Current Uses and Future Opportunities for US Industry in Rare Earth Elements and Critical Materials Technologies and Markets: Knowledge-Base Tool Development
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Objectives

Task 1: Identify the industrial opportunity for utilization of REE and REE-containing materials within the U.S. if a domestic supply of high purity REEs were to be available, and where could it be utilized to ensure that the REEs remain within the U.S.

Task 2: Identify current industries and specific companies that utilize rare earths within the U.S. Determine what volume of REEs would be necessary to supply these facilities and where these supply opportunities are located.

Task 3: Provide an overview of global CM resources, resource location, and processing of resource materials leading to the production of all 35 CMs.

Task 4: Provide a historical perspective of the quantity of all 35 CMs produced off-shore since 2000, and projected market potential through 2035. Similarly, provide a historical perspective that identifies the quantity of all 35 CMs imported currently to the U.S, as well as a projected market potential through 2035.
Objectives

Task 5: Identify the top 10 most imported products to the U.S that contain CMs.

Task 6: Identify the resource, location and quantity of all 35 CMs currently produced within the U.S. and the utilization of the CMs either domestically or as exports to produce intermediate and/or end-product materials, equipment, etc. throughout the entire global CM supply chain, and potentially future U.S. infrastructure needs for domestic production.

Task 7: Identify the industrial opportunity for utilization of CM and CM-containing materials within the U.S. if a domestic supply of high purity CMs were to be available, and where it could be within the U.S.
Task 1: Identify the industrial opportunity for utilization of REE and REE-containing materials within the U.S. if a domestic supply of high purity REEs were to be available, and where could it be utilized to ensure that the REEs remain within the U.S.
“Almost all of the American ore is mined in California and goes to China for processing, although a little is produced in Florida and processed in Utah.”

-Domestic situation of REE production, August 2022
Task 1
Task 1

Non-tradition Sources

- Known Coal Reserves
- Coal Waste
- Red Mud
- Slag
- Phosphogypsum
- Mine Waste
- Wastewater

U.S. National Technology Laboratory, 2016, Rare Earth Elements:
https://www.netl.doe.gov/File%20Library/Research/Coal/Rare%20Earth%20Elements/REE-Project-Portfolio-2016.pdf

U.S. Environmental Protection Agency, 2022, Technologically Enhanced Naturally Occurring Radioactive Materials:
https://www.epa.gov/radiation/technologically-enhanced-naturally-occurring-radioactive-materials-tenorm


Task 2: Identify current industries and specific companies that utilize rare earths within the U.S. Determine what volume of REEs would be necessary to supply these facilities and where these supply opportunities are located.
### Task 2

<table>
<thead>
<tr>
<th>Company</th>
<th>Industry</th>
<th>Sales in 2021 (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple Inc.</td>
<td>Consumer/Commercial Computer Technology</td>
<td>365.82 Billion</td>
</tr>
<tr>
<td>Arnold Magnetic Technologies</td>
<td>Permanent Magnets and Magnetics</td>
<td>143 Million</td>
</tr>
<tr>
<td>Boeing</td>
<td>Aerospace, Rocketry and Defense</td>
<td>62.3 Billion</td>
</tr>
<tr>
<td>Caterpillar</td>
<td>Machinery/Equipment</td>
<td>51 Billion</td>
</tr>
<tr>
<td>Dow Chemical</td>
<td>Catalysts, Chemicals</td>
<td>54.97 Billion</td>
</tr>
<tr>
<td>ExxonMobil</td>
<td>Petroleum, Including Plastics</td>
<td>285.64 Billion</td>
</tr>
<tr>
<td>General Electric</td>
<td>Industrial/ Energy Technology</td>
<td>74.19 Billion</td>
</tr>
<tr>
<td>General Motors</td>
<td>Commercial/ Non-commercial Vehicles</td>
<td>127 Billion</td>
</tr>
<tr>
<td>Gentex Corp</td>
<td>Specialty Glass</td>
<td>1.73 Billion</td>
</tr>
<tr>
<td>Tesla</td>
<td>Motorized Non-Commercial Vehicles</td>
<td>53.82 Billion</td>
</tr>
</tbody>
</table>

**Tesla**

- Motorized Non-commercial Vehicles
  - Tesla Models S,3,X,Y
    - Cerium, lanthanum, praseodymium, europium, gadolinium, terbium, dysprosium, indium, neodymium, tantalum, gallium (REE)
    - Lithium, cobalt, nickel, aluminum, copper, manganese, graphite, gold, silver (CM)

  90% of REE sourced in China
  Considerable CM sourcing from Australia, Canada, Chile
Task 2

Volumes Required for industry

- Proprietary
- Ever-evolving environment
- New initiative in exploration may dictate

Source: USGS Earth Mapping Resource Initiative
Task 2

Current issue with REE extraction and refining:
Task 3: Provide an overview of global CM resources, resource location, and processing of resource materials leading to the production of all 35 CMs.
Task 3

Not a lack of CM in the US; Lack of infrastructure or short Term economic opportunity.

https://mrdata.usgs.gov/pp1802/PP1802_Global.mp4
Task 3

Critical Mineral Processing examples:
Task 4: Provide a historical perspective of the quantity of all 35 CMs produced off-shore since 2000. Similarly, provide a historical perspective that identifies the quantity of all 35 CMs imported currently to the U.S.
Task 4

CM Imports, Top 5, 1991-2020 (metric tons)

CM Imports, 1991-2020 (metric tons)

Task 4
Task 5: Identify the top 10 most imported products to the U.S that contain CMs.
Task 5

Visualization of the all 2020 US imports, worth $2.24T. Computers imported were 4.12% of the total, putting the value of said imports at $92.288B.

Likewise, imports from China were valued at $436.8B.

**Task 5**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8705</td>
<td>Motor cars and other motor vehicles principally designed for the transport of persons, incl. station wagons and racing cars (excluding motor vehicles of heading 8702)</td>
<td>179,580,096</td>
<td>178,482,059</td>
<td>179,488,383</td>
<td>145,743,035</td>
<td>148,145,016</td>
</tr>
<tr>
<td>8471</td>
<td>Automatic data-processing machines and units thereof, magnetic or optical readers, machines for transcribing data onto data media in coded form and machines for processing such data, n.e.s.</td>
<td>84,777,288</td>
<td>93,309,125</td>
<td>90,970,087</td>
<td>104,802,217</td>
<td>118,181,595</td>
</tr>
<tr>
<td>8517</td>
<td>Telephone sets, incl. telephones for cellular networks or for other wireless networks; other apparatus for the transmission or reception of voice, images or other data, incl. apparatus for communication in a wired or wireless network [such as a local or wide area network], parts thereof (excluding than transmission or reception apparatus of heading 8443, 8529, 8527 or 8526)</td>
<td>113,304,245</td>
<td>111,166,445</td>
<td>101,407,797</td>
<td>94,887,491</td>
<td>111,542,529</td>
</tr>
<tr>
<td>8708</td>
<td>Parts and accessories for tractors, motor vehicles for the transport of ten or more persons, motor cars and other motor vehicles principally designed for the transport of persons, motor vehicles for the transport of goods and special purpose motor vehicles of heading 8701 to 8705, n.e.s.</td>
<td>66,264,918</td>
<td>71,042,801</td>
<td>69,127,529</td>
<td>59,890,158</td>
<td>74,076,623</td>
</tr>
<tr>
<td>8542</td>
<td>Electronic integrated circuits; parts thereof</td>
<td>33,455,963</td>
<td>34,807,334</td>
<td>32,819,161</td>
<td>31,901,097</td>
<td>41,251,253</td>
</tr>
<tr>
<td>9018</td>
<td>Instruments and appliances used in medical, surgical, dental or veterinary sciences, incl. scintigraphic apparatus, other electro-medical apparatus and sight-testing instruments, n.e.s.</td>
<td>22,907,416</td>
<td>25,322,206</td>
<td>27,937,633</td>
<td>27,318,227</td>
<td>31,990,525</td>
</tr>
<tr>
<td>8704</td>
<td>Motor vehicles for the transport of goods, incl. chassis with engine and cab</td>
<td>26,527,916</td>
<td>28,848,743</td>
<td>33,073,471</td>
<td>26,003,275</td>
<td>31,093,314</td>
</tr>
<tr>
<td>8528</td>
<td>Monitors and projectors, not incorporating television reception apparatus; reception apparatus for television, whether or not incorporating radio-broadcast receivers or sound or video recording or reproducing apparatus</td>
<td>24,519,843</td>
<td>24,390,355</td>
<td>23,910,749</td>
<td>22,213,389</td>
<td>27,083,255</td>
</tr>
<tr>
<td>8544</td>
<td>Insulated &quot;&quot;&quot;&quot;incl. enamelled or anodised&quot;&quot;&quot;&quot; wire, cable &quot;&quot;&quot;&quot;incl. coaxial cable&quot;&quot; and other insulated electric conductors; whether or not fitted with connectors; optical fibre cables, made up of individually sheathed fibres, whether or not assembled with electric conductors or fitted with connectors&quot;&quot;</td>
<td>19,927,087</td>
<td>22,107,681</td>
<td>21,370,171</td>
<td>19,434,140</td>
<td>24,886,596</td>
</tr>
<tr>
<td>8411</td>
<td>Turbojets, turbopropellers and other gas turbines</td>
<td>23,666,972</td>
<td>26,230,073</td>
<td>30,729,764</td>
<td>19,801,110</td>
<td>19,674,080</td>
</tr>
</tbody>
</table>

*Values reported in USD, thousands.

HS4 ID Codes and “ITC Import Product Label” sourced verbatim from the International Trade Centre Trade Map interactive data.

ITC calculations based on US Census Bureau statistics since January 2015.
## Task 5

<table>
<thead>
<tr>
<th>HS4 ID Code</th>
<th>Product</th>
<th>Imported Value in 2020 (USD)</th>
<th>Examples of CM Contents</th>
<th>Main Supplier (Country of Export)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8703</td>
<td>Motorized Non-Commercial Vehicles</td>
<td>144 Billion</td>
<td>Copper, Lithium, Cobalt, Nickel, Manganese, Graphite, Cerium, Lanthanum, Yttrium, Neodymium, Terbium, Dysprosium</td>
<td>Japan (22.6%) Canada (20.6%) Mexico (20.2%)</td>
</tr>
<tr>
<td>8471</td>
<td>Computer Technology</td>
<td>92.4 Billion</td>
<td>Titanium, Aluminum, Copper, Gallium, Indium, Beryllium, Germanium, Tantalum, Rhenium, Strontium</td>
<td>China (52.9%) Mexico (30.8) Taiwan (7.9%)</td>
</tr>
<tr>
<td>3004</td>
<td>Packaged Medicaments</td>
<td>84.1 Billion</td>
<td>Platinum, Copper, Lithium, Magnesium, Manganese, Cobalt</td>
<td>Ireland (17.1%) Switzerland (15.7%) Germany (12.9%)</td>
</tr>
<tr>
<td>8525</td>
<td>Broadcasting Equipment</td>
<td>82 Billion</td>
<td>Aluminum, Copper, Gadolinium, Dysprosium, Neodymium, Yttrium, Scandium, Terbium</td>
<td>China (57.9%) Vietnam (17.5%) Taiwan (4.07%)</td>
</tr>
<tr>
<td>8708</td>
<td>Vehicle Parts (Mechanical)</td>
<td>62.3 Billion</td>
<td>Copper, Lithium, Cobalt, Nickel, Manganese, Graphite, Corium, Lanthanum, Neodymium, Zirconium</td>
<td>Mexico (36.7%) China (13.5%) Canada (12.9%)</td>
</tr>
<tr>
<td>8473</td>
<td>Office Machinery/ Equipment</td>
<td>42.8 Billion</td>
<td>Aluminum, Copper, Yttrium, Europium, Magnesium, Manganese, Arsenic, Gadolinium, Terbium, Cerium</td>
<td>China (34.5%) Thailand (14.7%) South Korea (14.1%)</td>
</tr>
<tr>
<td>9018</td>
<td>Medical Instruments</td>
<td>28 Billion</td>
<td>Copper, Titanium, Platinum, Gadolinium, Promethium, Terbium, Thulium, Yttrium, Cobalt, Tantalum, Niobium</td>
<td>Mexico (27.5%) Germany (10.5%) Ireland (8%)</td>
</tr>
<tr>
<td>8704</td>
<td>Delivery/ Transport Vehicles</td>
<td>25.2 Billion</td>
<td>Copper, Lithium, Cobalt, Nickel, Manganese, Graphite, Corium, Lanthanum, Yttrium, Neodymium, Terbium, Dysprosium</td>
<td>Mexico (87.6%) Canada (6.05%) Japan (1.78%)</td>
</tr>
<tr>
<td>8542</td>
<td>Integrated Circuits</td>
<td>24.2 Billion</td>
<td>Tantalum, Tungsten, Tin, Aluminum, Copper, Germanium, Gallium, Arsenic, Indium, Antimony</td>
<td>Malaysia (33.3%) Mexico (10.9%) Taiwan (10.0%)</td>
</tr>
<tr>
<td>8411</td>
<td>Gas Turbines</td>
<td>23.8 Billion</td>
<td>Copper, Aluminum, Cobalt, Chromium, Nickel, Manganese, Lithium, Graphite, Tantalum</td>
<td>France (14.5%) United Kingdom (12.5%) Canada (12.4%)</td>
</tr>
</tbody>
</table>

HS4 ID Codes and “ITC Import Product Label” sourced verbatim from the International Trade Centre Trade Map interactive data.
ITC calculations based on US Census Bureau statistics since January 2015.
Task 6: Identify the resource, location and quantity of all 35 CMs currently produced within the U.S. and the utilization of the CMs either domestically or as exports to produce intermediate and/or end-product materials, equipment, etc. throughout the entire global CM supply chain, and potentially future U.S. infrastructure needs for domestic production.
Currently nearly no domestic production exists

<table>
<thead>
<tr>
<th>CM</th>
<th>Status</th>
<th>CM</th>
<th>Status</th>
<th>CM</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Minimal</td>
<td>Graphite</td>
<td>None</td>
<td>Rubidium</td>
<td>None</td>
</tr>
<tr>
<td>Antimony</td>
<td>None</td>
<td>Hafnium</td>
<td>None</td>
<td>Ruthenium</td>
<td>None</td>
</tr>
<tr>
<td>Arsenic</td>
<td>None</td>
<td>Indium</td>
<td>None</td>
<td>Tantalum</td>
<td>None</td>
</tr>
<tr>
<td>Barite</td>
<td>Minimal, import reliant</td>
<td>Iridium</td>
<td>None</td>
<td>Tellurium</td>
<td>Produced, import reliant</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Produced</td>
<td>Lithium</td>
<td>Minimal, import reliant</td>
<td>Tin</td>
<td>None</td>
</tr>
<tr>
<td>Bismuth</td>
<td>None</td>
<td>Magnesium</td>
<td>Produced</td>
<td>Titanium</td>
<td>Minimal, import reliant</td>
</tr>
<tr>
<td>Cesium</td>
<td>None</td>
<td>Manganese</td>
<td>None</td>
<td>Tungsten</td>
<td>None</td>
</tr>
<tr>
<td>Chromium</td>
<td>Minimal</td>
<td>Nickel</td>
<td>Produced, import reliant</td>
<td>Vanadium</td>
<td>None</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Produced, import reliant</td>
<td>Niobium</td>
<td>None</td>
<td>Zinc</td>
<td>Produced</td>
</tr>
<tr>
<td>Fluorspar</td>
<td>Minimal</td>
<td>Palladium</td>
<td>Minimal, import reliant</td>
<td>Zirconium</td>
<td>Produced, import reliant</td>
</tr>
<tr>
<td>Gallium</td>
<td>None</td>
<td>Platinum</td>
<td>Minimal, import reliant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germanium</td>
<td>Minimal, import reliant</td>
<td>Rhodium</td>
<td>None</td>
<td>Rare Earths</td>
<td>Produced, import reliant</td>
</tr>
</tbody>
</table>
Task 7: Identify the industrial opportunity for utilization of CM and CM-containing materials within the U.S. if a domestic supply of high purity CMs were to be available, and where it could be within the U.S.
Task 7

Domestic Aluminum Consumption, 2010-2021

Domestic Aluminum Exports, 2010-2021

Task 7

Sources: “The Aluminum Can Advantage: Sustainability Key Performance Indicators” (The Aluminum Association, November 2021); expert interviews; BCG analysis.

Note: Percentages are relative to overall volume. MRF = materials recovery facility. UBC = used beverage cans.

Mixed with other materials, contains liquids.
Task 7

100% of aluminum in ELVs
End-of-life vehicle

Light dismantling process before shredding

60%

High-value scrap isn't fully extracted from vehicles before shredding

25%

Shredder

Nonferrous shredder residue

3%

Volume of aluminum sent to landfills

Leakage

Only a fraction of aluminum scrap is sent to landfills because of downstream separation inefficiencies

Downstream separation

Zorba 70%

Exports

Twitch 12%

Foundry (die cast)

Lack of domestic supply and demand for upgraded zorba

Heavy gauge scrap (wheels, bumpers, large pieces)

15%

Secondary recycler

Thorough dismantling process

Dismantler

40%

Scrap dealer

Parts

Volume excluded from analysis

Definitions
- Zorba: shredded nonferrous mixture of metals (approximately 65% aluminum)
- Twitch: zorba that has been upgraded using density separation (approximately 90% to 98% aluminum)

Sources: Expert interviews; “Automotive Aluminum Recycling at End of Life: a Grave-to-Gate Analysis” (Worcester Polytechnic Institute, 2016); USGS; BCG analysis.

Note: Percentages are relative to overall volume. ELV = end-of-life vehicle.
Continued/ Follow-on Actions

• Continue to build interactive map of CM and REE
• Investigate domestic ability and capability for production and supply
• Build portfolios of supply chain complexity for chosen CM or REE
• Identify highest potentials for domestic production and refinement
Questions?