

Develop and test an integrated Acid Mine Drainage treatment and REE/CM extraction plant

USDOE Project DE FE00 31834

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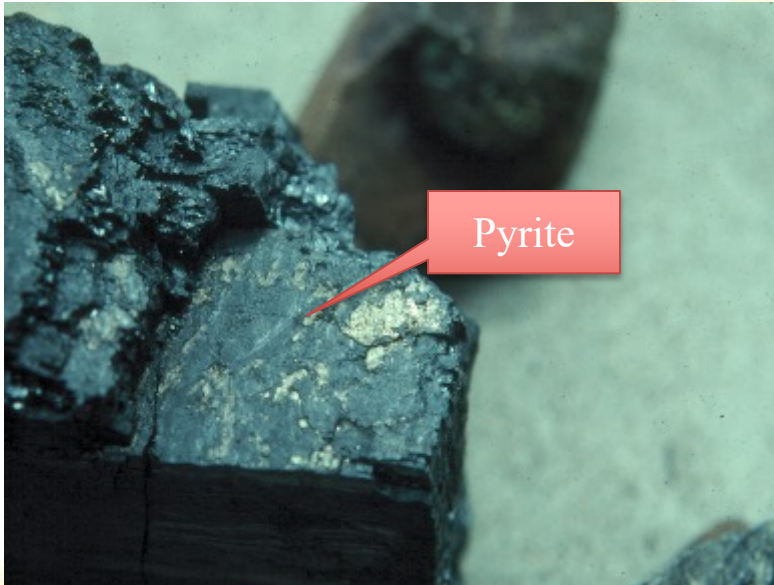
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ACID MINE DRAINAGE: AMD

1. H_2SO_4 leaches REE from shale
2. REEs precipitate with $\text{Fe}(\text{OH})_3$



AMD treatment includes capture, neutralization and sludge management

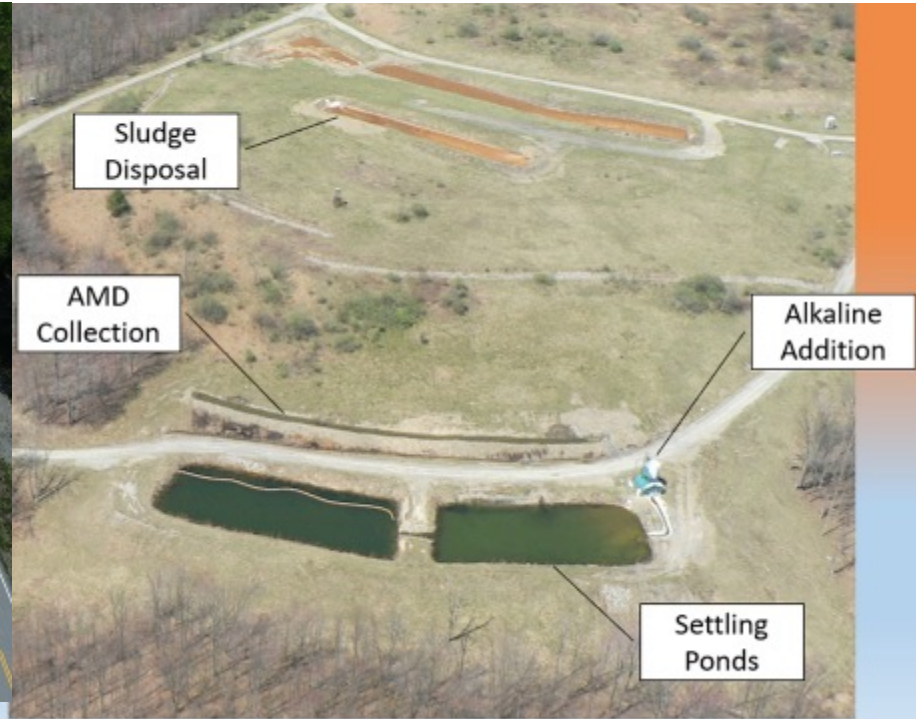


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AMD TREATMENT SYSTEMS



Passive vs. Active Acid Mine Drainage Treatment

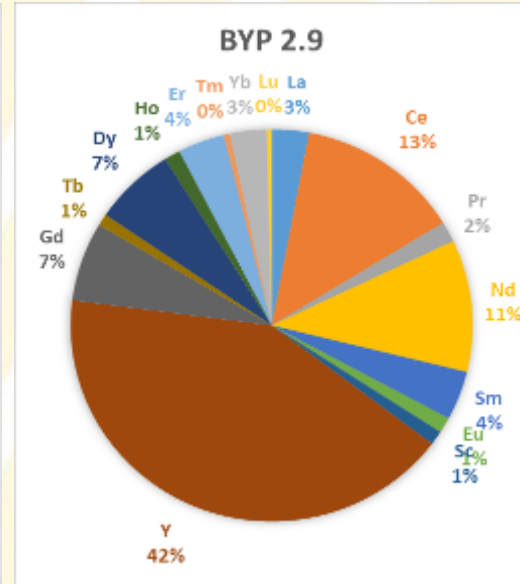
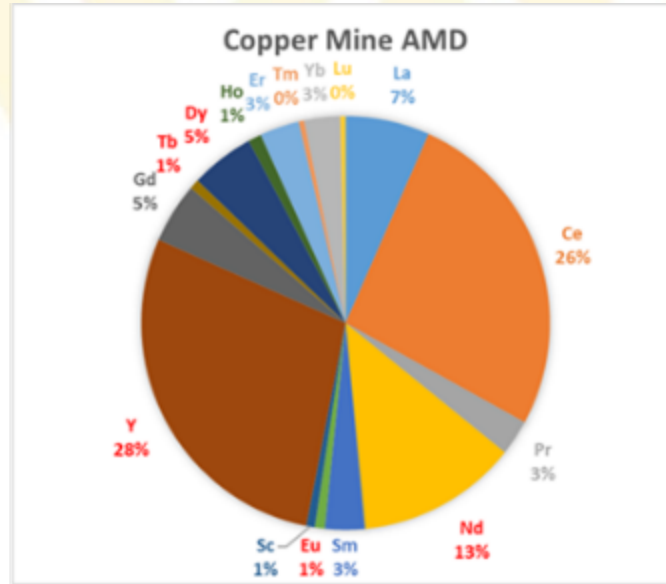
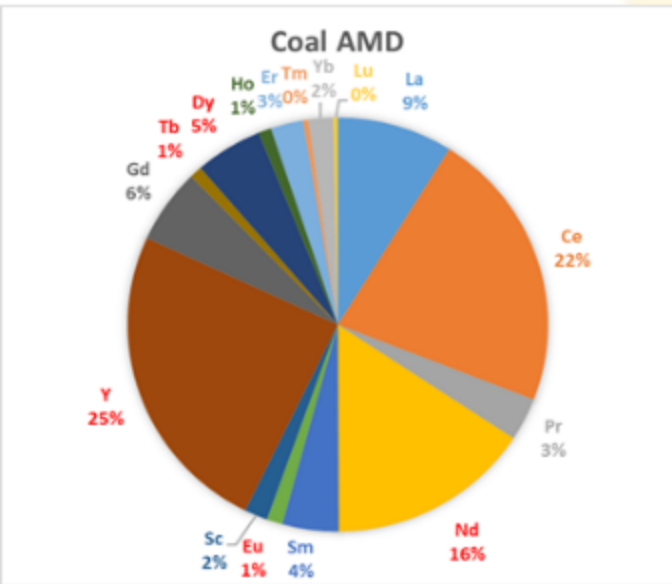


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Coal and Copper mine AMD samples have nearly identical REE distributions

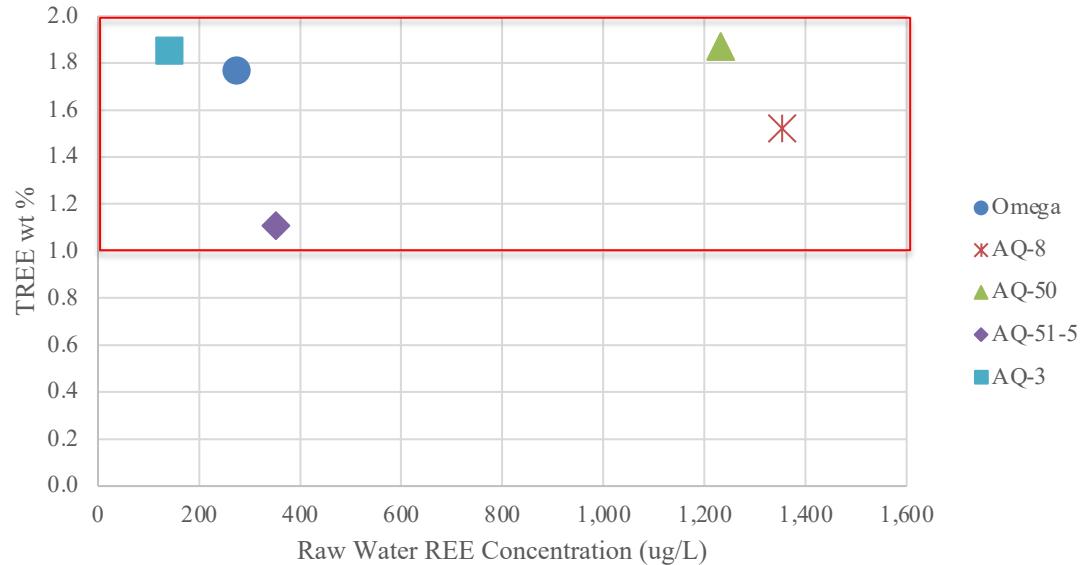


How Does Raw Water Quality Affect Grade?

Not at all:

Our process rejects most of the gangue then filters the residuals, resulting in a high degree of homogenization

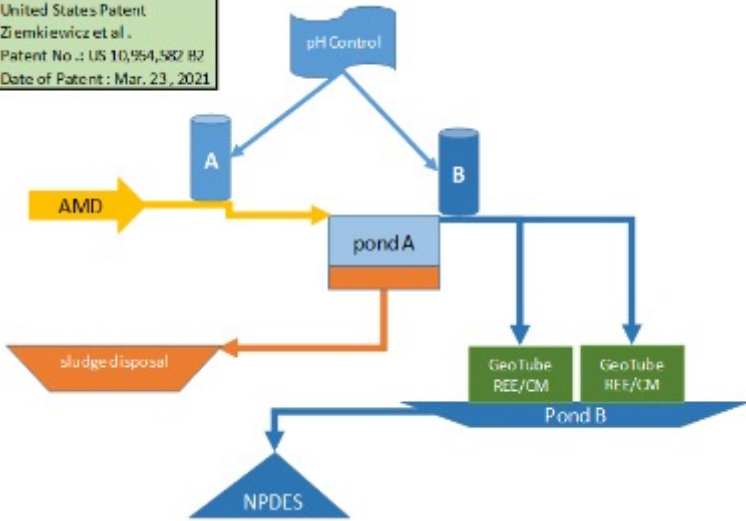
TREE Concentration vs REE Weight %



AMD TREATMENT WITH REE/CM RECOVERY



United States Patent
Ziemkiewicz et al.
Patent No.: US 10,954,582 B2
Date of Patent: Mar. 23, 2021



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Process:

1. Generate pre-concentrate (brown floc)
2. Passively dewater to 85% solids (brick)
3. Transport to a central processing facility
4. Convert it to high-grade PLS (green), then MREO
5. Elemental oxide, reduction to metal

Pre-conc. TREE: 0.5%



0.1% solids

Brick TREE: 0.5-5.0%



Hi grade PLS

PLS TREE: 100-1,800 mg/L



MREO



MREO TREE:
90-99%

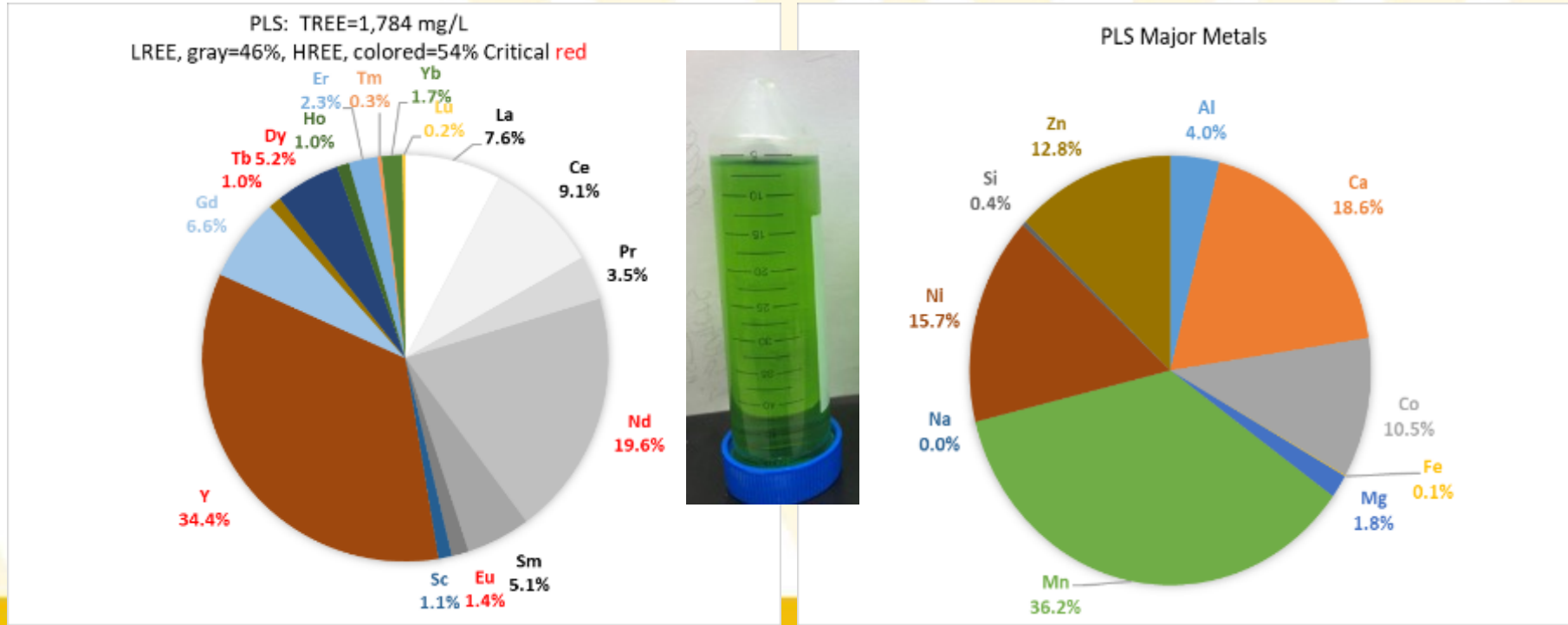


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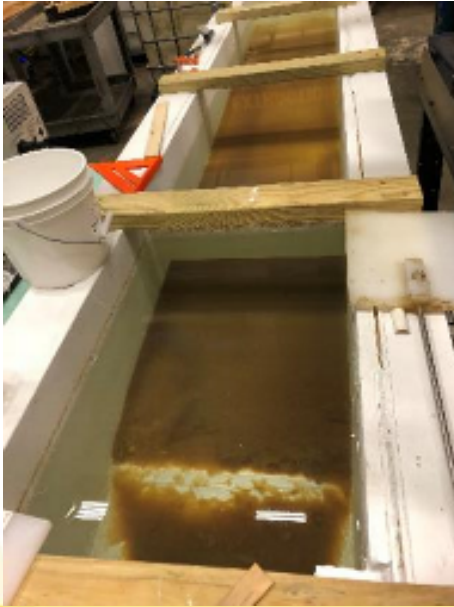
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Recent PLS production: 1,784 mg TREE/L, 54% HREE almost no Al, Si



Project ETD67: Mt. Storm Pilot Plant

AMD treatment: Up to 1,000 gpm,
Production rate ~ 1 tpy each:
REE, Cobalt, Nickel.



Conceptual supply chain: Concentrates move to central processing facilities

D. Iron Mt. CA



E. Butte MT



F. Iron Range MN



Potential source districts

- A: Northern/Central APP
- B: Southern APP/Illinois basin
- C: Southern Rockies metal belt
- D: Sierra metal belt
- E: Northern Rockies metal belt
- F: Minnesota iron range



C. Four Corners



B. Southern App Coal

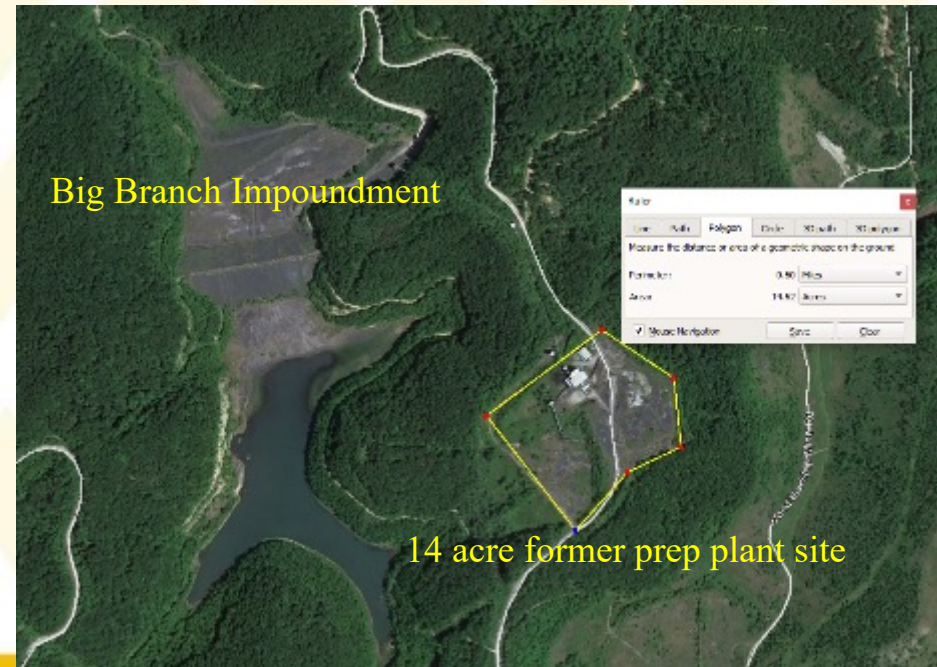
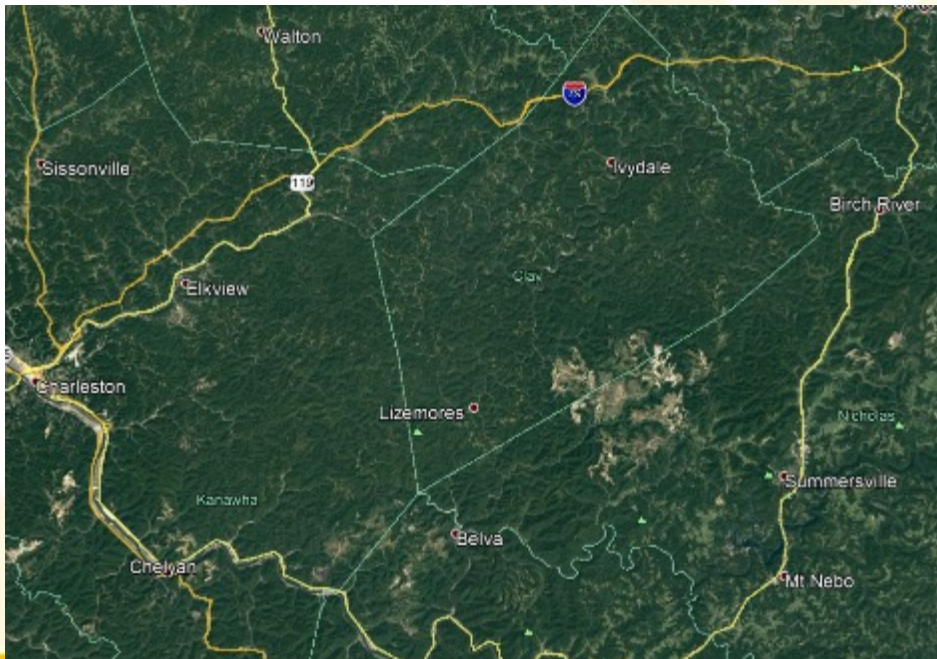


A. Northern App Coal



Fola Site, Clay/Nicholas Co:
Big Branch Prep Plant site:
Dedicated rail to site 12 mi:

20 sq. miles, total property area
14 acres, Prep Plant Site
Jct. w/N&S, CSX at Belva WV



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Disadvantages of sourcing REE/CM from AMD

- Low concentrations
- Requires collection from many sites
- Need to manage upstream supply chain
- Quality control: moisture, grade



Advantages of sourcing REE/CM from AMD

- Already permitted sites, no delays due to permitting
- Easy to quantify yield, minimal exploration cost
- Environmentally beneficial, byproduct is clean water
- Solid wastes are RCRA subtitle D, non hazardous
- Distributes jobs and benefits across broad areas
- Incentivizes treatment of legacy AMD discharges
- Uniform feedstock, across mines and sectors
- Attractive economics
- **No rads**



Feasibility Study: FEL-2

Key Components

1. Resource estimate
2. Performance modeling/process engineering
3. Capital and operating cost estimate
4. Financial analysis
5. Risk analysis and technology gap analysis
6. Project execution plan
 - Interphase Test Work
 - FEL-3 Definitive Feasibility Study
 - Detailed Engineering
 - Project Execution

National Energy Technology Lab
U.S. Department of Energy

Contract Number: 89243320CFE000059
Option 1 Feasibility Case Study
April 20, 2021 – November 16, 2021

Production of Rare Earth Products and Critical Minerals from Coal-Based
Resources at an Engineering Prototype Scale

Final Report

Submitted by:
Paul Ziembiewicz, PhD
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Submission Date:
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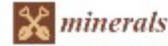
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Approach and Assumptions

- Techno-economic assessment was conducted to evaluate overall economic feasibility of the concept. Key components:
 - Revenue estimate
 - Capital cost estimate (Class IV, $\pm 40\%$)
 - Operating cost estimate
 - Life cycle financial analysis
 - Sensitivity analysis
 - Monte Carlo simulation
- Results were recently published in a special edition of the *Minerals* journal.



Article

A Fundamental Economic Assessment of Recovering Rare Earth Elements and Critical Minerals from Acid Mine Drainage Using a Network Sourcing Strategy

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Methods to extract rare earth elements (REE) and other critical minerals (CM) from acid mine drainage (AMD) have emerged as a promising, non-traditional source of rare earth elements (REE) and other critical minerals (CM) such as cobalt and manganese. In this regard, AMD provides a natural dump leaching stream that contains and concentrates REE/CM from the host mine, resulting in a partially sorted feedstock available for downstream extraction, separation, and recovery. While several prior studies have described processes and approaches for the valorization of AMD, very few have described the supply chain and infrastructure requirements as well as the associated economic assessment. To that end, this paper provides a fundamental techno-economic assessment of REE/CM recovery from AMD using a network sourcing strategy in addition to a robust, flexible feedstock separation and refining facility. The methodology of this paper follows that of a typical techno-economic analysis with capital and operating costs estimated using ASCE Class IV (FE) 2) guidelines. It demonstrates the range of possible outcomes, hour pricing scenarios were modeled including contemporary prices (September, 2021) as well as the minimum and maximum prices over the last decade. In addition, five production scenarios were considered reflecting variations in the product suite, ranging from full elemental separation to magnet REE and CM production only (i.e., Nd, Nd₂O₃, Dy, Y, Sc, Co, and Mn). The results of this analysis show that, with the exception of the minimum price scenario, all operational configurations have positive net present value over the last decade. In addition, the optimal configuration prior to 2015 is the REE and CM production only (i.e., Nd, Nd₂O₃, Dy, Y, Sc, Co, and Mn). The results of this analysis show that, with the exception of the minimum price scenario, all operational configurations have positive net present value over the last decade. In addition, the optimal configuration prior to 2015 is the REE and CM production only (i.e., Nd, Nd₂O₃, Dy, Y, Sc, Co, and Mn). The results of this analysis show that capital cost and HCl consumption are the two major factors influencing rate of return, thus indicating opportunities for future technology development and cost optimization. Implementation of the study and a cooperative profit-sharing model for sourcing are also described.

Keywords: techno-economic analysis; rare earth elements; acid mine drainage; solvent extraction; critical minerals; cobalt; manganese

1. Introduction

Over the last decade, critical minerals have become an increasingly important matter of both technical and societal importance. While several US federal and international agencies (e.g., U.S. Departments of Energy, Commerce, Defense, USGS, the European Commission, the International Energy Agency, Geoscience Australia, etc.) have provided press definitions for mineral criticality, they all generally capture the combined factors of importance to modern society and risk for supply chain disruptions [1–7]. Many public and private organizations have developed policies and investment strategies to diversify

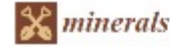


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Approach and Assumptions

- Operational Configurations:
 - REO Facility
 - Complete Facility
 - REE, no Mischmetal
 - REE + Co, no Mischmetal
 - REE + Co + Mn, no Mischmetal
 - CREE + Co + Mn, no Mischmetal**
- Price Scenarios
 - September 2021 (feasibility study)**
 - December 2020 (conceptual study, NETL guidance)
 - Minimum 2014 – 2021
 - Maximum 2014 - 2021



Article

A Fundamental Economic Assessment of Recovering Rare Earth Elements and Critical Minerals from Acid Mine Drainage Using a Network Sourcing Strategy

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Methods to extract rare earth elements (REE) and critical minerals (CM) from acid mine drainage (AMD) have emerged as a promising secondary source of rare earth elements (REE) and other critical minerals (CM) such as cobalt and manganese. In this regard, AMD provides a natural dump leaching stream that contains and concentrates REE/CM from the host mine, resulting in a partially purified feedstock available for downstream extraction, separation, and recovery. While several prior studies have described processes and approaches for the valorization of AMD, very few have described the supply chain and infrastructure requirements as well as the associated economic assessment. To that end, this paper provides a fundamental economic assessment of REE/CM recovery from AMD using a network sourcing strategy. In addition to a robust, flexible feedstock separation and refining facility, the methodology of this paper infers that a typical techno-economic analysis with capital and operating costs estimated using ASCE Class F (FE) 2) guidelines. It demonstrates the range of possible outcomes. Key pricing scenarios were modeled including contemporary prices (September, 2021) as well as the minimum and maximum prices over the life decade. In addition, five production scenarios were considered reflecting variations in the product suite, ranging from full elemental separation to magnet REE and CM production only (i.e., Fe, Nd, Dy, Y, Sc, Co, and Mn). The results of this analysis show that, with the exception of the minimum price scenario, all operational configurations have positive net present value with rates of return varying from 25% to 205% for the contemporary price scenario. The optimal configuration was determined to be production of Co, Mn, and all REE except for mischmetal, which is not recovered. Sensitivity analysis and Monte Carlo simulation show that capital cost and HCl consumption are the two major factors influencing rates of return, thus indicating opportunities for future technology development and cost optimization. Implications of the study and a cooperative profit-sharing model for sourcing are also described.

Keywords: techno-economic analysis; rare earth elements; acid mine drainage; solvent extraction; critical minerals; cobalt; manganese

1. Introduction

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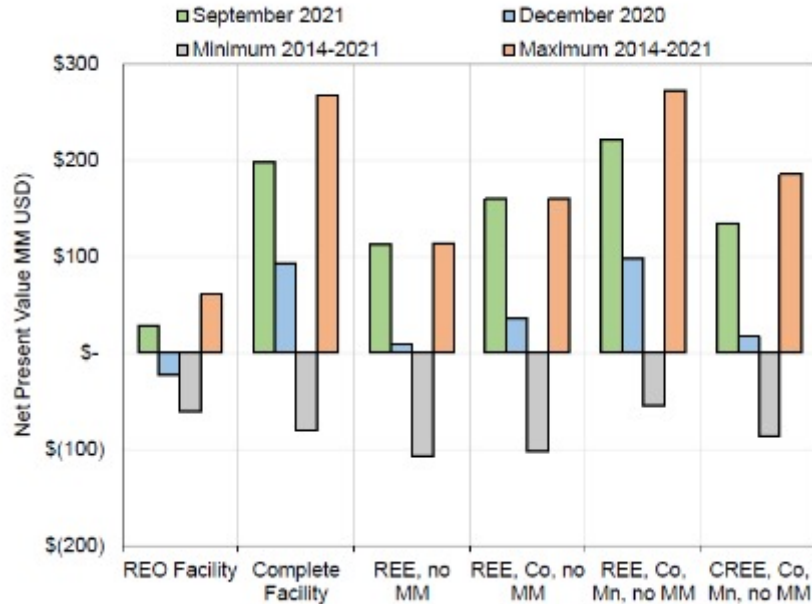
Capital and Operating Cost Summary

Revenues and Costs	<u>Plant Configuration</u>					
	REO Facility	Complete Facility	REE, no MM	REE + Co, no MM	REE + Co + Mn no MM	CREE + Co + Mn no MM
Revenues, Sept 2021 (MM USD)	\$20.24	\$70.46	\$49.42	\$58.59	\$69.70	\$56.58
Total Operating Cost (MM USD/year)	\$14.62	\$25.00	\$21.14	\$22.24	\$24.41	\$24.41
Capital Cost (MM USD)	\$22.10	\$185.81	\$130.79	\$148.60	\$154.83	\$142.20

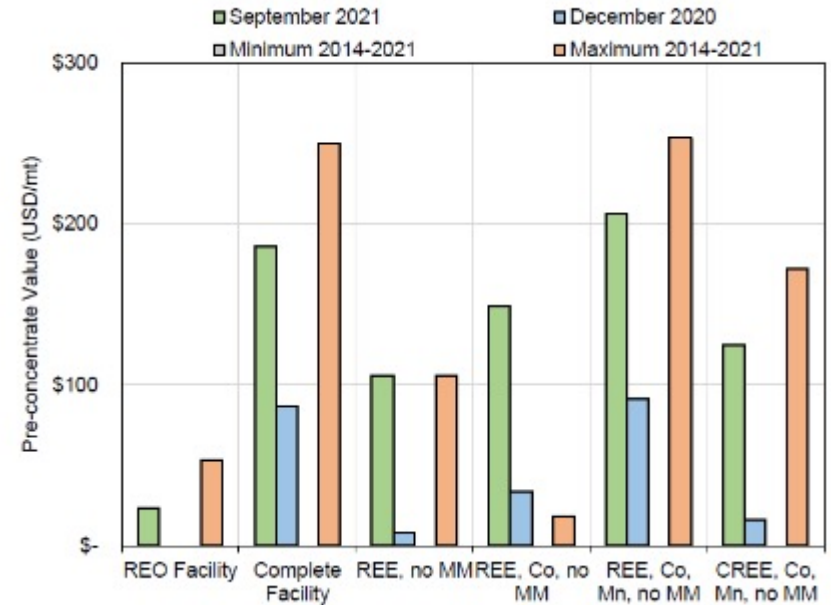


Scenario Analysis Results

Net Present Value



PC Value at 10% ROR



Questions?

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