Data-Mining the Rare-Earth-Element (REE) Potential of Old Mine-Mouth Power Plants

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Richard W. Arnseth, PhD, PG, PMP
Tom Gray, BS, MBA, PE
Robert Kennedy, BS, MS, PE
What Are REEs?
“Rare Earths” Are Not Actually Rare...
...but Are Very Difficult to Mine

REEs roughly as abundant as specialty industrial metals, e.g., cobalt, nickel, vanadium, tin
CCR: Resource or Waste?

- Many chemical elements are concentrated in coal beds and associated sedimentary horizons
  - Heavy metals, actinides (e.g., U) and rare earth elements (REEs)
  - Orders of magnitude concentrations over average crustal rock

- Power generation (coal combustion) has concentrated many of these elements further in the CCR
  - Additional 1 order of magnitude concentration

- During ~200 years of coal mining in the USA
  - ~60 billion metric tons of coal mined
  - ~3-6 billion metric tons of CCR generated
  - Over half, or ~3 billion tons sequestered in ash ponds and landfills
  - REE potential
    - US coal ash may contain an inventory of ~1 million tons of REE minerals
    - Order of magnitude greater than current global production
    - Value ~$10 billion
# Annual Trace Element Discharge – US Coal Combustion (Klein et al. 1975)

<table>
<thead>
<tr>
<th>Element</th>
<th>Slag and Fly Ash (tons/yr)</th>
<th>Potential Inventory in Ash Ponds and Landfills since 1975, est. by Tetra Tech (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt</td>
<td>1,000</td>
<td>100,000</td>
</tr>
<tr>
<td>Copper</td>
<td>2,900</td>
<td>290,000</td>
</tr>
<tr>
<td>Iron</td>
<td>3,780,000</td>
<td>378,000,000</td>
</tr>
<tr>
<td>Manganese</td>
<td>11,700</td>
<td>1,170,000</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>3,100</td>
<td>310,000</td>
</tr>
<tr>
<td>Nickel</td>
<td>5,600</td>
<td>560,000</td>
</tr>
<tr>
<td><strong>Scandium</strong></td>
<td><strong>770</strong></td>
<td><strong>77,000</strong></td>
</tr>
<tr>
<td>Uranium</td>
<td>760</td>
<td>76,000</td>
</tr>
<tr>
<td>all REEs</td>
<td></td>
<td><strong>~1,000,000</strong></td>
</tr>
</tbody>
</table>

*Chemically grouped with REEs

~10X total global production REE minerals in 2011 value >$10 billion

1 scales from known concentration of Sc
Beneficial Use of CCR – Value Proposition

- landfilling, maintenance, monitoring, remediating ash
  - example catastrophic event:
    - Kingston ash spill cleanup cost
      - $1 billion/5 million tons of ash
      - $200/ton or $0.10/lb of ash
      - $0.01/pound of the original coal
    - Value of the electricity – $0.17-$0.35 cents/pound of coal
    - Cleanup costs ~3-6% of the value of the electricity
  - commercial value of the chemical elements themselves, esp. REEs, offers possibility of self-financing CCR management
# Heavy and Light REE

**Rare Earths Expected to be in Short Supply in the next 15 years**

*Neodymium, Europium, Terbium, Dysprosium, Yttrium*

### Light Rare Earths
- Lanthanum (La)
- Cerium (Ce)
- Praseodymium (Pr)
- Neodymium (Nd)
- Samarium (Sm)

**Accounted for 66.8% of global demand in 2010**

### Heavy Rare Earths
(Less common and more valuable)
- Europium (Eu)
- Gadolinium (Gd)
- Terbium (Tb)
- Dysprosium (Dy)
- Holmium (Ho)
- Erbium (Er)
- Thulium (Tm)
- Ytterbium (Yb)
- Lutetium (Lu)
- Yttrium (Y)

**Notes:**
- Yttrium is lighter than the light rare earths, but included in the heavy rare earth group because of its chemical and physical associations with heavy rare earths in natural deposits.

*Ernst & Young - Technology Minerals – The rare earths race is on! - April 2011*
## Share of Global Rare Earth Mine Production, 2015 (USGS Data)

### World Mine Production and Reserves:

<table>
<thead>
<tr>
<th>Country</th>
<th>Mine Production</th>
<th>Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2014</td>
<td>2015</td>
</tr>
<tr>
<td>United States</td>
<td>5,400</td>
<td>4,100</td>
</tr>
<tr>
<td>Australia</td>
<td>8,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Brazil</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>China</td>
<td>105,000</td>
<td>105,000</td>
</tr>
<tr>
<td>India</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>240</td>
<td>200</td>
</tr>
<tr>
<td>Russia</td>
<td>2,500</td>
<td>2,500</td>
</tr>
<tr>
<td>Thailand</td>
<td>2,100</td>
<td>2,000</td>
</tr>
<tr>
<td>Other countries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>123,000</td>
<td>124,000</td>
</tr>
</tbody>
</table>

**USGS 2015 Data:**
- U.S. Rare Earth Consumption was ~ 13% of World Production
- 91% Imported from China
- U.S. Reserves are ~ 2% of World Total

*NOTE: The sole U.S. Production Operation went Bankrupt in 2015 and Idled the Facilities*
REE Prognostication

"By the year 2000, we will not be wasting our coal ash, in which geochemists have shown that there is a notable concentration of rare elements, such as germanium and rare earths. We will be recovering these elements."

Dr. Edward Steidle,
Mineral Forecast 2000 AD (1952),
The Pennsylvania State College
• USGS National Coal Resources Data System – Began in 1975
• Data Base of publicly available data – includes major and minor element content
• Used to identify REE in coal
• 2014 U.S. DOE NETL retained LTI and Tetra Tech to complete an “Assessment of Rare Earth Elemental Contents in Select United States Coal Basins”
• Report was published in June 2015
• Available on U.S. DOE NETL website
  https://exd.netl.doe.gov/rec/
REE Source - Lifecycle

Sources of Rare Earths in a Sedimentary Coal Basin

- Volcanic Ignimbrites
- Yellowstone Events
- Carbonatite - Bear Lodge, Wyoming & Mountain Pass, California
- Dike Source (Trinidad, Colorado)
- Magma Source of Rare Earths
  - Alkaline Enriched
- Diapir, Diatreme & Kimberlite
- Erosion - Heavy Sands containing monazite, xenotime, zircon, magnetite, rutile, etc.
- Deltaic Process: (Breathitt Fm, Kentucky)
- REE ionic trapping in clays "Ash"
- Supergene Enrichment
- Lateral Environment (Jiangxi Province, South China)
- Hydrothermal Mineralization: Iron, Niobium, Fluorite, REE (Bayan Obo, Inner Mongolia)
- Faults
Total REEs vs Ash in Coals

All USGS CoalQual Samples
REEs vs Aluminum in Coals

All USGS CoalQual Samples

- Y-axis: Total REE (ppm)
- X-axis: Aluminum in Coal (ppm)
Pennsylvania Coal Bed – Lower Kittanning

Strip Mine
Somerset County, Pennsylvania
Lower Kittanning Bed

X-Axis Scale: 0-350 ppm

<20% Ash
>20% Ash

Maryland Coal – Lower Kittanning

Deep Mine
Garrett County, Maryland
Allegheny Formation, Lower Kittanning Bed

Montana Coal – Morrison Formation

East Belt (Deep Mine)
Cascade County, Montana
Morrison Formation, Unnamed Bed

X-Axis Scale: 0-800 ppm

<20% Ash  >20% Ash

- 10.20% Ash
- 15.44% Ash
- 8.28% Ash
- 21.64% Ash
- 25.44% Ash

Arkansas Coal – Wilcox Formation

Clay Pit (Strip Mine)
Hot Spring County, Arkansas
Wilcox Formation, Unnamed Bed

X-Axis Scale: 0-2000 ppm
- <20% Ash
- >20% Ash

Data from Zubovic, N. B., Sheffey, and P. T. Stadnichenko, "Distribution of Minor Elements in Some Coals in the Western and Southwestern Regions of Interior Coal Province", USGS Bulletin 1117-D, 1967
## Coal Ash Produced Annually

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>proj. 2033</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly Ash</td>
<td>53,400,000</td>
<td>54,600,000</td>
</tr>
<tr>
<td>FGD Material</td>
<td>35,200,000</td>
<td>38,800,000</td>
</tr>
<tr>
<td>Bottom Ash</td>
<td>14,500,000</td>
<td>14,700,000</td>
</tr>
<tr>
<td>Boiler Slag</td>
<td>1,400,000</td>
<td>800,000</td>
</tr>
<tr>
<td>FBC Ash</td>
<td>10,300,000</td>
<td>11,800,000</td>
</tr>
</tbody>
</table>

Source: Production and Use of Coal Combustion Products in the U.S., American Coal Ash Association June 2015
### Coal Produced Annually

<table>
<thead>
<tr>
<th>Region</th>
<th>Million Short Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Appalachia</td>
<td>107.1</td>
</tr>
<tr>
<td>Central Appalachia</td>
<td>77.8</td>
</tr>
<tr>
<td>Southern Appalachia</td>
<td>12.8</td>
</tr>
<tr>
<td>Illinois Basin</td>
<td>103.3</td>
</tr>
<tr>
<td>Other Midwest Basins</td>
<td>41.9</td>
</tr>
<tr>
<td>Powder River Basin</td>
<td>334.4</td>
</tr>
<tr>
<td>Uinta Basin</td>
<td>28.0</td>
</tr>
<tr>
<td>Other Western Basins</td>
<td>68.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>773.9</strong></td>
</tr>
</tbody>
</table>

Source: USEIA Annual Coal Report 2017
Proposed Screening

• Create an Inventory
  ▪ Coal Fired Power Plants
  ▪ Coal Ash Storage Facilities

• Where REEs are in Coal
  ▪ High concentrations found in coal associated materials – under clays, inseam partings
  ▪ Associated with Past Igneous/Coal forming Activity
  ▪ Collect Data on Coal Quality at Plants from Public Sources
Proposed Screening (continued)

- For Low Coal Quality Power Plants
  - ID Suppliers – including seams and/or locations
- Develop Sampling Plan for Top 10 Potential Locations
- Collect Samples
- Screen samples using XRF
- Perform ICP-MS for Samples >300 ppm
Conclusions

• A stable supply of REE’s is needed for security and to sustain our economy and lifestyle
• REE’s are available domestically in CCR’s
• Need to find highest value locations
• Proposed Action
  ▪ Screen CCR Storage Sites
  ▪ Correlate with Coal Source
  ▪ Create Resource Inventory
Questions?

Rare Earth Elements

by Geology.com

Lanthanides

La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

Actinides

Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr