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

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Industry: Tom Larochelle, L3 Process Development,
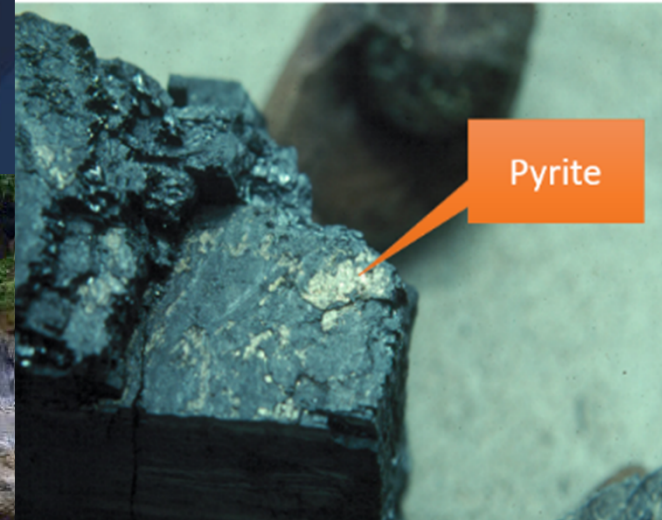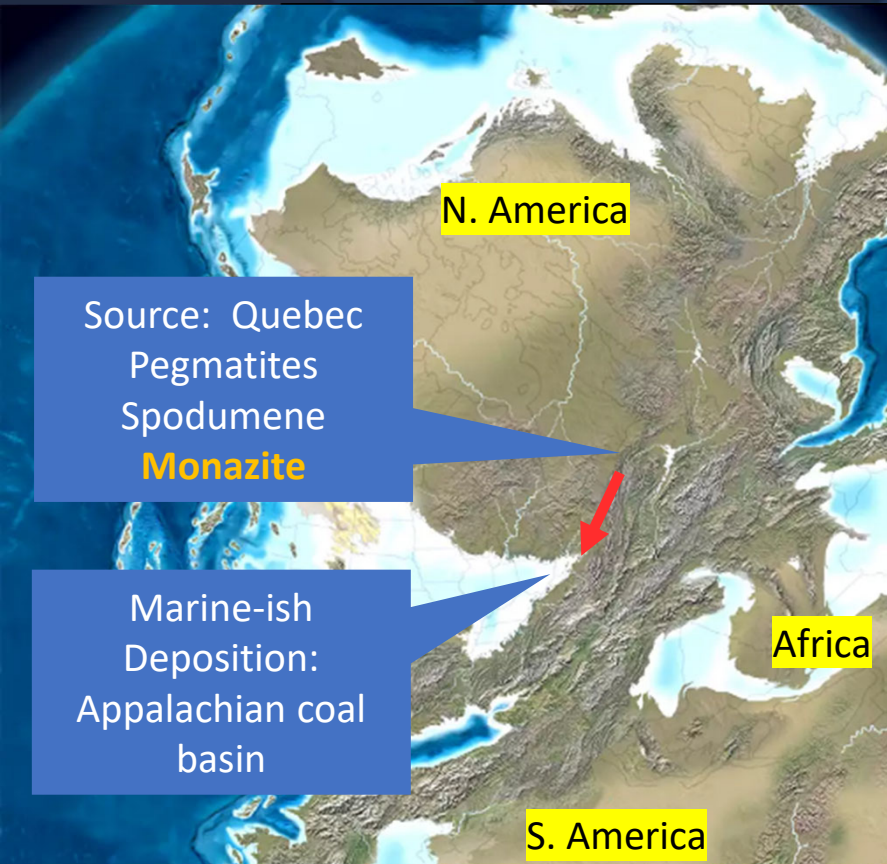**WVDEP:**   Rob Rice

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Background*, Late Pennsylvanian time
*Paul's unified field theory: Free acid drives REE recovery

N. America

Source: Quebec Pegmatites Spodumene **Monazite**

Marine-ish Deposition: Appalachian coal basin

Africa

S. America

Acid Mine Drainage: AMD

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

1. H_2SO_4 leaches REE from shale
2. REE co-precipitate with Al, Fe(OH

Monazite dissolution favors HREE

Pyrite

cross-bedded sandstone

coal

interbedded shale & sandstone

cross-bedded sandstone

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Integrated AMD treatment/REE/CM recovery
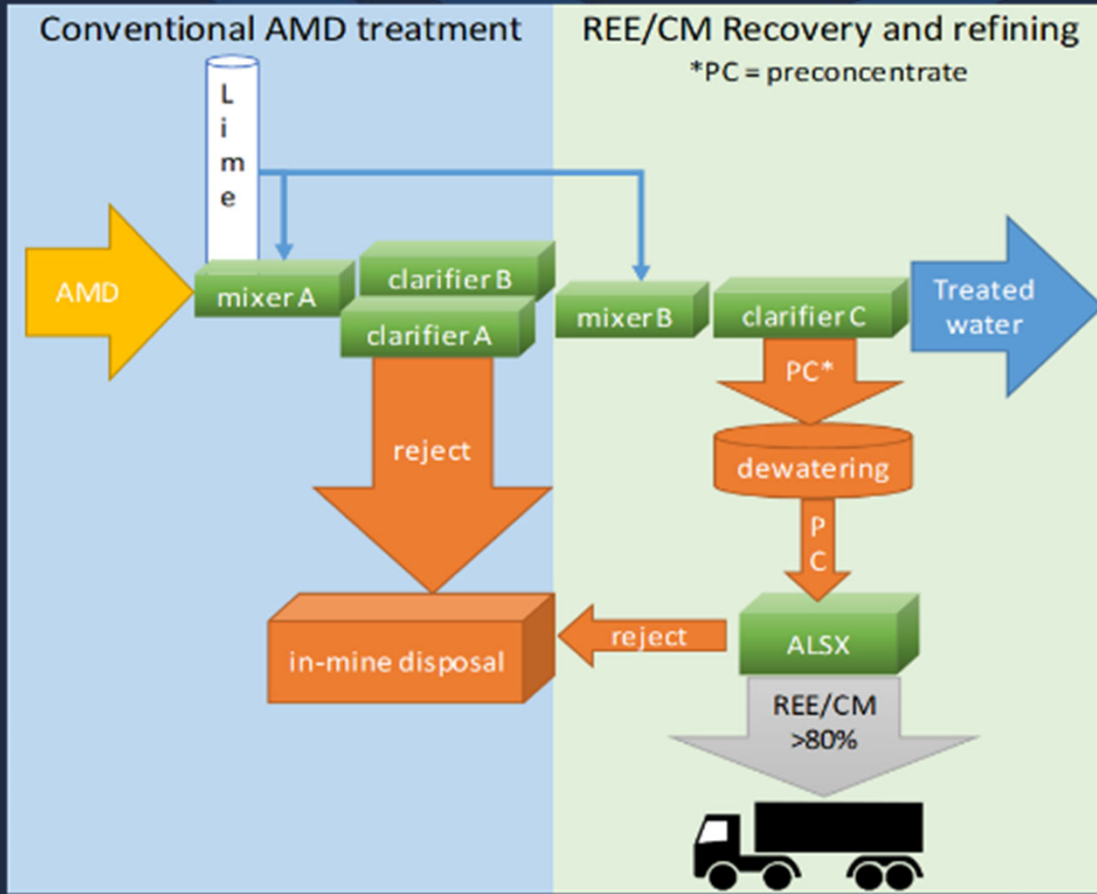
Consistent feedstock: average of 140 sites

Conventional AMD treatment | REE/CM Recovery and refining
*PC = preconcentrate

APPALACHIAN COAL AMD
45% Heavy REO   avg 462 ug/L
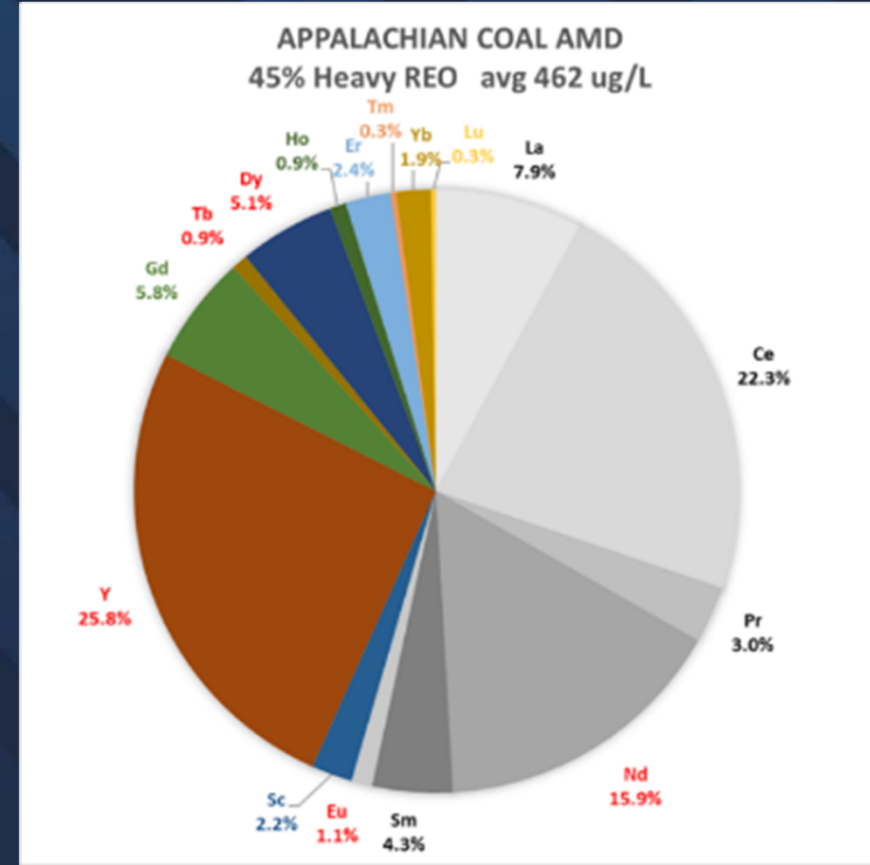
Process:

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%

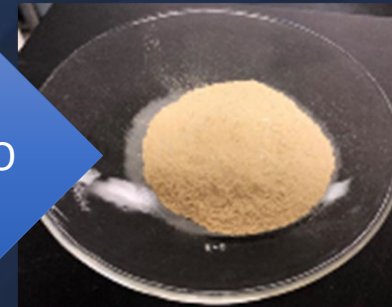PLS TREE: 80-100 mg/L

0.1% solids

Hi grade PLS

MREO

MREO TREE: 90-99%

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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

95% LREO   95% HREO

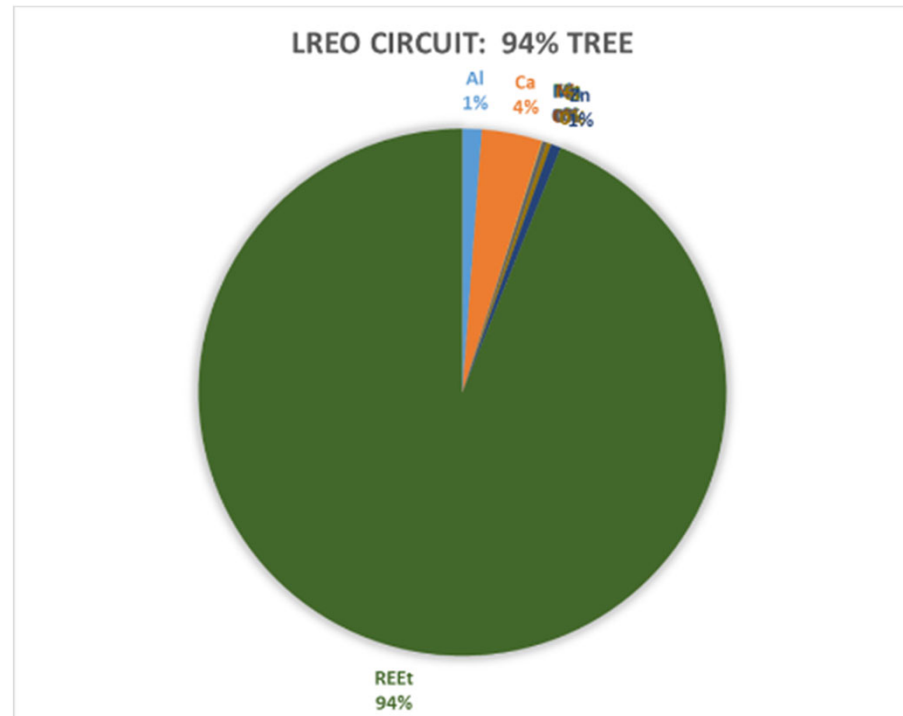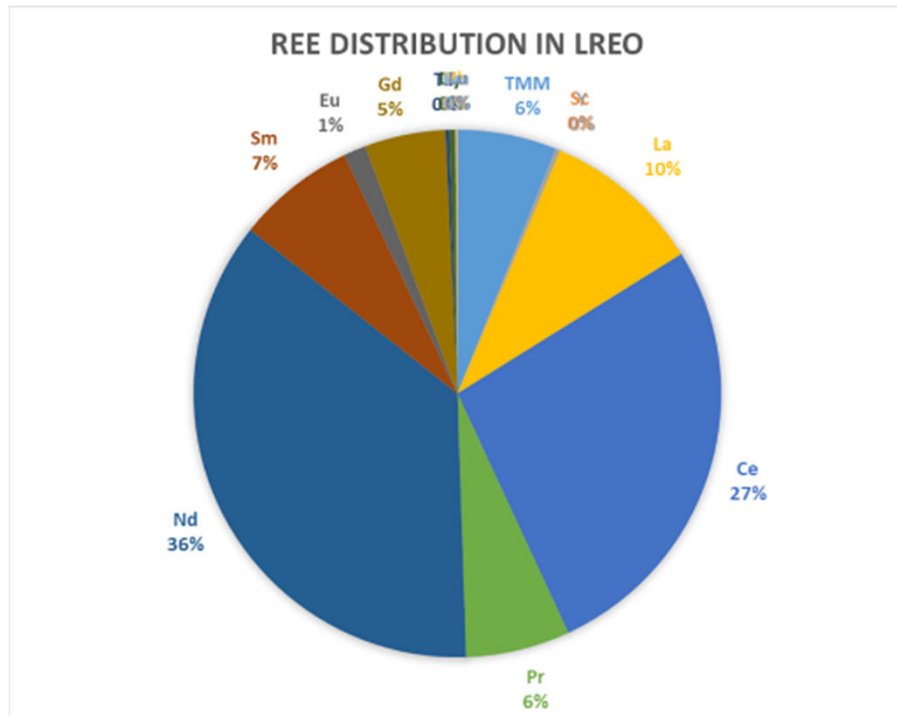1. Dewatered Preconcentrate

2. Leach, precipitate

3. Produce LREO and HREO

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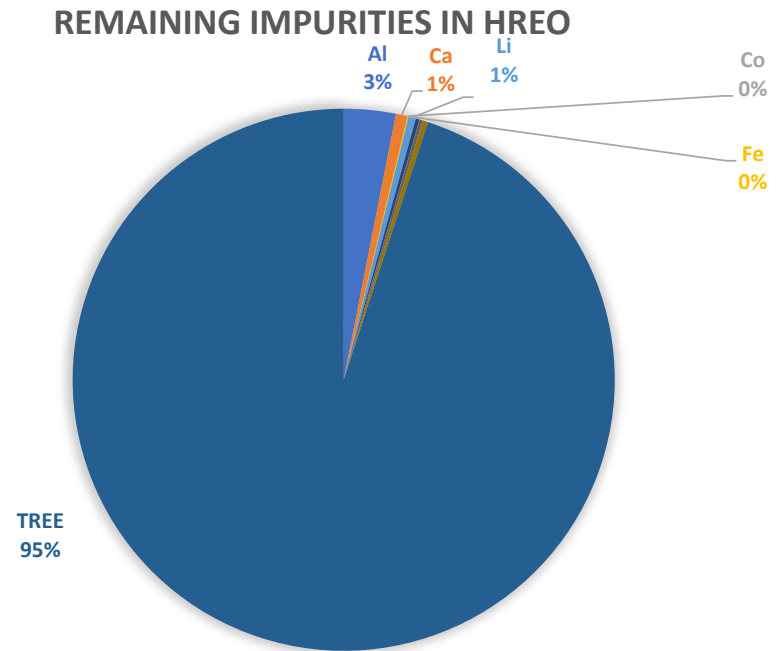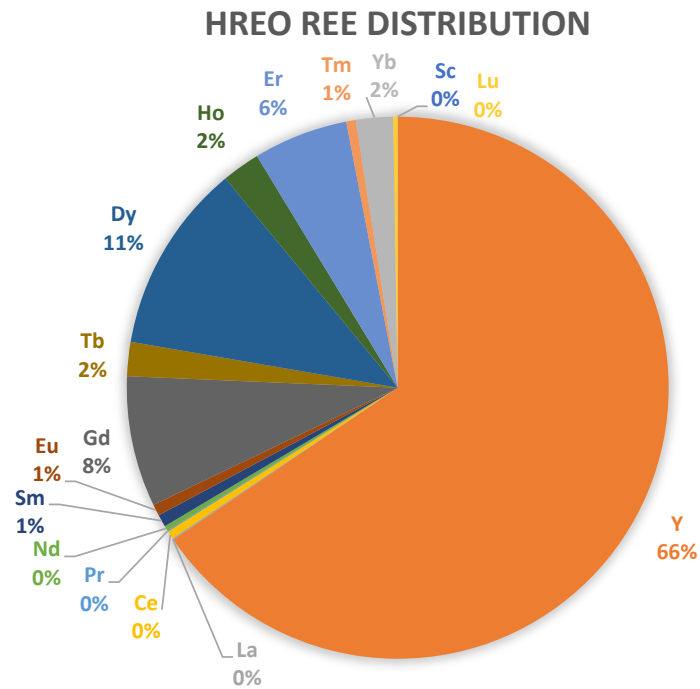WEST VIRGINIA
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Recent Results at REE Pilot Plant
Light REO 94% grade

Recent Results at REE Pilot Plant
Heavy REO 95% grade

HREO REE DISTRIBUTION

Ho 2%, Er 6%, Tm 1%, Yb 2%, Sc 0%, Lu 0%, Dy 11%, Tb 2%, Eu 1%, Gd 8%, Sm 1%, Nd 0%, Pr 0%, Ce 0%, La 0%, Y 66%

REMAINING IMPURITIES IN HREO

Al 3%, Ca 1%, Li 1%, Co 0%, Fe 0%, TREE 95%

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

Coal and Copper mine AMD samples have nearly identical REE distributions
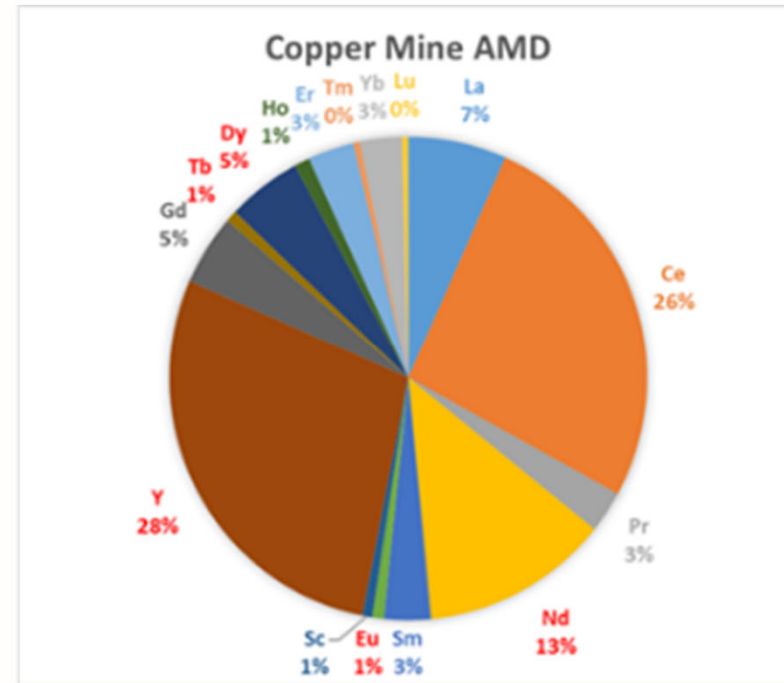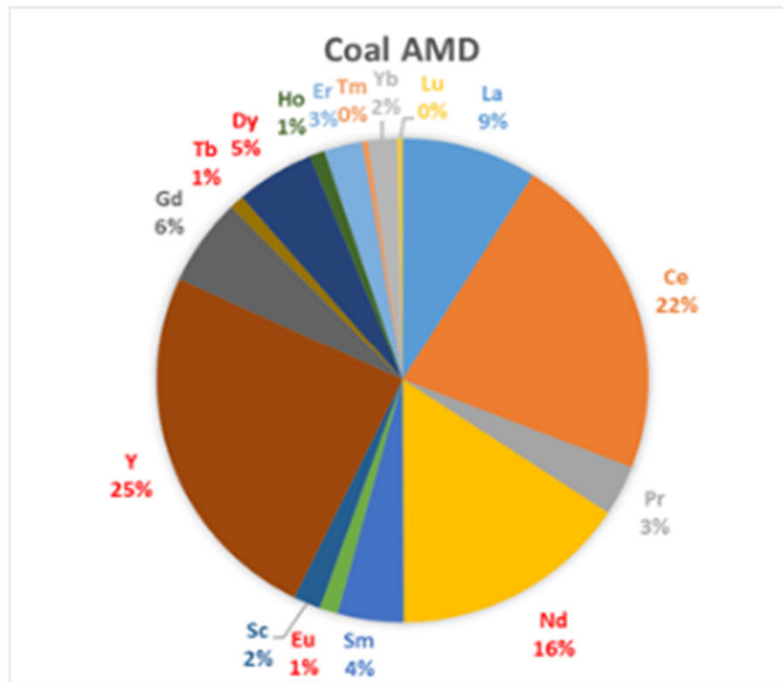
Project ETD99 USDOD IBAS-Copper Mine AMD:
Converted a conventional HDS AMD plant to HPC production in a <u>month.</u>
<u>30% solids in Geotubes within a week</u>

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

Production rate	2	kg/12 hrs
Operating hours	4160	hrs/yr @ 80 hrs/wk
Term	2	yrs
^Yield	1387	kg MREO
	555	kg LREO
	832	kg HREO

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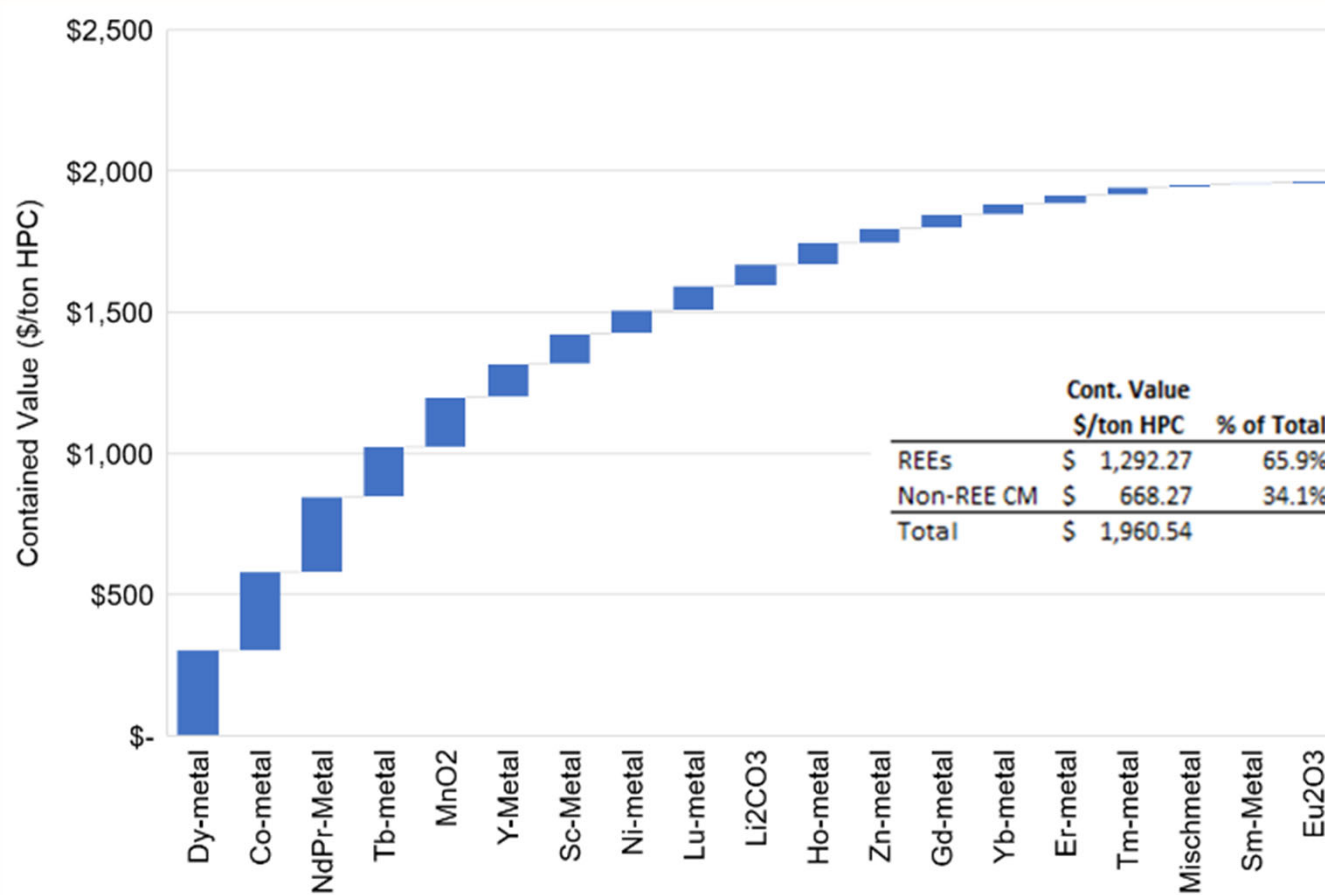- 266 dry t/yr of HPC @ 1.5% TREE

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
  - 17.0 t Zn/yr
  - 63.8 t/yr REE/CM oxide basis

BSX

HPC

Techno-Economic Assessment

Aaron Noble

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

	Avg Conc mg/kg	% of TREE
Sc	32.3	0.3%
Y	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%
Ho	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

	Cont. Value $/ton HPC	% of Total
REEs	$ 1,292.27	65.9%
Non-REE CM	$ 668.27	34.1%
Total	$ 1,960.54	

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.

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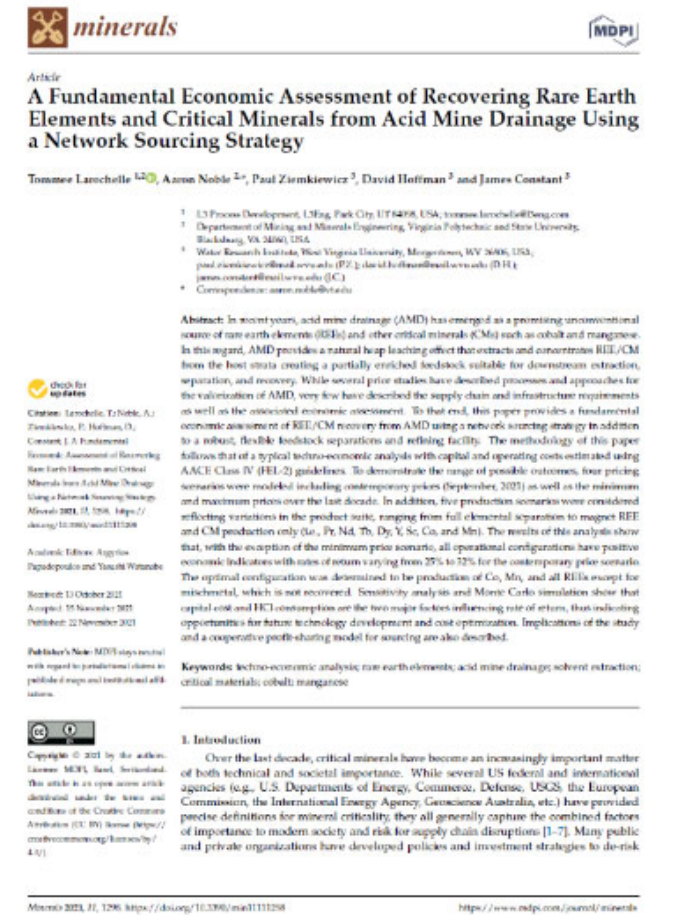
Techno-Economic Analysis

Revenues and Costs	Plant Configuration					
	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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95% LREO   95% HREO

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