Current Project: Integrated Acid Mine Drainage treatment and REE/CM extraction plant *USDOE Project DE FE00 31834*

Project Leadership:

West Virginia University
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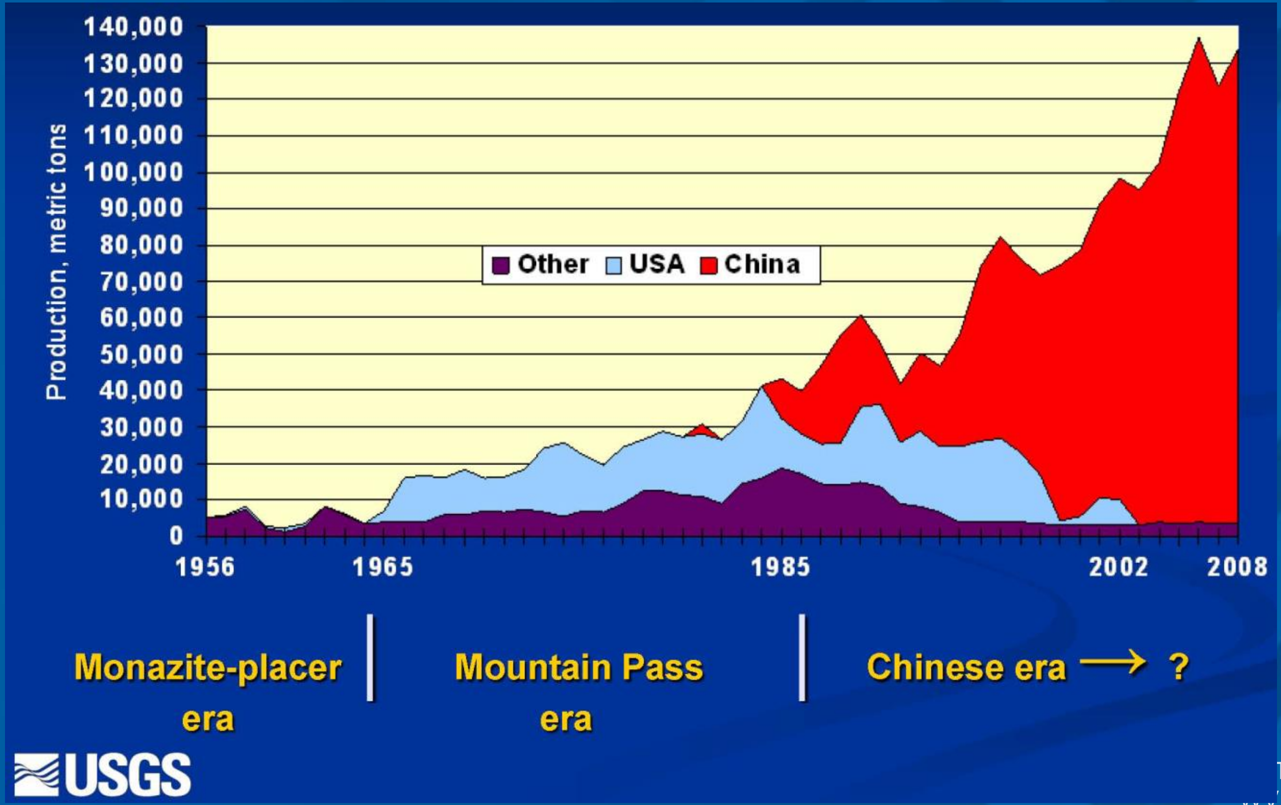
Virginia Tech
Aaron Noble

State:
WVDEP-Office of Special Reclamation

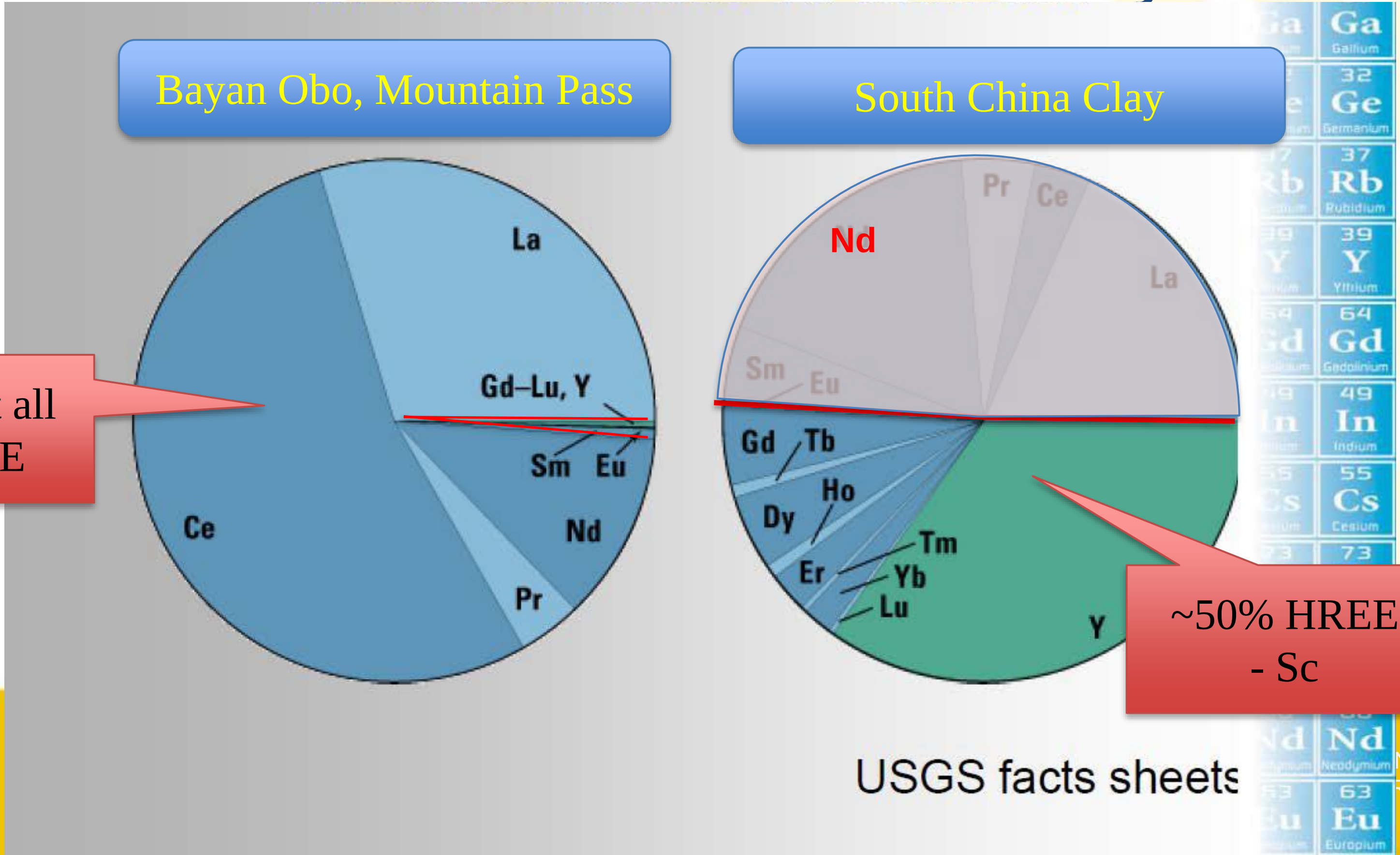
Industry:
Rockwell Automation
TenCate Corporation
L3 Eng

Our strategic disadvantage: China controls exports ~ 35kt/yr



Distribution of HREE in AMD sludge is similar to south China clays

almost all LREE



~50% HREE
- Sc

Projected REE demand through 2025 (tons/year)

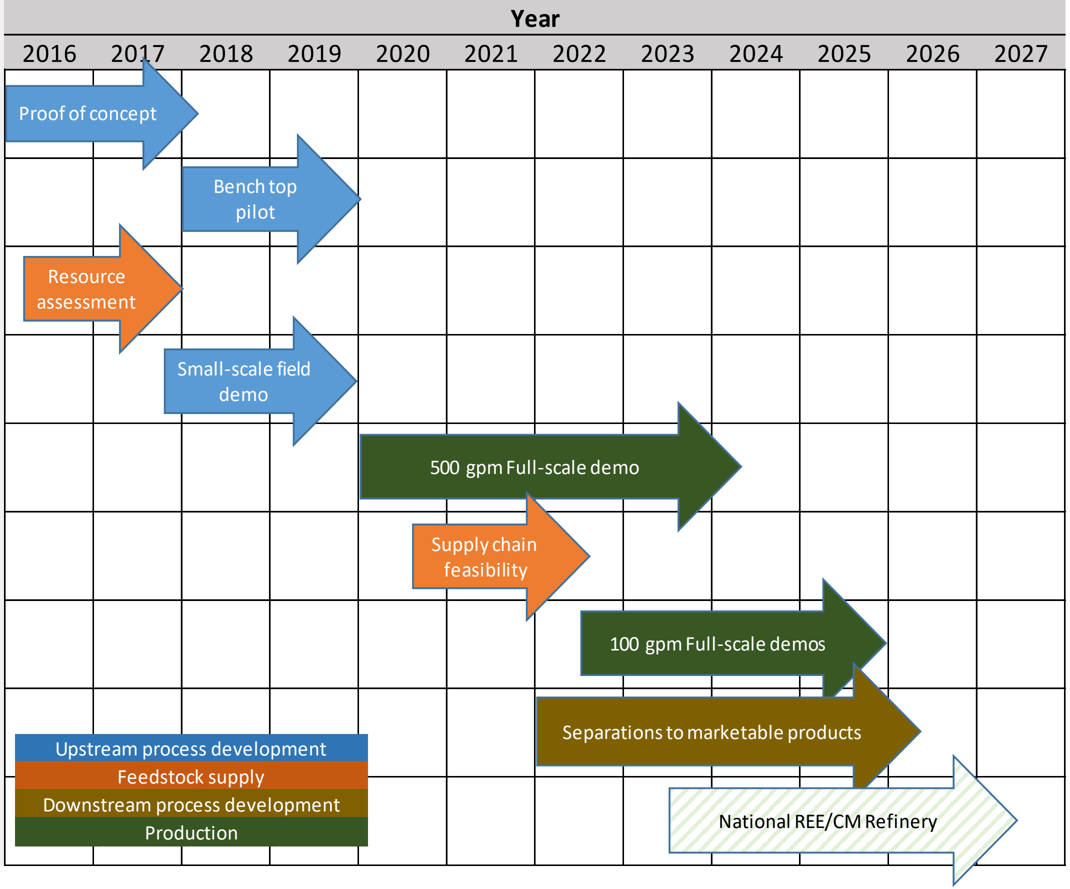
	Global demand @ 7% ann. Growth	USA demand total*	USA demand defense**
2017	158,403	15,840	792
2018	169,845	16,984	849
2019	182,176	18,218	911
2020	195,469	19,547	977
2021	209,804	20,980	1,049
2022	225,265	22,527	1,126
2023	241,947	24,195	1,210
2024	259,951	25,995	1,300
2025	279,387	27,939	1,397

* 10% global

** 5% USA demand

This assumes that USA manufacturing demand does not increase beyond current rates

Water Research Institute: Recovering REE/CM from Acid Mine Drainage Technology Development Strategy



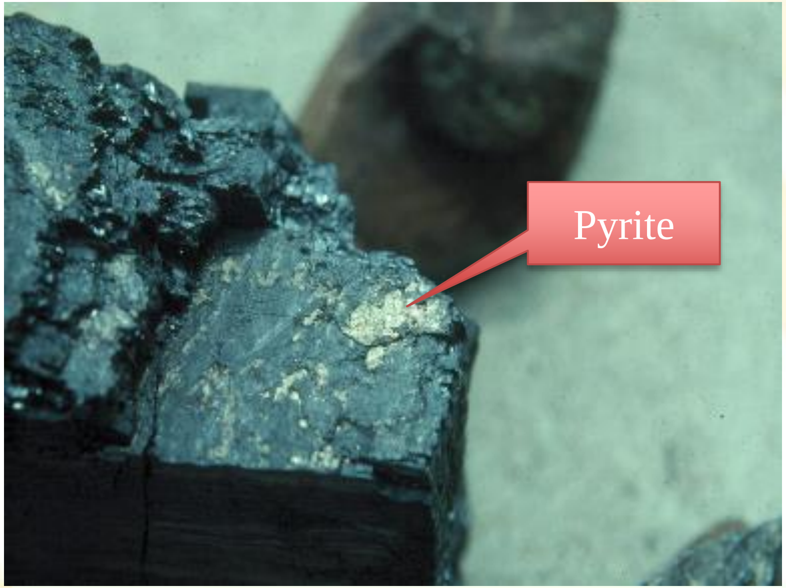
WVU Project #	Funding Support: Federal	Non-Federal	Total
ETD30	$ 749,994	$ 200,540	**$ 950,534**
ETD50	$ 2,661,878	$ 727,000	**$ 3,388,878**
ETD39	$ 400,000		**$ 400,000**
ETD53	$ 644,060	$ 205,606	**$ 849,666**
ETD67	$ 4,998,954	$ 1,887,250	**$ 6,886,204**
ETD84	$ 2,132,429		**$ 2,132,429**
ETD85	$ 131,410	$ 360,000	**$ 491,410**
ETD95	$ 199,997	$ 50,000	**$ 249,997**
ETD112	FOA Expected in late 2022		
	$ 11,918,722	$ 3,430,396	**$ 15,349,118**

Acid Mine Drainage: AMD

1. H_2SO_4 leaches REE from shale
2. REE precipitate with $Fe(OH)_3$

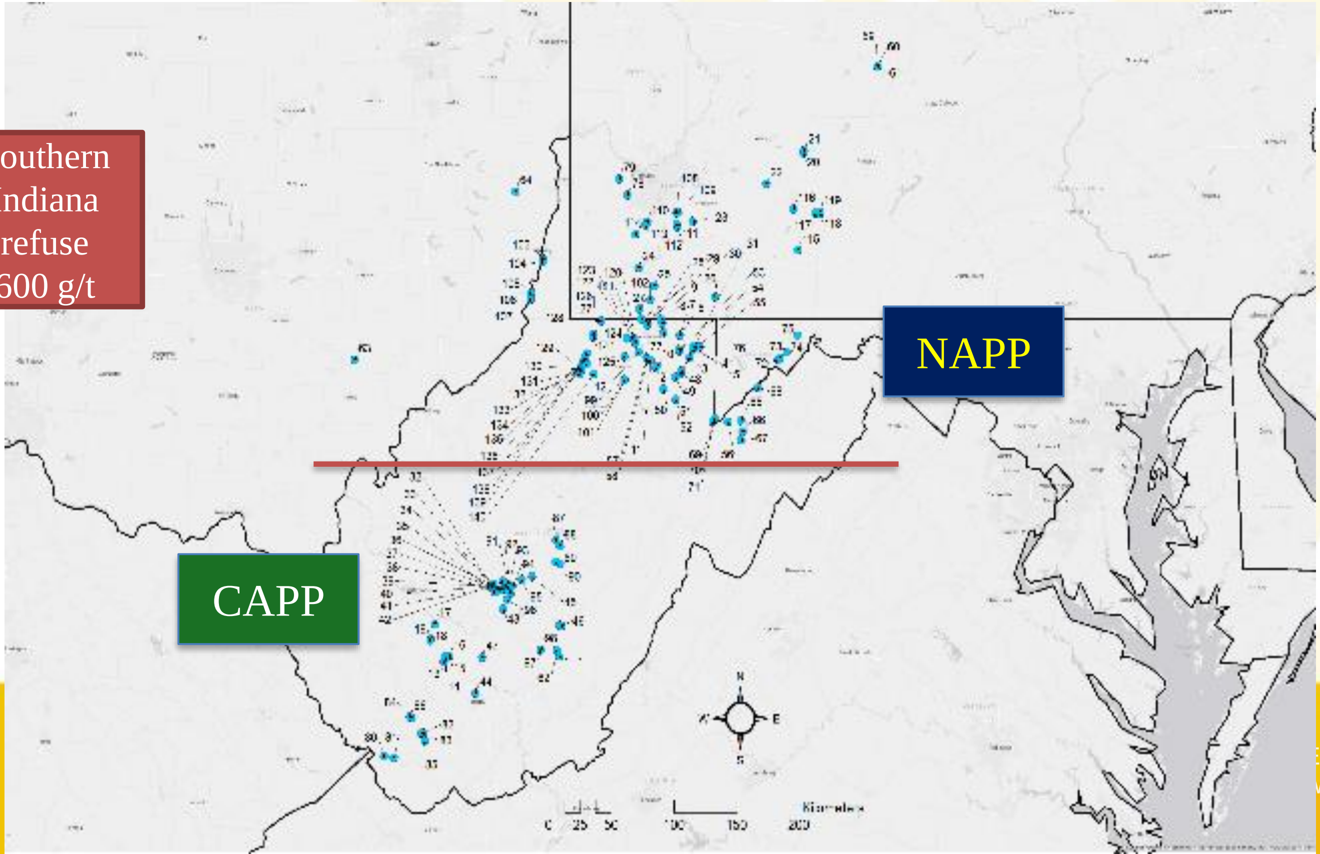
$Fe^{2+} + O_2 + OH^- = Fe(OH)_3$

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



140 SAMPLED LOCATIONS: MD, OH, PA, WV

Southern Indiana refuse 600 g/t



REE in NAPP vs. CAPP whole coal. Physical separation can increase REE concentrations to about 500-600 g/t

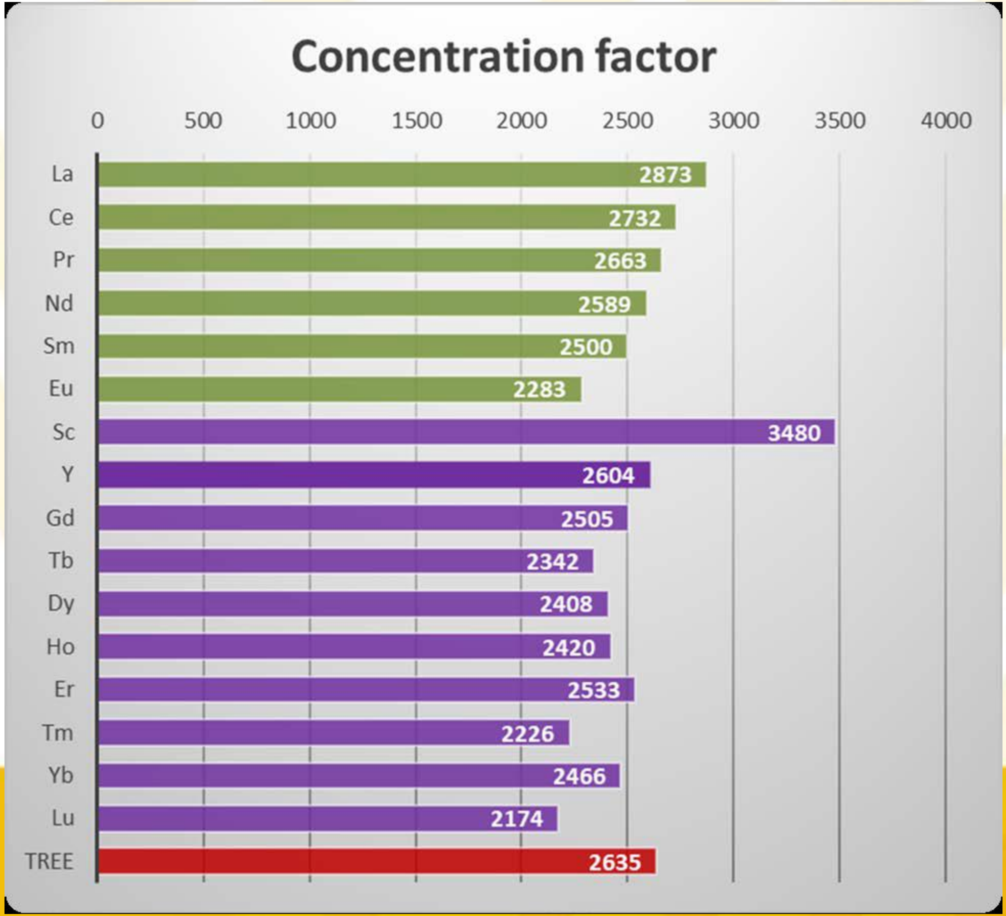
Pittsburgh Seam	
mg TREE/kg	
max	146.3
mean	34.6
min	7.3
st. dev.	22.0

NAPP

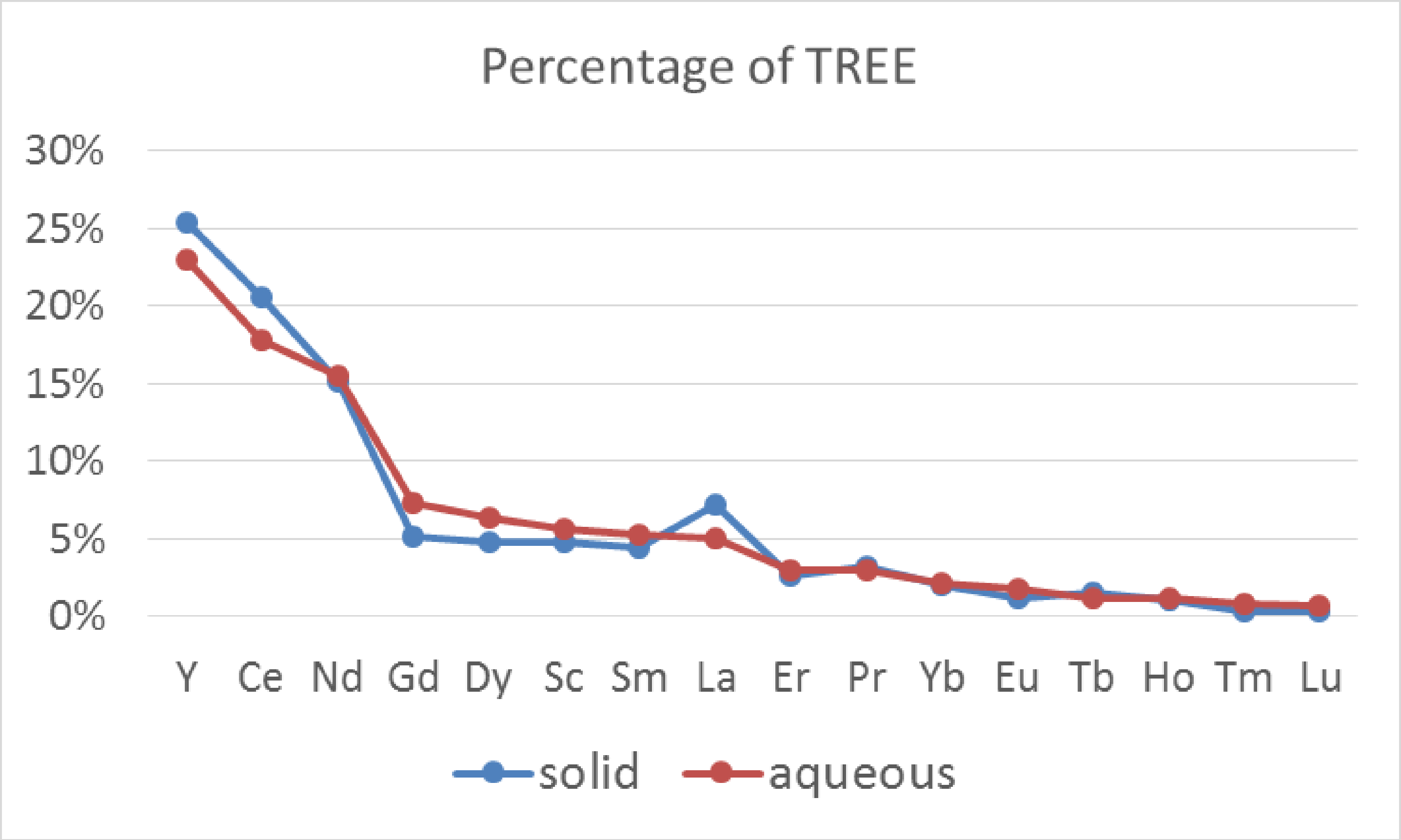
Eagle Seam	
mg TREE/kg	
max	225.7
mean	49.5
min	9.3
st. dev.	42.2

CAPP

AMD treatment concentrates REE in sludge to about 700 g/t



All REEs precipitate to AMD sludge nearly equally



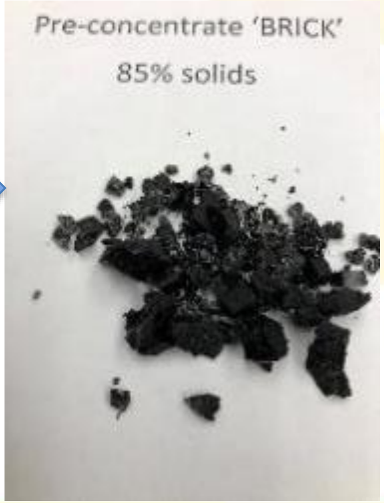
Process:

1. Generate pre-concentrate (brown floc)
2. GeoTubes passively dewater to 40-85% solids
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%



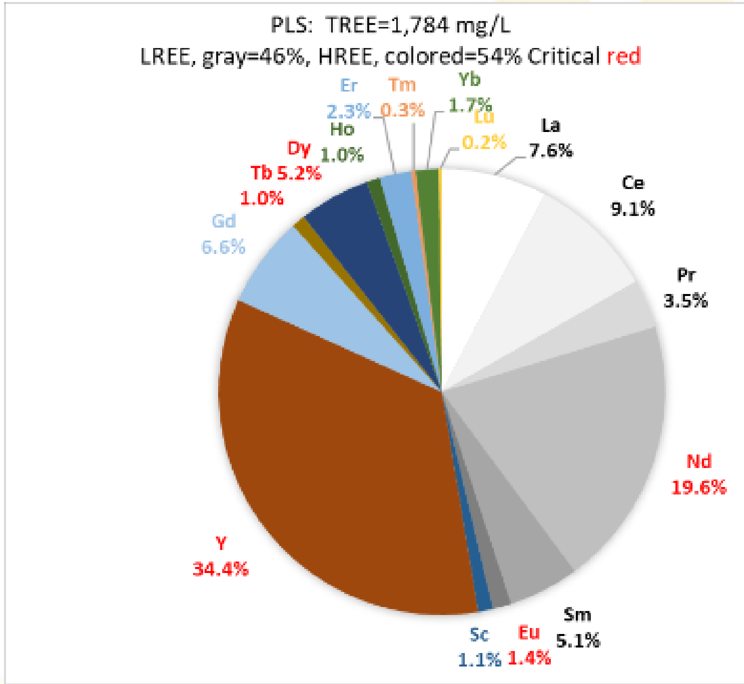
Hi grade PLS

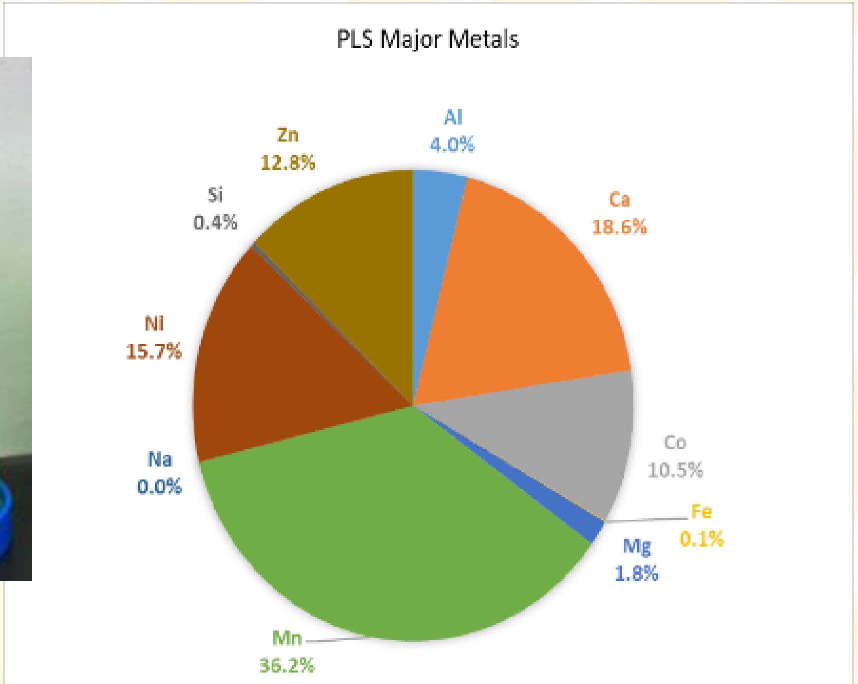
PLS TREE: 100-1,800 mg/L

MREO

MREO TREE:
90-99%

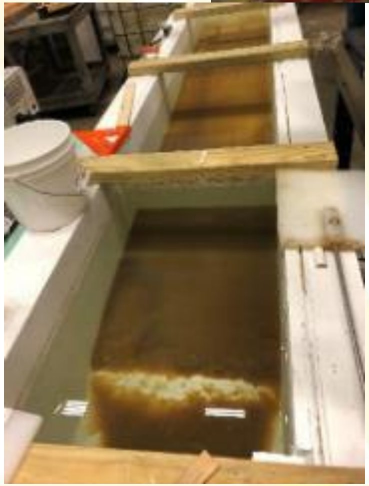
Recent PLS production: 1,784 mg TREE/L, 54% HREE almost no Al, Si



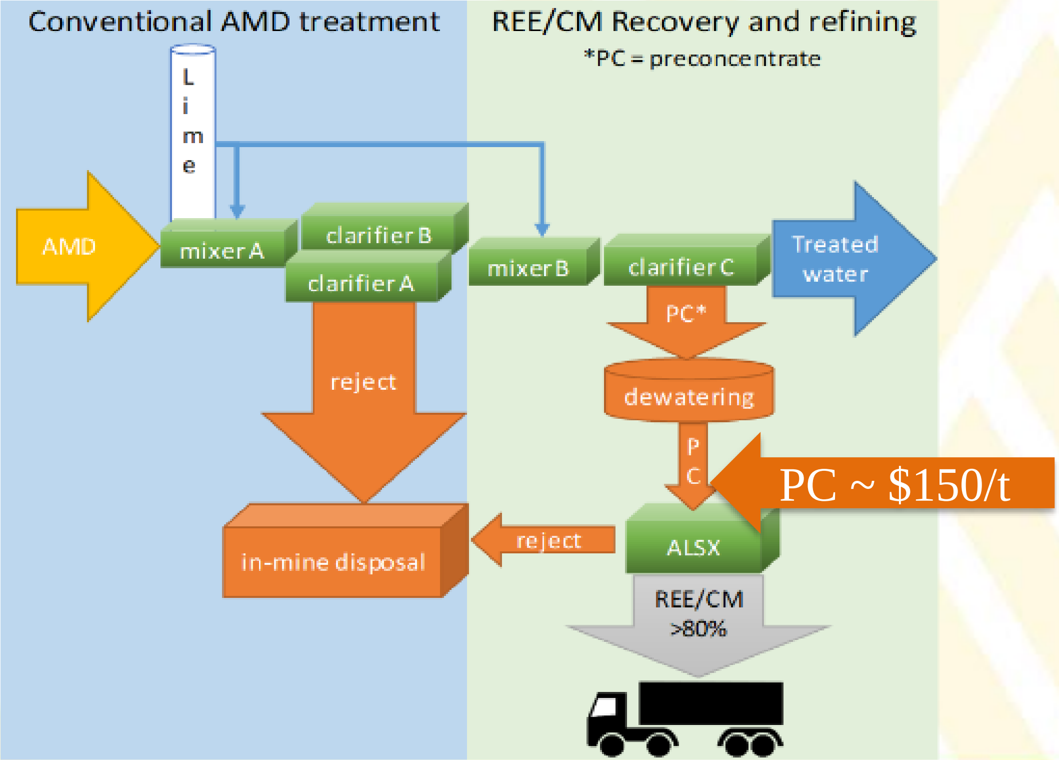


Project ETD67: Mt. Storm Pilot Plant

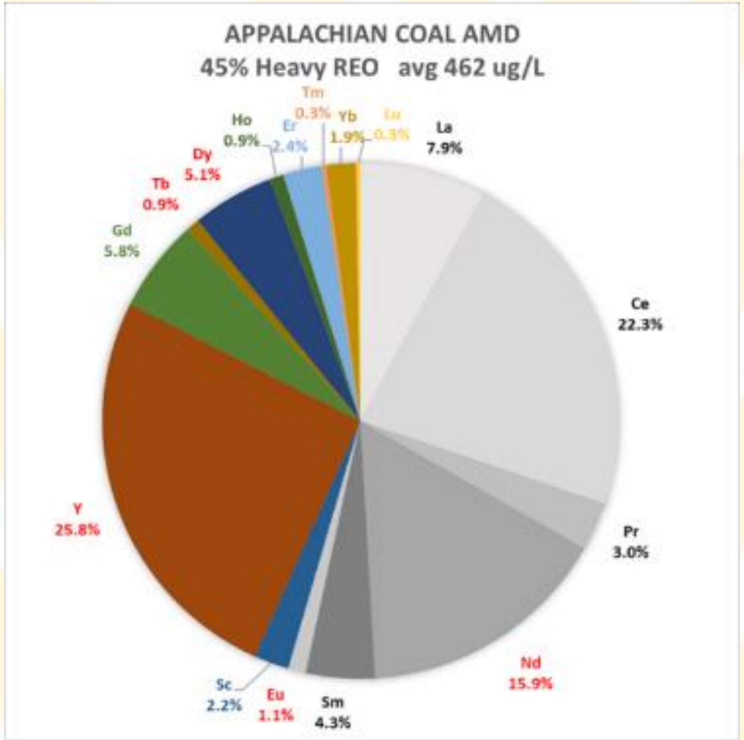
AMD treatment: Up to 1,000 gpm,
Production rate ~ 1 tpy each: REE, Cobalt, Nickel
Much more: Manganese, Lithium, Zinc



Integrated AMD treatment/REE/CM recovery



Consistent feedstock: average of 140 sites



A34 components

Inside the Lime Silo

Three clarifiers

Downstream Processing

Solvent Extraction

Raffinate Storage

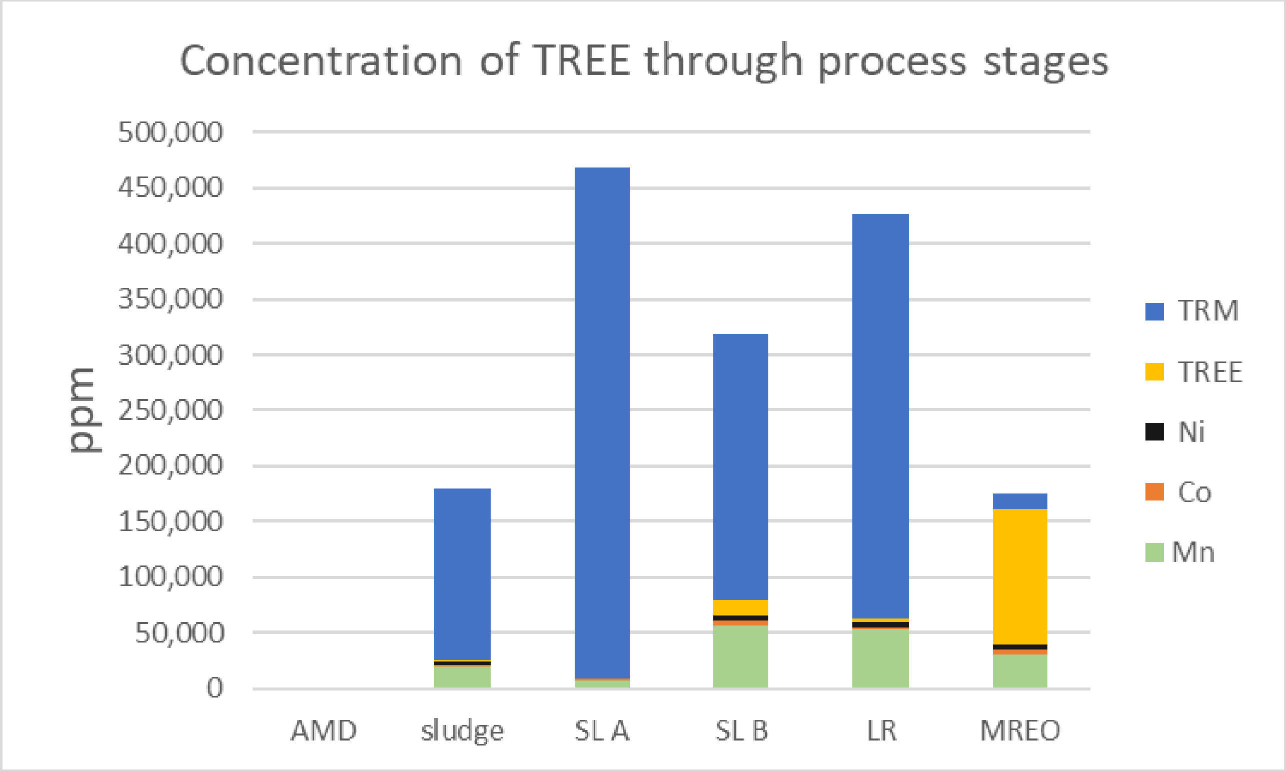
First Batch of Preconcentrate leaving A34

28 Sept 2022

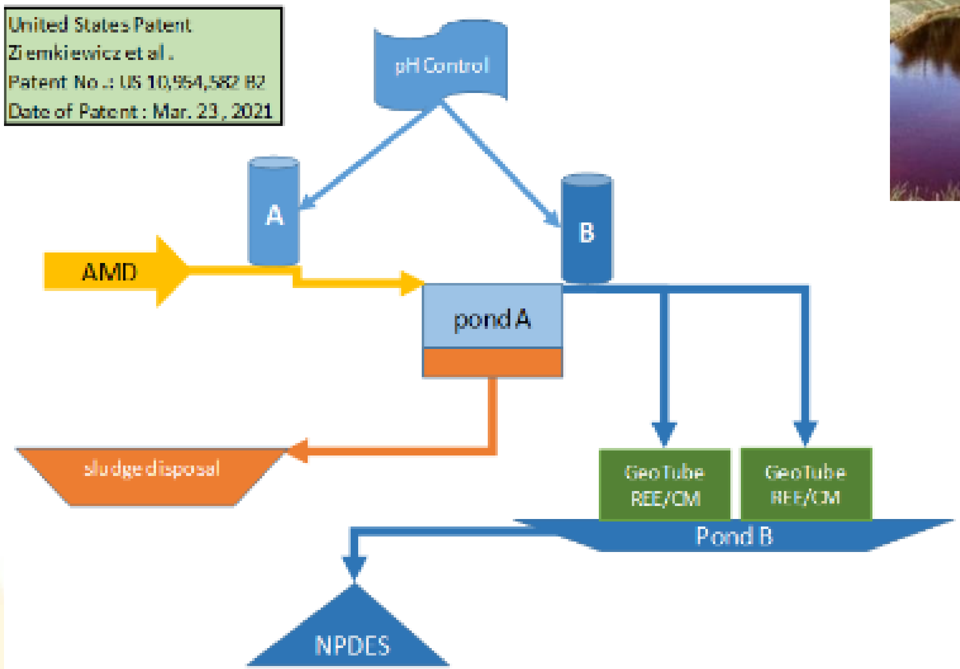
Our process increases the REE/CM grade from AMD to Product

	AMD	SL pond	SL A	SL B	LR	MREO
Concentration (ppm)						
Mn	24	19,236	7,879	56,834	53,327	30,314
Co	1	1,957	92	4,825	2,406	4,227
Ni	1	2,196	200	4,782	3,306	5,635
TREE	1	2,727	352	12,941	3,964	120,678
TRM	184	154,022	458,818	239,684	363,281	13,782
Enrichment factors (% increase)						
Mn	1	787	322	2,325	2,182	1,240
Co	1	2,419	114	5,964	2,975	5,225
Ni	1	2,381	217	5,185	3,584	6,110
TREE	1	2,343	302	11,116	3,405	103,665
TRM	1	837	2,494	1,303	1,975	75

Rejection of gangue
Ni, Co report to other circuits for recovery



AMD Treatment with REE/CM recovery

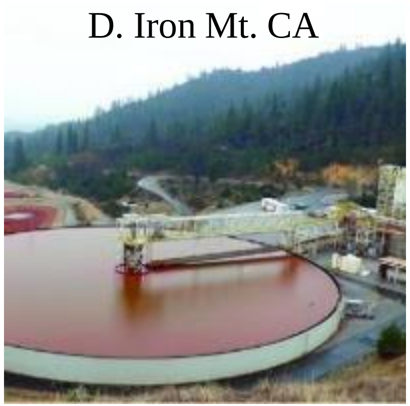


CENTRAL REFINERY CONFIGURATION, PRODUCT LINE, AND TECHNICAL FEASIBILITY

Class 4 Feasibility Study for USDOE

WEST VIRGINIA UNIVERSITY
WV Water Research Institute

Conceptual supply chain: Concentrates move to central processing facilities



Potential source districts

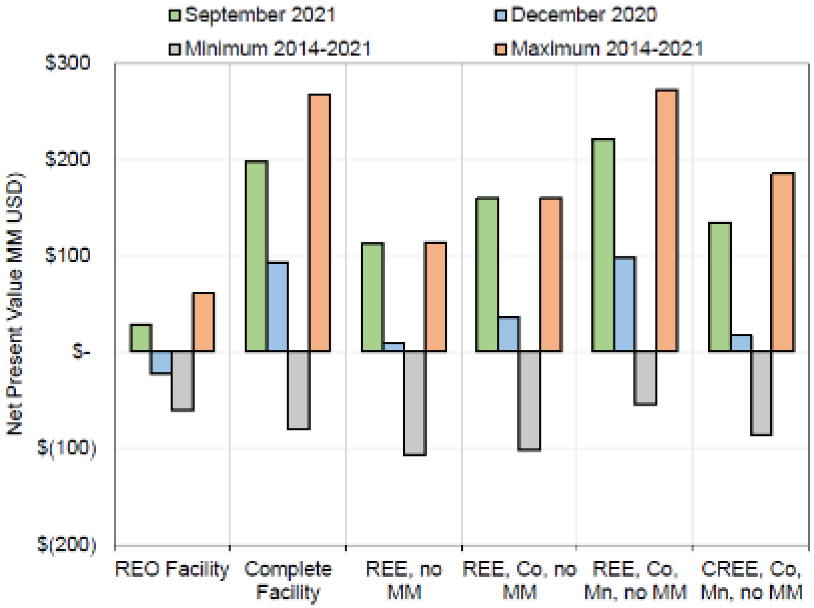
A: Northern/Central APP
B: Southern APP/Illinois basin
C: Southern Rockies metal belt
D: Sierra metal belt
E: Northern Rockies metal belt
F: Minnesota iron range

Estimated REE/CM yields: USDOE requirements 1-3 tpd, >50% coal based

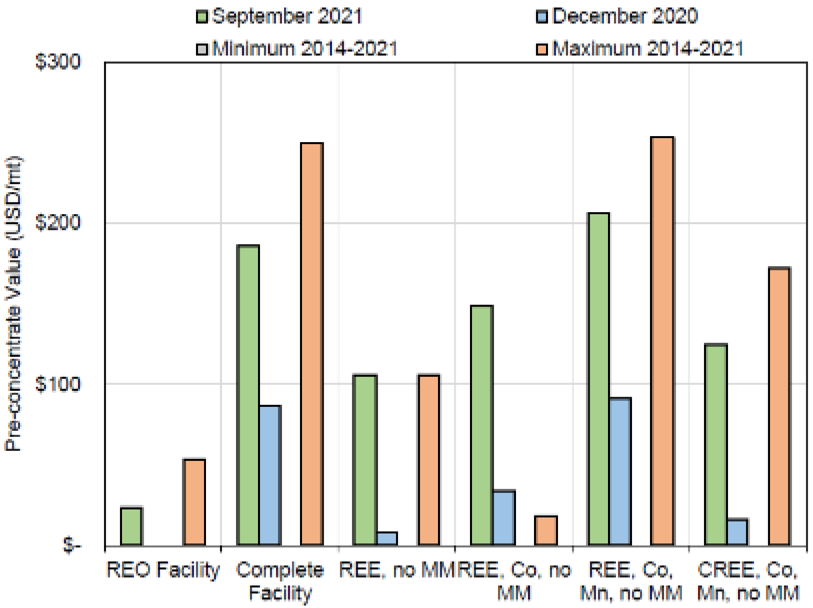
Estimated Yield	n	Source	Oxide TREE t/yr	Oxide Co t/yr	Oxide Mn[2] t/yr	REE+Co t/yr	REE+Co+Mn t/yr
measured	112	WVU samples 2017	17.8	20.3	180.0	38.1	218.1
measured	51	WVU samples 2021	36.0	40.0	417.9	75.9	493.8
measured	28	USGS PA[4]	10.8	26.4	257.5	37.2	294.7
	191	Measured coal AMD	64.6	86.6	855.4	151.2	1006.6
Inferred [1,3]	132	TN, KY, WV, OH, PA, MD	72.4	81.6	857.3	154.0	1011.3
	323	Total Coal	137.0	168.2	1712.7	305.2	2018.0
	6	Measured Hard Rock	167.2	114.0	1644.6	281.3	1925.9
Total yield	329	Coal + Hard Rock	304.2	282.3	3357.4	586.5	3943.9
		Coal/Hard rock	0.82	1.48	1.04	1.09	1.05

Scenario Analysis Results

Net Present Value



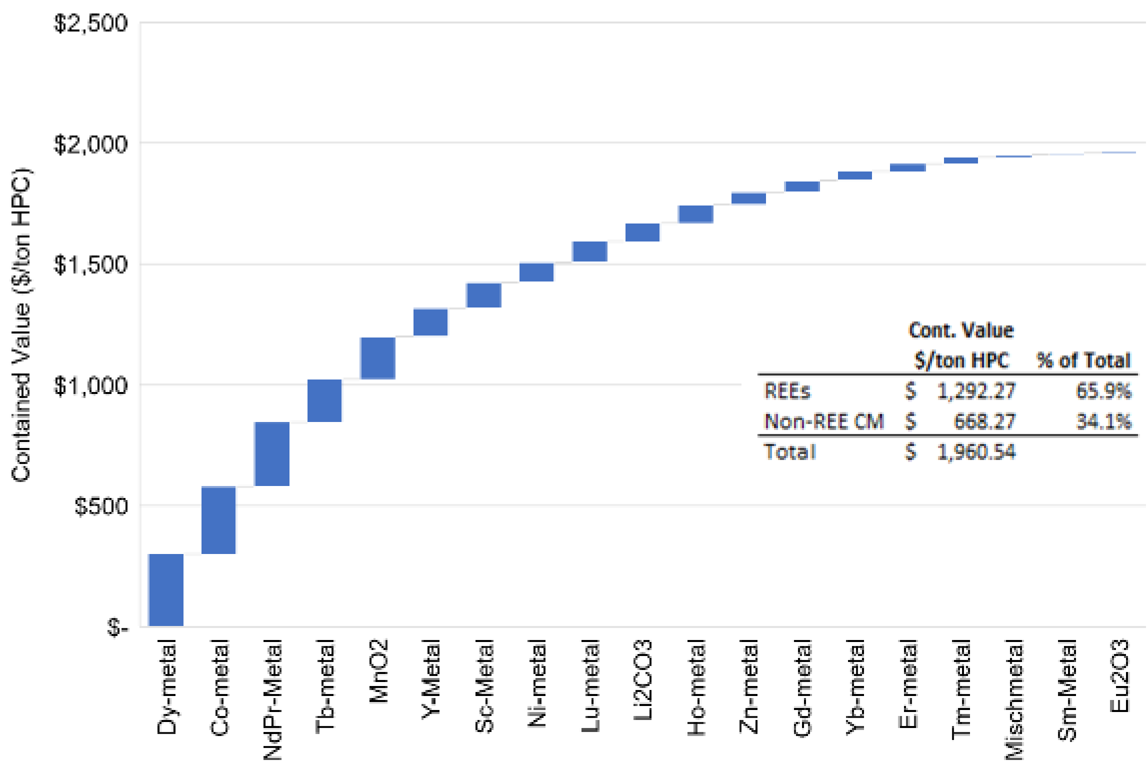
PC Value at 10% ROR



Recovery of REE+Co+Mn without mischmetal 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

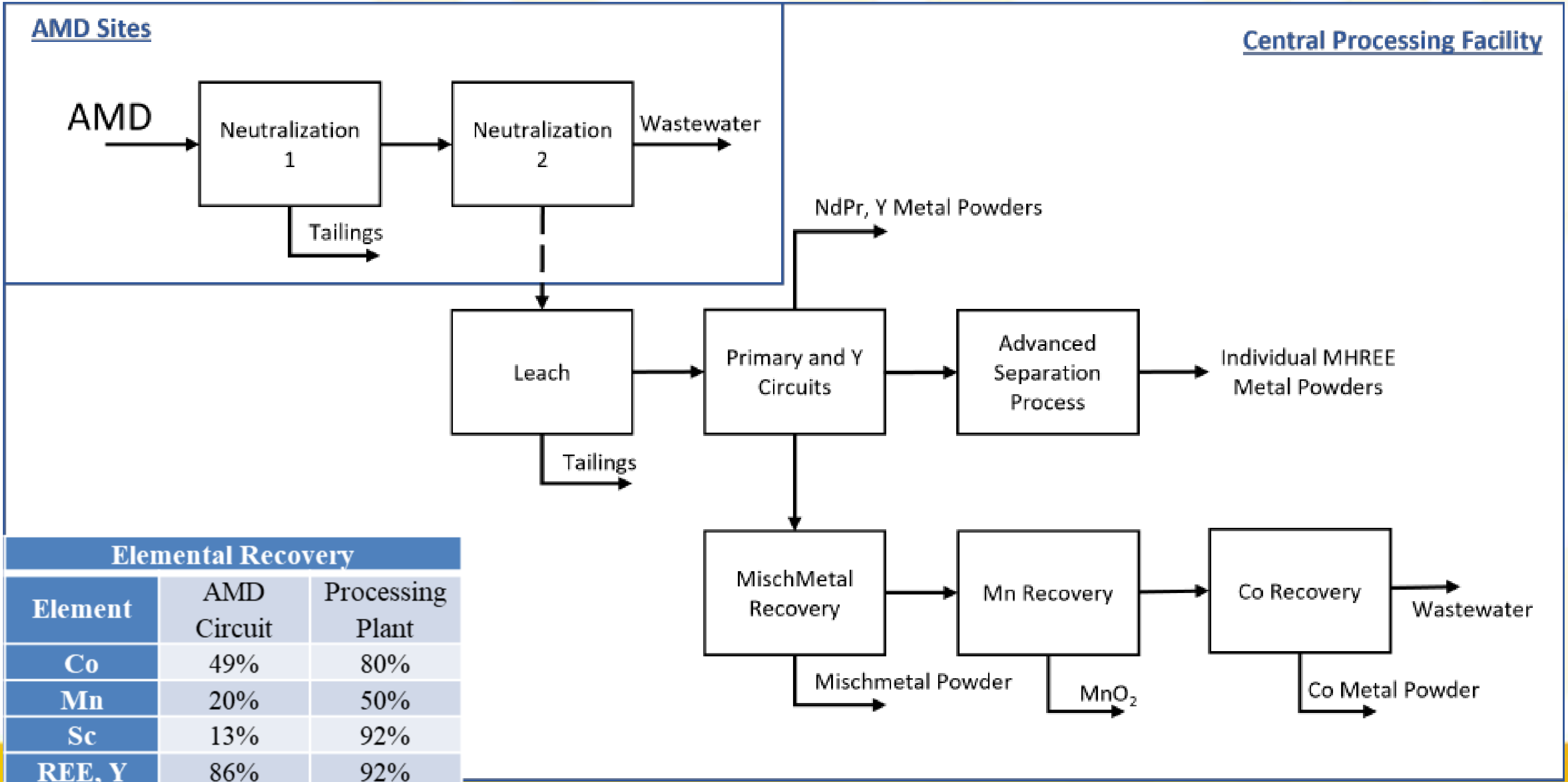
Preconcentrate: Contained Value $1,960



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

	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	

Process: At source recovery to metal refining



Elemental Recovery		
Element	AMD Circuit	Processing Plant
Co	49%	80%
Mn	20%	50%
Sc	13%	92%
REE, Y	86%	92%

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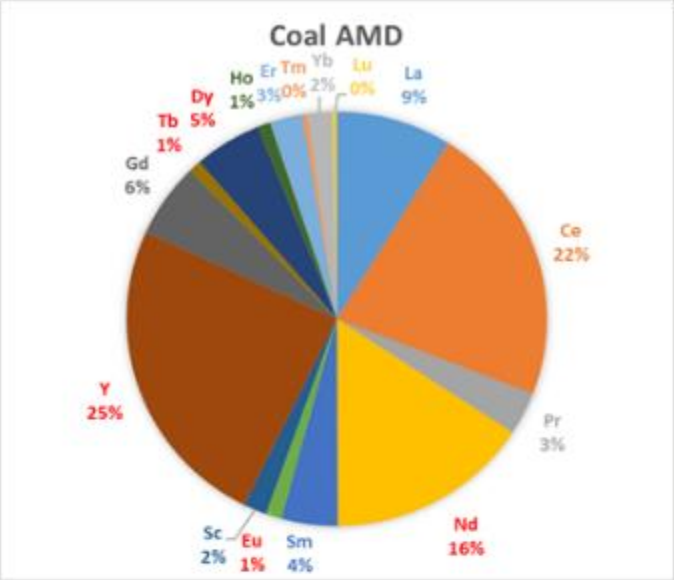
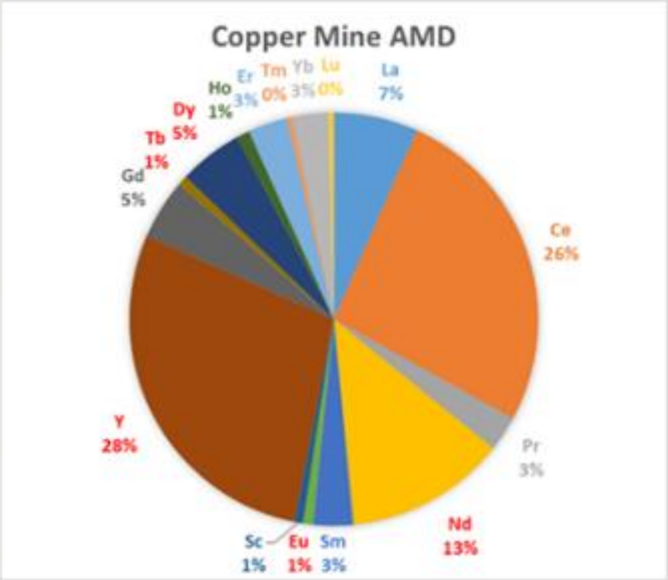
Coal and Copper mine AMD samples have nearly identical REE distributions





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

WVU Water Research Institute

REE/CM Recovery from Acid Mind Drainage: Summary of progress 2016-2022

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