Development and testing of an integrated AMD/REE-CM Plant

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• West Virginia Dept. of Environmental Protection
• TenCate Corp.
• Rockwell Automation, Inc.
• Shonk Investments LLC
Federal Goals

Develop secure, domestic source of rare earth elements and critical minerals to support U.S. industry and defense establishment

e.g. advanced radars, miniaturized electronics, turbine blades, F-35s

Funding: USDOE/National Energy Technology Laboratory

Sources—Coal derived wastes:

Acid Mine Drainage—AMD:
• Applications to Hardrock AMD
• Coal Ash
• Coal Tailings—Refuse
Project Objectives and Goals

Develop and test a pilot-scale, continuous process for treating Acid Mine Drainage (AMD) while producing an enriched Rare Earth, Critical Mineral product

Goals:

- Design, construct and operate a full-scale upstream concentrator and ALSX unit at an active AMD discharge treatment site.
- Pre-Concentrate grade: exceeding 0.5% REE/CM
- Final MREO grade exceeding 90% grade with > 50% HREE+CM/TREE
- Demonstrate production capacity of > 500 kg/yr
- Commercially attractive efficiencies and processing costs.
- Net environmental benefit.
Acid mine drainage is a water quality problem and a resource opportunity.

Acid forms and leaches REE from coal waste rock.

AMD moves along pit floor.

Coal tailings or spoil.

Acid neutralization and oxidation.

Precipitate separation.

Decant to regulated discharge.

Dewatering cells.

Deep mine.
WVDEP’s Muddy Creek AMD Project

Highly automated and efficient

Interior of plant showing controls

clarifiers, mixers, control room and lime silo
REEs in Acid Mine Drainage

Average of 155 coal AMD sites

HREE (colored)/TREE = 44.5%
HREE+Critical (red label)/TREE = 60.9%

REEs content:
- Y: 24%
- Nd: 15%
- Sc: 3%
- Eu: 1%
- Gd: 6%
- Tb: 1%
- Dy: 5%
- Er: 1%
- Tm: 2%
- Yb: 2%
- Lu: 9%
- La: 9%

Berkeley Pit, Copper mine

TREE: 291 g/t
HREE/TREE=49%, HREE+Critical)/TREE=64%

REEs content:
- Y: 31%
- Nd: 14%
- Sc: 1%
- Eu: 1%
- Gd: 4%
- Tb: 4%
- Dy: 1%
- Er: 1%
- Tm: 3%
- Yb: 0%
- Lu: 3%
- La: 7%
Project ETD67: Pilot Plant-WVDEP A34 Permit

230 ac, 500 gpm
pH 2.8

Rockwell’s control unit and automated SX plant

REE/CM Refinery

Onsite solids disposal
mixer
Pre concentrate
Acid Leach
Solvent extraction
Precipitation

MREO

Clean water

Lime

0.5-5% TREE

AMD treatment, Upstream Concentrator

0.005 udg AMD

500 gpm AMD treatment, Upstream Concentrator

REE/CM Refinery
Refining REE/CM from feedstock

CCB/tailings concentrates

Hard rock AMD sludge/PC

Coal AMD sludge/PC

Rockwell’s controller and automated SX plant

90-100% MREO
Recent AL/SX results - AMD sludge:
Simple circuit optimized for HREE

Improved Acid Leach Procedure:
PLS = 200-320 mg TREE/L

<table>
<thead>
<tr>
<th>Sample # 2880</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>TREE</td>
<td>100.0%</td>
</tr>
<tr>
<td>LREE</td>
<td>51.2%</td>
</tr>
<tr>
<td>HREE</td>
<td>48.8%</td>
</tr>
<tr>
<td>HREE+CM</td>
<td>67.2%</td>
</tr>
</tbody>
</table>
The Resource base: two strategies

**AMD Sludge Recovery >300 g/t (ppm)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD sludge cells sampled</td>
<td>76</td>
</tr>
<tr>
<td>REE Basket price</td>
<td>$237 $/kg</td>
</tr>
<tr>
<td>Sludge mass DWB</td>
<td>1,062,413 t</td>
</tr>
<tr>
<td>Average TREE grade</td>
<td>663 g/t</td>
</tr>
<tr>
<td>TREE mass</td>
<td>350 t</td>
</tr>
<tr>
<td>Estimated contained value</td>
<td>$79,633,629</td>
</tr>
</tbody>
</table>

**Direct AMD Recovery**

**REE production from AMD: Northern + Central APP**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMD production</td>
<td>1,503,371 gpm</td>
</tr>
<tr>
<td>Average TREE conc.</td>
<td>0.269 mg/L</td>
</tr>
<tr>
<td>TREE production</td>
<td>807 t/yr</td>
</tr>
<tr>
<td>Estimated contained value</td>
<td>$191,362,343</td>
</tr>
</tbody>
</table>

**AMD sludge dewatering cell in Central WV**

In-situ value = $1.3 million
Copper Mine AMD, Butte MT

Berkeley Pit
900 ft deep
1 mile across
AMD precipitates:
  140 MM m$^3$
Estimated REE:
  12,000 t DW
Economic and Environmental Benefits

Streams restored while recovering REE/CM

Anticipated ‘profit’ from A34 plant

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basket price</td>
<td>$237/kg MREO</td>
</tr>
<tr>
<td>Total processing cost</td>
<td>$54/kg MREO</td>
</tr>
<tr>
<td>Estimated profit</td>
<td>$183/kg MREO</td>
</tr>
<tr>
<td>AMD feed</td>
<td>500 gpm</td>
</tr>
<tr>
<td>AMD quality</td>
<td>0.8 mg TREE/L</td>
</tr>
<tr>
<td>Production</td>
<td>880 kg MREO/yr</td>
</tr>
<tr>
<td></td>
<td>669 kg Cobalt/yr</td>
</tr>
<tr>
<td>Production</td>
<td>1,549 kg/yr</td>
</tr>
<tr>
<td>Estimated annual profit*</td>
<td>$184,448</td>
</tr>
</tbody>
</table>

Does not include: capital cost recovery, taxes, elemental losses, oxide separation costs
Economic Feasibility Analysis

<table>
<thead>
<tr>
<th>Economic Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Feed Rate/Grade</td>
<td>175 TPD @ 2% REE</td>
</tr>
<tr>
<td>Product Rate/Grade</td>
<td>2 TPD @ 90% MREO</td>
</tr>
<tr>
<td>Operating Period</td>
<td>20 years; 10% discount rate</td>
</tr>
<tr>
<td>REE Basket Price</td>
<td>$147 /kg</td>
</tr>
<tr>
<td>REE Recovery</td>
<td>59%</td>
</tr>
<tr>
<td>Plant CAPEX</td>
<td>$20 Million</td>
</tr>
<tr>
<td>Plant OPEX</td>
<td>$54 / kg</td>
</tr>
<tr>
<td>NPV</td>
<td>$80 Million</td>
</tr>
<tr>
<td>IRR</td>
<td>61%</td>
</tr>
<tr>
<td>Payback period</td>
<td>1.5 operating years</td>
</tr>
</tbody>
</table>

REE Basket Price = $147/kg
### Technology Status: Market needs

#### Distributed supply chains:
Forestry, Power gen, Agriculture

Hypothetical Hub and Spoke Arrangement for collecting AMD concentrates for regional processing facilities

<table>
<thead>
<tr>
<th>Feedstock Supply strategy</th>
<th>Collection technology</th>
<th>Collection economics</th>
<th>Collection infrastructure</th>
<th>ID separation technology</th>
<th>Modify AMD treatment</th>
<th>Precipitation</th>
<th>Solvent Extraction</th>
<th>Acid leaching</th>
<th>Pre concentrate</th>
<th>MREO production</th>
<th>System economics</th>
<th>Resource estimate</th>
<th>Preliminary economics</th>
<th>ID feedstock</th>
<th>REEi metal</th>
<th>REEi oxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

**Current TRL**

**Anticipated after Current Projects**

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Downstream refining

Upstream gathering system

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DS

US

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U.S. DEPARTMENT OF ENERGY

14
Permitting: Net Environmental Benefit

Regulatory Environment:
- Active permits: State primacy CWA sec 402
- Abandoned mines: CWA sec 404 (maybe)
- Federal OSHA
- No NORMS: Naturally occurring radioactive materials
- Compliance with NRC limits:
  - < 1 mSv/yr over background

Abandoned coal mine AMD:
No one is sorry to see this go away
Nearly all waste remains at the AMD treatment plant

- Near Bismarck WV
- Designed to:
  - Treat AMD to meet CWA compliance levels
  - Recover high grade Rare Earth Oxide
- Waste is AMD sludge without the Rare Earths
  - Non-hazardous
  - Onsite disposal
Key Points

Low upfront cost/risk

1. Leveraging: Our feedstock is a byproduct of AMD treatment—most capital costs are included in the AMD treatment plant

1. Environmentally Benign:
   1. Supports stream and river remediation efforts
   2. No Radioactivity in the tailings

2. High value product: 67% Heavy + Critical to Total REE

3. No to minor permitting issues

4. Short time to reach production: months
   • Minimum exploration costs
   • No mining cost
   • Pre development cost

• Future needs:
  • scale up to continuous production
  • develop upstream supply chain
Questions:

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