A Partnership of Inventure, TMRC, PSU & K-Tech

Recovery of Rare Earth Elements from Coal Mining Waste Materials
Presented by Rusty Sutterlin Ph.D (Chief Science Officer)
LETTERS OF SUPPORT

Governor Kay Ivey
Robert Aderholt Member of Congress
Terri Sewell Member of Congress
Mayor Walt Maddox
Senator Richard Shelby
The Search for REE’s
Refined the Methodology of Using Yttrium as an Indicator to Estimate Total Rare Earth Element Concentration

Figure 6. Linear fits of REY versus Y for samples B1-B7

Source: Xiaojing Yang, Daniel Kozar, Daniel Gorski, Anthony Marchese, James Pagnotti, Rusty Sutterlin, Mohammad Rezaee, Mark S. Klima, Sarma V. Pisupati, “Using Yttrium as an Indicator to Estimate Total Rare Earth Element Concentration: A Case Study on the Rare Earth Element and Yttrium Distribution Patterns of Materials Associated with Pennsylvanian Coals”, Manuscript to be submitted to Journal of Rare Earth Elements
North Eckley, Pa. Site

Pagnotti Enterprises, Inc

- Phase 1 Search Resulted in
  - Analyzed 74 coal overburden samples from 9 mine sites
  - 17 AMD sludges with more to go
North Eckley, Pa. Site

N. Eckley Trench

REE PPM - ASH BASIS

SAMPLE NUMBER ON TRENCH FACE

Sample #10 Zone
Sample #11 Zone
Sample #12 Zone
Sample #13 Zone
## Acid Mine Drainage Sludge

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Total REE ppm (Whole Dry Basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central, PA</td>
<td>AMD 1</td>
<td>604</td>
</tr>
<tr>
<td>Central, PA</td>
<td>AMD 2</td>
<td>1716</td>
</tr>
<tr>
<td>Central, PA</td>
<td>AMD 3</td>
<td>734</td>
</tr>
</tbody>
</table>
Extraction and Separation of REE’s and Valuable BiProducts
Multi-Feedstock Extraction Process to Generate a Pregnant Leach Solution (PLS)

Coal Biproducts and Coal Products → Carbon Rich Fraction


Gravity Separation Unit Op. → (Heavier) Mineral

Optional Stream (Fly Ash) → Solids (Pozzolans)

Acid Pressure Digestion Unit Op. → Acid

(Dissolution and IX extraction with Acid Unit Op.) → PLS rich in Acid

PLS → CIX/CIC Unit Op. to isolate REE’s

AMD Sludge → (Lights) Clay

Acid as Needed - Most should come from the “PLS rich in Acid” after the Acid Pressure Digestion Unit Op.
Method 1 to Generate a PLS
High Temperature (210°C) Pressure Leach
Method 2 to Generate a PLS
Ambient Acid Leaching
Separation Process - Anion Exchange

CIX/CIC Unit Operation to Isolate REE’s and other Metals of Interest

- Extraction using HCl
- PLS in HCl
- Anion Exchange Column
- FeCl₃
- Mono and Divalent Cations
- CIX-1a Stage 1
- CIX-1b Stage 1
- CIC Stage 2
- CIC Stage 3
- Individual REEs
- AlCl₃
- Al₂O₃
- HCl

Inventure
3HCl + Fe → FeCl₃
4HCl (excess) + Fe → FeCl₄⁻¹
FeCl₄⁻¹ + H₂O (wash) → FeCl₃

The FeCl₃ solution is a popular water flocculating agent used all over the world for water purification.
Separation Process - Anion Exchange
Iron Removal Step
Separation Process – CIX Stage 1
Non-REE Removal

CIX/CIC Unit Operation to Isolate REE’s and other Metals of Interest

- Extraction using HCl
  - PLS in HCl
  - Anion Exchange Column
    - FeCl₃
  - Mono and Divalent Cations
  - CIX-1a Stage 1
  - CIX-1b Stage 1
- HCl, Al₂O₃, AlCl₃
  - CIC Stage 2
    - Lights
    - Mids
    - Heavies
  - CIC Stage 3
    - Individual REEs
Separation Process – CIX Stage 1

REEs recovered after acid mine drainage sludge has passed through the CIX system.
Separation Process – CIX Stage 2
Separation to Lights, Mids and Heavies.
Separation Process – Stage 2
Separation to Lights, Mids and Heavies.

Smaller chromatography system used for stage 2 that separates the REEs into their light, mid and heavy fractions.

<table>
<thead>
<tr>
<th>Lights</th>
<th>Mids</th>
<th>Heavies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Individual REE, 314.88 ppm</strong></td>
<td><strong>Individual REE, 107.56 ppm</strong></td>
<td><strong>Individual REE 33.06 ppm</strong></td>
</tr>
<tr>
<td>SC – 29.76</td>
<td>Pr – 9.63</td>
<td>Tb – 1.95</td>
</tr>
<tr>
<td>Y- 8.05</td>
<td>Nd – 63.29</td>
<td>Dy – 8.05</td>
</tr>
<tr>
<td>La - 62.92</td>
<td>Sm – 13.66</td>
<td>Ho – 10.24</td>
</tr>
<tr>
<td>Ce – 214.15</td>
<td>Eu – 4.27</td>
<td>Er – 5.85</td>
</tr>
<tr>
<td></td>
<td>Gd -16.71</td>
<td>Tm – 1.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yb – 4.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lu – 1.00</td>
</tr>
</tbody>
</table>

The results after Stage 2 that show the REE’s divided up into three fractions.
Separation Process – Stage 3
Separation to Individual REEs.
Separation Process – Stage 3
Separation to Individual REEs.

REE Samples
Do REE’s Make Money?
# Revenue Streams of Aluminum, Iron and REE’s

Assuming 200 MTPD with our Elemental Composition and DOE REE Pricing

<table>
<thead>
<tr>
<th></th>
<th>MT/year</th>
<th>Recovery %</th>
<th>Sell Price ($/MT)</th>
<th>Gross Component Revenue ($/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>5544</td>
<td>0.75</td>
<td>2350</td>
<td>13,028,400</td>
</tr>
<tr>
<td>Iron</td>
<td>4950</td>
<td>0.75</td>
<td>52</td>
<td>257,400</td>
</tr>
<tr>
<td>REEs TOTAL</td>
<td>19</td>
<td>0.75</td>
<td>From Worksheet</td>
<td>4,753,730</td>
</tr>
</tbody>
</table>

Note: Iron Chloride is $400/Ton and is a 40% solution. (14% Ferric Ion)
Other Extraction and Separation of REE’s
REEs were extracted and concentrated to 2% on a dry and whole sample basis with 95% recovery.
Proprietary PSU ligand B was developed and thereby reduced extraction pH to 5 with high recovery (90%)
Inventure Recent Success

- Vitamin E Plant in China
- Final Engineering of Two Fatty Acid Acidulation Plant
- Detailed Engineering Phase of a Glycerin to Propylene Glycol Plant in Louisiana
- Partnership with Air Liquide/Lurgi to market oleochemical technologies.

Inventure is quickly becoming a provider of multiple new technologies and taking those technologies to commercial scale.