AMDREE-Integrated Treatment of Acid Mine Drainage and Rare Earth Recovery



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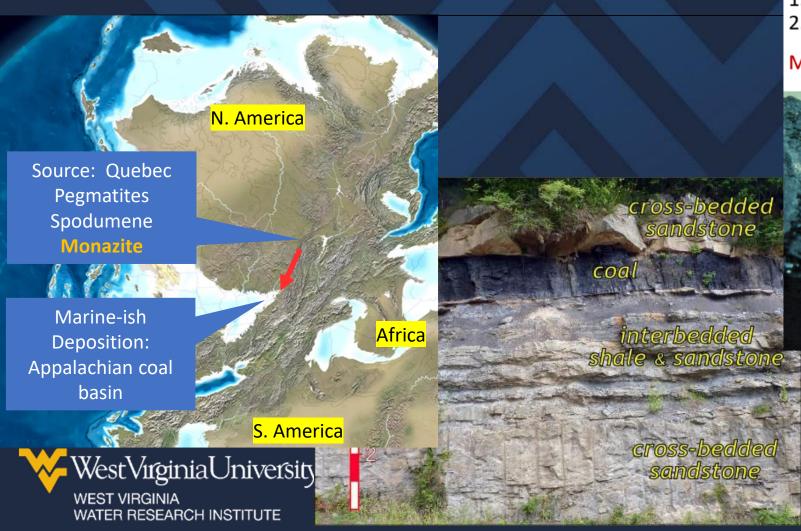
WVDEP: Rob Rice





Background*, Late Pennsylvanian time

*Paul's unified field theory: Free acid drives REE recovery



Acid Mine Drainage: AMD

Pyrite + O_2 + $H_2O = Fe^{2+} + H_2SO_4$

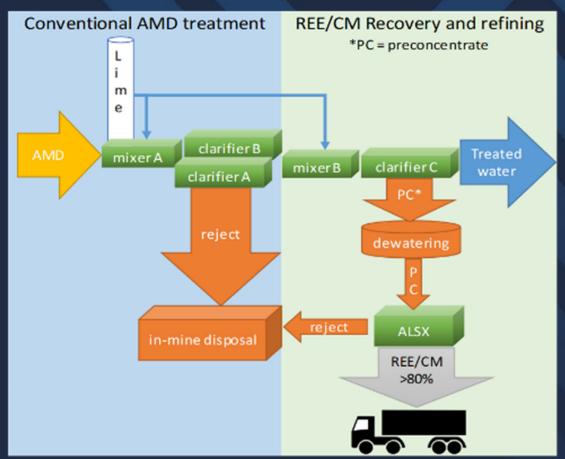
- 1. H₂SO₄ leaches REE from shale
- 2. REE co-precipitate with Al, Fe(OH

Monazite dissolution favors HREE



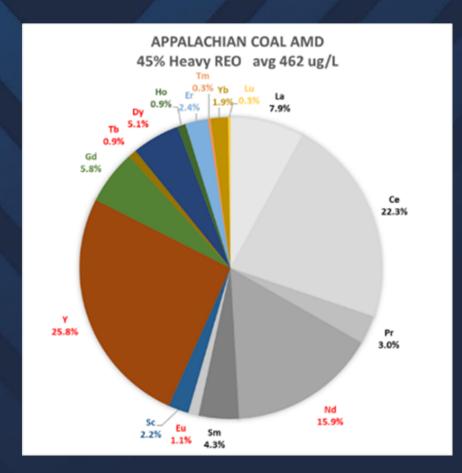
VIRGINIA TECH.

Integrated AMD treatment/REE/CM recovery



West Virginia University, west virginia water research institute

Consistent feedstock: average of 140 sites

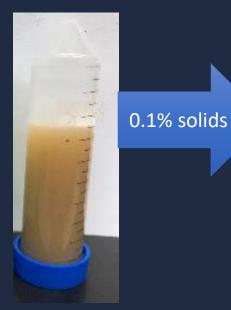




Process:

- 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

8.5 pH underflow



HPC: 0.5-5.0%



PLS TREE: 80-100 mg/L

Hi grade PLS





MREO TREE: 90-99%





A34: World's first AMD/REE pilot facility WVDEP Mt. Storm (DE FE0031834)

Inside the Lime Silo



Three clarifiers







@ pilot scale MREO Production ~12 hrs/kg



1. Dewatered Preconcentrate

2. Leach, precipitate

3. Produce LREO and HREO



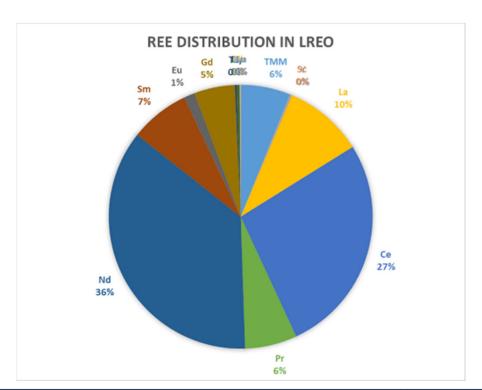


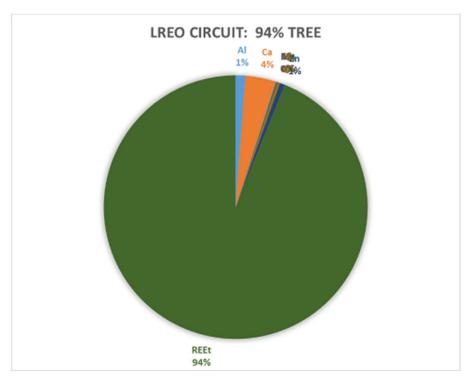


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Recent Results at REE Pilot Plant

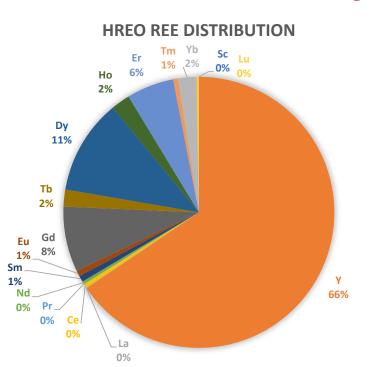
Light REO 94% grade

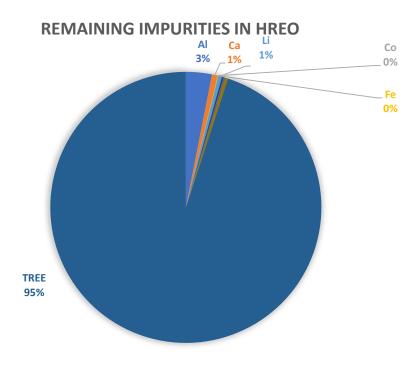






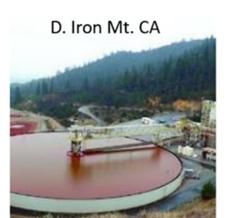
Recent Results at REE Pilot Plant Heavy REO 95% grade







Conceptual supply chain: Concentrates move to central processing facilities





3. D.



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



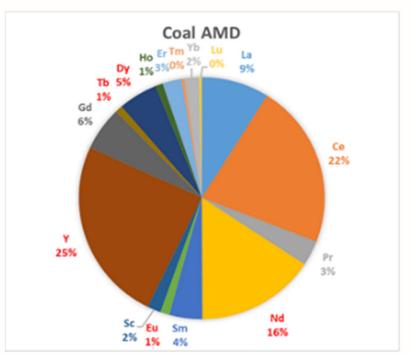


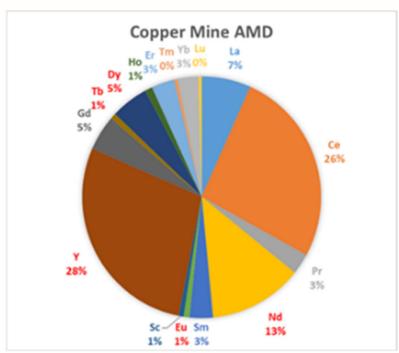






Coal and Copper mine AMD samples have nearly identical REE distributions







Project ETD99 USDOD IBAS-Copper Mine AMD:

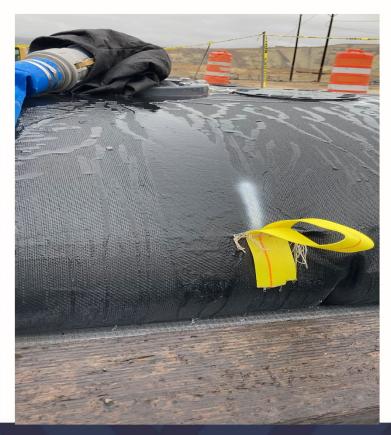
Converted a conventional HDS AMD plant to HPC production in a month.

30% solids in Geotubes within a week

Horseshoe Bend AMD Plant











Estimated MREO Production

Assumes 4 day/ 20 hours per day operation

Assumes:

- Plant is fully automated
- Plant is running at designed efficiency
- No downtime
- Two PLS trains
- Does not account for LREO and HREO separation
- 95% TREE Purity
- 4.68 kg MREO/day
- 1.71 t MREO/yr

Production at A34:

- 7.5 kg MREO
- 1 kg MREO/12 hrs
- 40% LREO
- 60% HREO



Mixed Rare Earth Oxide @95% grade Estimated yield from the A34 REE Pilot Plant

2	kg/12 hrs
4160	hrs/yr @ 80 hrs/wk
2	yrs
1387	kg MREO
555	kg LREO
832	kg HREO
	4160 2 1387 555

To Central refinery for ISHP





Maximum Production

Assumes 24/7/365 Operation

Solvent extraction via BSX vs. mixer-settlers

Estimated yields at 600 gpm:

HPC:

- 729 dry kg/day of HPC
- 266 dry t/yr of HPC @ 1.5% TREE

MREO

- 9.7 kg MREO/day at 90% purity assuming 80% recovery of TREE
- 3.6 t MREO/yr
- Plus roughly:
 - 7.2 t (Ni+Co)/yr in equal proportions
 - 36.0 t Mn/yr
 - <u>17.0 t Zn/yr</u>
 - 63.8 t/yr REE/CM oxide basis





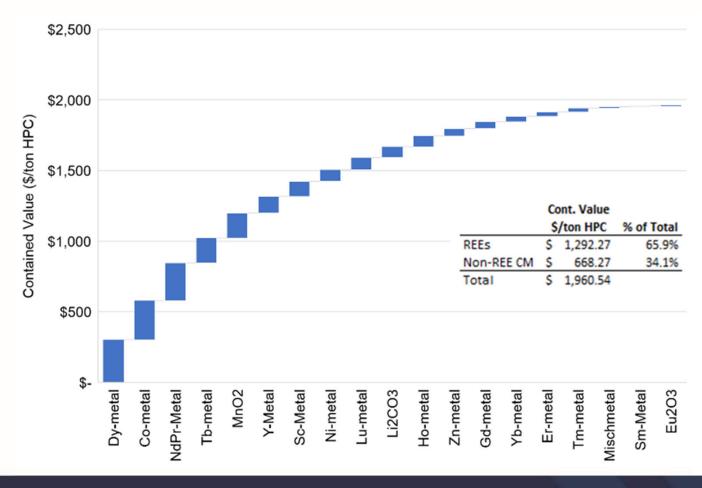


Techno-Economic Assessment Aaron Noble





Preconcentrate: ^Contained Value: \$1,960/t



	Avg Conc	% of	
	mg/kg	TREE	
Sc	32.3	0.3%	
Υ	2,908.4	30.7%	
La	629.8	6.6%	
Ce	1,572.2	16.6%	
Pr	302.8	3.2%	
Nd	1,592.2	16.8%	
Sm	459.4	4.8%	
Eu	115.0	1.2%	
Gd	688.6	7.3%	
Tb	95.6	1.0%	
Dy	521.9	5.5%	
Но	96.3	1.0%	
Er	250.4	2.6%	
Tm	30.3	0.3%	
Yb	166.6	1.8%	
Lu	24.6	0.3%	
TREE	9,486.4		

Non-REE CM			
Co	4,765.9		
Ni	4,730.1		
Mn	56,124.3		
Li	2,865.0		
Zn	17,555.3		





Perspectives on sourcing REE/CM from AMD

Objectives

- Objective: conduct a feasibility study to assess the production of 1-3 tpd of REE/CM oxides and metals from an AMD-based feedstock
- Keys to the technical approach:
 - AMD is an abundant and accessible, though disperse, resource for REE/CM.
 - Valorization of AMD can incentivize treatment, particularly for abandoned mines. There are also other notable societal and environmental advantages.
 - Advanced process engineering is needed to integrate feedstock robustness.
 - Process modeling, techno-economic analysis, life cycle analysis, and economic impact analysis are all to be conducted to further quantify the benefits.





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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Abstract: In recent years, acid mine drainage (AMD) has emerged as a promising a source of rare earth elements (IEEEs) and other critical minerals (CMs) such as cobalt and manganese In this regard, AMD provides a natural heap leaching effect that extracts and concentrates HIII/CM from the host strata creating a partially enriched feedstock suitable 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 reas well as the associated exeromic assessment. To that end, this paper provides a fundamental oconomic assessment of REL/CM recovery from AMD using a network securcing strategy in addition to a robust, flexible feedstock separations and refining facility. The methodology of this paper follows that of a typical techno-economic analysis with capital and operating costs estimated using AACE Class IV (FEL-2) guidelines. To demonstrate the range of possible outcomes, four pricing marios were modeled including contemporary prices (September, 2021) as well as the mir and maximum prices over the last decade. In addition, five production scenarios were considered reflecting variations in the product state, ranging from full elemental separation to magnet REE and CM production only (i.e., Pr. Nd. Th. Dv. Y. Sc. Co. and Mn). The westlis of this analysis show that, with the exception of the minimum price scenario, all operational configurations have positive economic indicators with rates of return varying from 25% to 52% for the contemporary price scenario The optimal configuration was determined to be production of Co, Mn, and all RIIIs 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 rate of return, thus indicating apportunities 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; now earth elements; acid mine drainage; solvent extraction critical materials; cobalt; manganese

Over the last decade, critical minerals have become an increasingly important matter armse MEPI, Revi. Sericetand. of both technical and societal importance. While several US federal and international agencies (e.g., U.S. Departments of Energy, Commerce, Defense, USCS, the European Commission, the International Energy Agency, Geoscience Australia, etc.) have provided peecles 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 de-risk

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https://www.psdpi.com/journal/minerals



Techno-Economic Analysis

	Plant Configuration					
Revenues and Costs	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





Feasibility Study: Recovery of REE+Co+Mn yields the most favorable economics

Parameter	REE + Co + Mn no MM
REE Production (t/y)	289.8
Total Production (t/y)	6,099.80
Net Present Value _{10%} (\$ mil)	\$248.38
Rate of Return	34.70%
Discounted Payback Period	6.5





Current Partners

Private Sector

- Rockwell Automation
- Northrop Grumman
- Rivian
- Endress & Hauser
- Solmax
- L3 Process Development
- Terves
- Hela Novel Metals
- Montana Resources

Government

- WVDEP-OSR
- USDOE-FECM
- USDOD-IBAS
- USDI-OSMRE

Academic

- Virginia Tech-Mineral Processing
- Montana Tech-Geology



Questions?



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