growth and Value

**Demand, 2025**
- Catalysts: 23%
- Polishing: 11%
- Batteries: 5%
- Others: 28%

**Raw material value, 2025 (2019 US$ price)**
- Magnets: 81.2%
- Catalysts: 3.7%
- Others: 15.2%

**Global demand for fresh NdPr Oxide**

Source: Roskill

Source: Lynas Corporation
In 2018, 93% of all passenger EVs sold used permanent magnet traction motors.

– Adamas Intelligence
Projected Offshore Wind Deployment

Installed Capacity by Region and Scenario

Major hindrances to the deployment of direct drive permanent magnet wind turbines is cost and availability of permanent magnets.

European Union and China account for 70% of the global offshore wind market to 2040, but a number of countries enter the market and increase their capacity.

Source: IEA Offshore Wind Outlook 2019
Opportunities for Demand Growth

By Element and Application

MAGNETICS
- Computer Hard Drives
- Disk Drive Motors
- Anti-Lock Brakes
- Automotive Parts
- Frictionless Bearings
- Magnetic Refrigeration
- Microwave Power Tubes
- Power Generation
- Microphones & Speakers
- Communication Systems
- MRI

DEFENSE
- Satellite Communications
- Guidance Systems
- Aircraft Structures
- Fly-by-Wire
- Smart Missiles

CERAMICS
- Capacitors
- Sensors
- Colorants
- Scintillators
- Refractories

CATALYSTS
- Petroleum Refining
- Catalytic Converter
- Fuel Additives
- Chemical Processing
- Air Pollution Controls

METAL ALLOYS
- NiMH Batteries
- Fuel Cells
- Steel
- Super Alloys
- Aluminum/Magnesium

GLASS & POLISHING
- Polishing Compounds
- Pigments & Coatings
- UV Resistant Glass
- Photo-Optical Glass
- X-Ray Imaging

PHOSPHORS
- Display phosphors
- CRT, LCD
- Fluorescents
- Medical Imaging
- Lasers
- Fiber Optics

Nd, Eu, Tb, Dy, Y, Lu, Sm, Pr, La
Nd, Y, Eu, Dy, Lu, Gd, La, Ce, Pr
Nd, Gd, Er, Ho, La, Ce, Pr
Nd, Gd, Er, Ho, La, Ce, Pr
Nd, Gd, Er, Ho, La, Ce, Pr
Domestically, the supply chain is broken with few links connected to one another
  - Ore producers ship offshore for processing
  - Catalyst producers are importing raw materials
  - Finished goods are produced offshore and imported

Internationally, supply chain is vertically integrated
  - Each link feeds directly into the next

Source: DOE EERE AMO 2020
Challenges for a Domestic REE Supply Chain

- Existing Vertically Integrated Supply Chain
- China’s head start: 30+ years of subsidies
- Responsible Waste Disposal Options
Supply Chain Takeaways

- Opportunities exist across the board in mining, extraction, separation, alloy production, and finished goods manufacturing
- Utilization of rare earths is going to continue to grow
- The US has significant reserves of rare earth containing materials: ore, tailings, recycled materials, and even coal
  - Hub & spoke transportation models could present opportunities for feedstocks that are distributed in smaller quantities across the country
- Endless Possibilities
  - End uses exist for each REE if supply exists and prices are stable
  - Domestic industry is on the sidelines due to concerns over supply, limiting innovation
Opportunity for Coal-Based Feedstocks

Mountain Pass (Bastnasite) ~8% REO

Bayan Obo (Bastnasite) ~6% REO

Southeast Guangdong (Xenotime) ~0.5% REO

Mount Weld (Monazite) ~8% REO

Source: Argus Media
Opportunity for Coal-Based Feedstocks

Filling the First Gap to a Domestic REE Supply Chain

• Coal-based feed sources include:
  • Coal (anthracite, bituminous, subbituminous, lignite)
  • Coal refuse
  • Fly ash
  • Acid mine drainage (AMD)
  • Mining underclay and shale
• These feed sources could be utilized with other domestic REE resources to produce the foundation for a domestic REE supply chain
Filling Domestic Supply Chain Gaps

Additional Opportunities

• Cooperatives (profit sharing)
  • Vertical integration of every step within the supply chain, no missing links

• Private investment at large scale
  • Royalty and streaming agreements

• Government Subsidies along the entire supply chain
  • Price guarantees, loan guarantees, etc.

• Research & development opportunities
  • New domestic REE feedstocks
  • New end uses for REE
    • New alloys, new metallurgical processes for metal and alloy production, etc.
  • The existence of a domestic supply chain would entice industry to expand R&D into innovative materials and uses for REE materials
With…

- Demand projections for rare earth elements set to grow over the next 10 to 20 years in high and low value applications
- Domestic dependence on the offshore REE supply chain for raw material, processing, and finished goods

**Now is the time to develop a domestic supply chain for rare earths**

Rare earth elements could be the building blocks for an innovation revolution…
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- Produce Rare Earth Elements
- Fortify National Security
- Produce Feedstock for Advanced Materials
- Produce Clean Water