Pilot-Scale Testing of an Integrated Circuit for the Extraction of Rare Earth Minerals and Elements from Coal and Coal Byproducts Using Advanced Separation Technologies

PRINCIPAL INVESTIGATOR: Dr. Rick Honaker
University of Kentucky

DOE Award Number: DE-FE0027035
Period of Performance: 3/1/2016 – 2/28/2020
NETL Program Manager: Charles Miller

2018 Project Review Meeting
Rare Earth Elements Research Portfolios
Tuesday, April 10, 2018
Project Objectives

• Develop, design and demonstrate a pilot-scale processing system for the efficient, low-cost and environmentally benign recovery of high-value rare earth elements (REEs) from coal and coal byproducts.
  • Integrate both physical and chemical separation processes;
  • Pilot-scale circuit will have a dry solids feed rate of ¼-ton/hr (0.23 tonne/hr) and will be capable of producing 5 - 7 pounds (2.3 – 3.2 kg) per hour of combined concentrates with purity levels of at least 2% total REEs by weight;
  • Technical and economic feasibility of the proposed system will be fully evaluated with respect to separation performance, throughput capacity, capital/operating costs, and environmental acceptability.

• The pilot-scale plant will be mobile and evaluated at two different locations and multiple feed stocks during the project period.
### Phase 2 Budget Period 2 Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Q4</th>
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## Phase 2 Budget Period 3 Schedule

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</table>
Flowsheet Concept

Feed Type A1
(Plant Coarse Reject)

Feed Type A2
(Refuse Pile)

Feed Type B1
(Plant Fine Reject)

Feed Type B2
(Pond Fines)

Feed Type C1
(Natural Leachate)

Feed Type C2
(Pile Leachate)

Feed Type C3
(Leach Pad)

Sorter → Crush/Grind → Coal Recovery → Alkali Rejection

REM Recovery → Roast/Crack

Leach/Exchange

Hydromet Precip → Solvent Extraction → Precipitation

COAL PRODUCT

BULK REE CONCENTRATE

SPENT WASTE
Hydrometallurgy Circuit
Solvent Extraction Circuit

Solids Feed, Precipitate or Natural Leachate

Raffinate Bleed

Leach Circuit

Acid Solution Make-up

SX Load Stage 1

SX Load Stage 2

SX Scrubbing Stage

SX Stripping Stage

Contaminants

REE Mix Concentrate

2 M NaOH

2 M NaOH

0.2 M HCl

6 M HCl

Sc Concentrate

SX Sc Stripping Stage
Solvent Extraction REE Products

<table>
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<tr>
<th>Rare Earth Element</th>
<th>REE Oxide (ppm)</th>
<th>Fire Clay</th>
<th>W. KY No. 13</th>
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<tr>
<td></td>
<td>Middlings</td>
<td>TUF</td>
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<td>Terbium</td>
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<td>Dysprosium</td>
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<td>Ytterbium</td>
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<td>Lutetium</td>
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<td>Total</td>
<td><strong>511,685</strong></td>
<td><strong>34,470</strong></td>
<td><strong>85,357</strong></td>
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Selective Precipitation Option

- 80% total REE recovery;
- 52% manganese oxide, 60% copper sulfide and 60% zinc sulfide;
- Achieved using a continuous process in a lab environment;
- Patent application submitted.

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<th>REEs</th>
<th>Content (%)</th>
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<td><strong>Total</strong></td>
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Configuration Options

**Configuration “A”**
Low-Ash Feed Containing Significant REMs and High-Value Metallurgical Coal

- Feedstock
- Feedstock Preparation
- HHS Decarbonization
- HHS REM Extract/Dealkalinization
- Acid Leaching/Ion Exchange
- Cracking
- REE Product
- Solvent Extraction/Precipitation
- Waste Solids

**Configuration “B”**
Low-Ash Feed Containing Significant REMs and Medium-Value Steam Coal

- Feedstock
- Feedstock Preparation
- HHS or Flotation Decarbonization
- HHS or Flotation Dealkalinization
- Acid Leaching/Ion Exchange
- Cracking
- REE Product
- Solvent Extraction/Precipitation
- Waste Solids

**Configuration “C”**
High-Ash Feed Containing Significant REMs and Little or No Valuable Coal

- Feedstock
- Flotation Decarbonization
- HHS REM Extract/Dealkalinization
- Acid Leaching/Ion Exchange
- Cracking
- REE Product
- Solvent Extraction/Precipitation
- Waste Solids
Configuration Options

**Configuration “D”**
Low-Ash Feed Containing Little/No REMs and High-Value Metallurgical Coal

1. Feedstock Preparation
2. HHS Decarbonization
3. Flotation Dealkalinization
4. Acid Leaching/Ion Exchange
5. Solvent Extraction/Precipitation
6. Waste Solids
7. REE Product

**Configuration “E”**
Low-Ash Feed With Little/No REMs and Medium-Value Coal

1. Feedstock Preparation
2. HHS or Flotation Decarbonization
3. Flotation Dealkalinization
4. Acid Leaching/Ion Exchange
5. Solvent Extraction/Precipitation
6. Waste Solids
7. REE Product

**Configuration “F”**
High-Ash Feed Containing Little/No REMs and Little/No Valuable Coal

1. Feedstock Preparation
2. Flotation Decarbonization/Dealkalinization
3. Acid Leaching/Ion Exchange
4. Solvent Extraction/Precipitation
5. Waste Solids
6. REE Product
Process Train Layouts

1.00 – Preconcentration (Mine Site)
2.00 – Size Reduction/Liberation
3.00 – Physical Separation
4.00 – Acid Leaching
5.00 – Solvent Extraction & Precipitation
6.00 – Chemical Storage
7.00 – Rare Earth Mineral Concentration
Construction work in progress...
1.00 - Preconcentration

(Elevation View)

(Simplified Plan View)

Estimated Area = 35 ft x 8 ft
1.00 - Preconcentration

Belt Sampler

Vibrating Screen

Sized Product (50x6 mm)

Electronic X-Ray Sorter

Product & Reject Conveyors

Coarse Waste

Middling Product

Coarse Feedstock

Reject Conveyor (+ 50 mm/-6 mm)

Oversize/Fines Pile
1.00 - Preconcentration

- **Feed Conveyor (Low Speed)**
- **Scanning Conveyor (High Speed)**
- **X-Ray Source**
- **Compressed Air Jets**
- **Electronics & Controls**
- **X-Ray Detector**
- **Coal**
- **Rock**
- **Reject**
- **Clean**
1.00 - Preconcentration

Feed

DriJet™ Sorter

Pass

Eject

Magnified Image
1.00 - Preconcentration
1.00 - Preconcentration

West Kentucky No. 13 – Bed Strata X-Ray Analysis
1.00 - Preconcentration

![Graph showing Ash (%) on the x-axis and X-Ray Response (West KY 13) on the y-axis, with TREE (ppm) on the secondary y-axis.](image)

- Ash (%) ranges from 0 to 100.
- X-Ray Response values range from 3514 to 3548.
- TREE (ppm) values range from 0 to 1000.
1.00 - Preconcentration
1.00 - Preconcentration
1.00 - Preconcentration
2.00 – Size Reduction/Liberation

(Elevation View)

(Simplified Plan View)

Estimated Area = 15 ft x 6 ft

Estimated Area = 28 ft x 6 ft
2.00 – Size Reduction/Liberation

(Elevation View)
2.00 – Size Reduction/Liberation
3.00 – Physical Separation

(Elevation View)

(Simplified Plan View)

*Estimated Area = 15 ft x 6 ft*
3.00 – Physical Separation

Ground Slurry

From Feed Holding Tank

Valve

Wash Water

Decarbonization Flotation

To HHS

Disc Filter

Coal Product

Decarbonized Slurry

Thickener

To SX Waste Filter

Pressure Filter

Leach Feed Cake

Filter Sump & Pump

Leach Tank

Filtrate Pump

To SX

Waste

Filter

HHS

Decarbonized Slurry

To Leach Tank

Leach

Coal Product
3.00 – Physical Separation

NOTE: Water head tank not shown.
4.00 – Acid Leaching

(Elevation View)

(Simplified Plan View)

Leach Feed Cake
From Physical Separation

Leach Tank #1

Thickener #1

Reductive Tank

Neutralization Tank

Leach Tank #2

Thickener #2

Acid Solution

Filter Sump & Pump

Pressure Filter (With Rinse)

Leach Tank #2

To SX/Precip. Circuit

Waste Tails

Filtrate Pump

Alternate Feedstocks

Lime Solution

REE Precip.

Iron Precip.

Waste Precip.

Water Pump

To Waste Filter

Estimated Area = 34 ft x 6 ft

Estimated Area = 10 ft x 6 ft
4.00 – Acid Leaching

Two-Stage Leaching Circuit
4.00 – Acid Leaching
4.00 – Acid Leaching
4.00 – Acid Leaching
(Contaminant Bleed)
5.00 – Solvent Extraction/Precipitation

(Elevation View)

(Simplified Plan View)

Estimated Area = 45 ft x 6 ft
5.00 – Solvent Extraction/Precipitation
5.00 – Solvent Extraction/Precipitation
5.00 – Solvent Extraction/Precipitation
5.00 – Solvent Extraction/Precipitation
6.00 – Chemical Storage

(Elevation View)

(Simplified Plan View)

Water Supply

H₂SO₄ Solution

H₂SO₄ Makedown/Delivery

Estimated Area = 20 ft x 6 ft

HCl Solution

HCl Makedown/Delivery

Reducing Solution

Reducing Makedown/Delivery

Oxalic Solution

Oxalic Makedown/Delivery

Estimated Area = 10 ft x 6 ft

NH₄OH Solution

NH₄OH Makedown/Delivery

Lime Solution

Lime Makedown/Delivery

Estimated Area = 6 ft x 6 ft
7.00 – REM Concentration

(Elevation View)

(Simplified Plan View – Alternative Configuration)

30 ft x 6 ft Bay (Mobile Towable Trailer)
7.00 – REM Concentration

(Elevation View)

Decarbonized Product

Coal Dispersion Tank
Coal Strip Tank
Coal Extraction Column
Coal Pressure Filter
REM Dispersion & Strip Tanks
REM Extraction Column
REM Feed Tank
REM Dilute Tank
REM Pressure Filter
HL Condenser
HL Storage Tank

Coal Product

REM Product

To Leach Bay

HL Storage Tank

Note: N2 Generator Not Shown

7.00 – REM Concentration

(Elevation View)

Decarbonized Product

Coal Dispersion Tank
Coal Strip Tank
Coal Extraction Column
Coal Pressure Filter
REM Dispersion & Strip Tanks
REM Extraction Column
REM Feed Tank
REM Dilute Tank
REM Pressure Filter
HL Condenser
HL Storage Tank

Coal Product

REM Product

To Leach Bay

HL Storage Tank

Note: N2 Generator Not Shown
7.00 – REM Concentration
7.00 – REM Concentration
Site/Property Layouts

Dotiki Mine Site
Site Photographs
Process Train Layouts
Berms/Drains
Electrical Services
Miscellaneous
Dotiki – Building Structure
Dotiki – Building Floor Plan
Dotiki – Accommodations
Dotiki – Working Area
Dotiki – Module Configuration

Train 1.00 – Preconcentration (SCREEN/SORTER AT MINE SITE)

Train 2.00 – Size Reduction

Train 3.00 – Physical Separation

Train 4.00 – Acid Leaching

Train 5.00 – Solvent Extraction/Precipitation

Train 6.00 – Reagent Storage

Train 7.00 – REM Concentration
Summary

• Mobile ¼-tph REE pilot-plant will be operational by July 2018.
• System will be tested on multiple feed stocks at two locations.
• Plant consists of seven distinctly different process bays.
• Analyses capabilities will be available onsite to improve efficiency of test program.
• Aspen will be used for systems analyses and a techno-economic study.