


Design and evaluation of an acid leaching-solvent extraction process to extract rare earth elements from acid mine drainage precipitates

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Nomenclature

Rare Earth Elements

Light
Heavy

Critical
*Unstable

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	**Y**	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															
			Ce	Pr	**Nd**	Pm*	Sm	**Eu**	Gd	**Tb**	**Dy**	Ho	Er	Tm	Yb	Lu	
			Th	Pa	U	Np	Pt	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Our REE Projects

DE-FE0026927

- Phase 1 ETD30 Completed
  - Development of a cost-effective & environmentally benign process to treat and recover REEs from AMD
  - Perform a preliminary process system Design and Techno-Economic Analysis
- Phase 2 ETD50
  - Build and operate a bench-scale pilot plant
  - Update cost and performance metrics
  - Target product grade = 2% REE

DE-FE0026444-ETD39 Poster

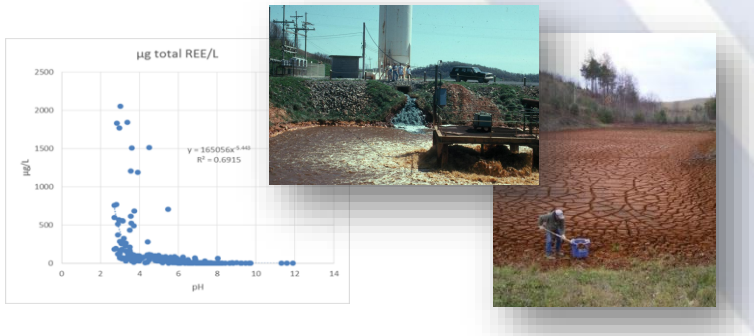
- Conduct a broad sampling campaign
- (> 150 sites).
- Perform a detailed assessment at promising sites
- Report REE concentrations and elemental distributions

DE-FE0031524-ETD53 Poster

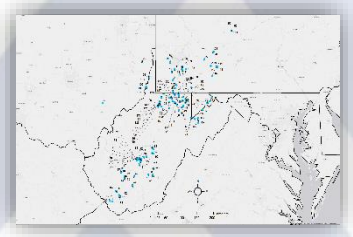
- Develop a novel process of capturing REEs upstream of AMD treatment
- Synthesize with a downstream process to produce high-grade REE products, >90% REO

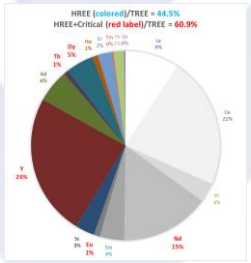
Presentation Outline

1. REEs in AMD



2. Resource Characterization





3. Process Design/Test

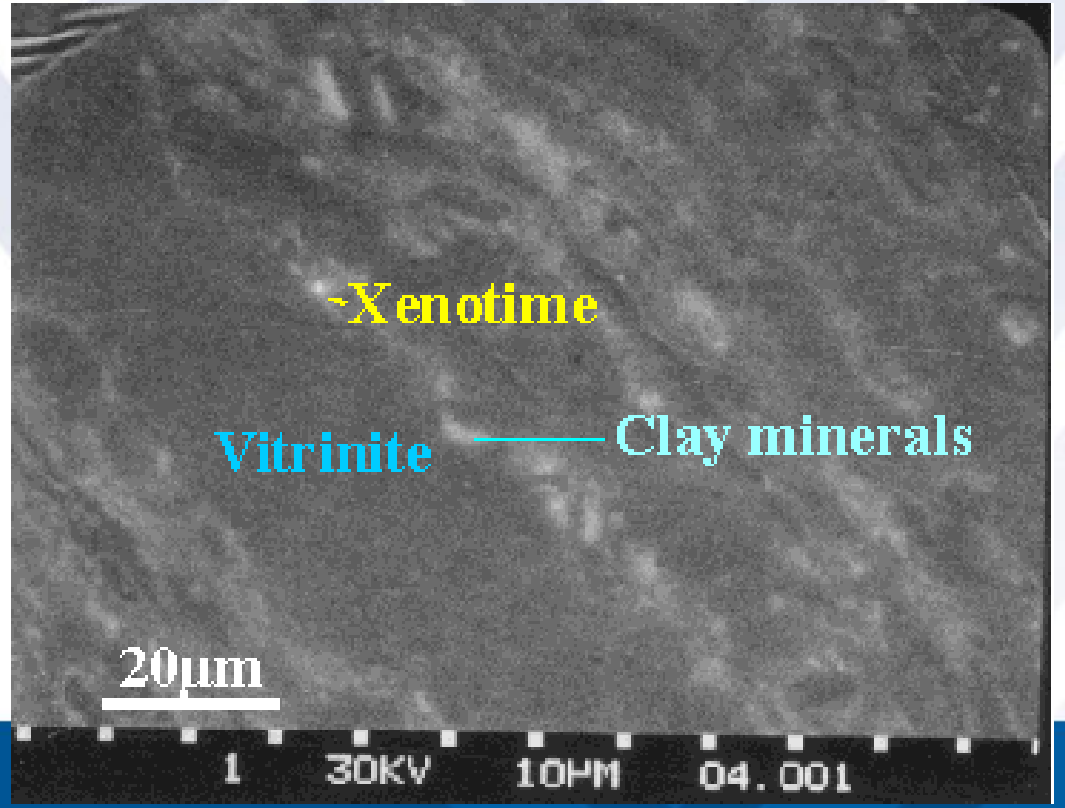
4. Summary and Questions

RARE EARTH ELEMENTS IN AMD SLUDGE

Mineral associations in WV coals

from WVGES

- Monazite (less commonly xenotime): REE (PO_4 SiO_4) weathered from granite as micron-sized particles
- Does not dissolve in weak acid, requires concentrated acid to liberate REEs
- When burned in a PC
  - boiler nearly all of the inert
  - minerals fuse into
  - alumino-silicate glass
- Which is even more
  - Resistant to acid attack

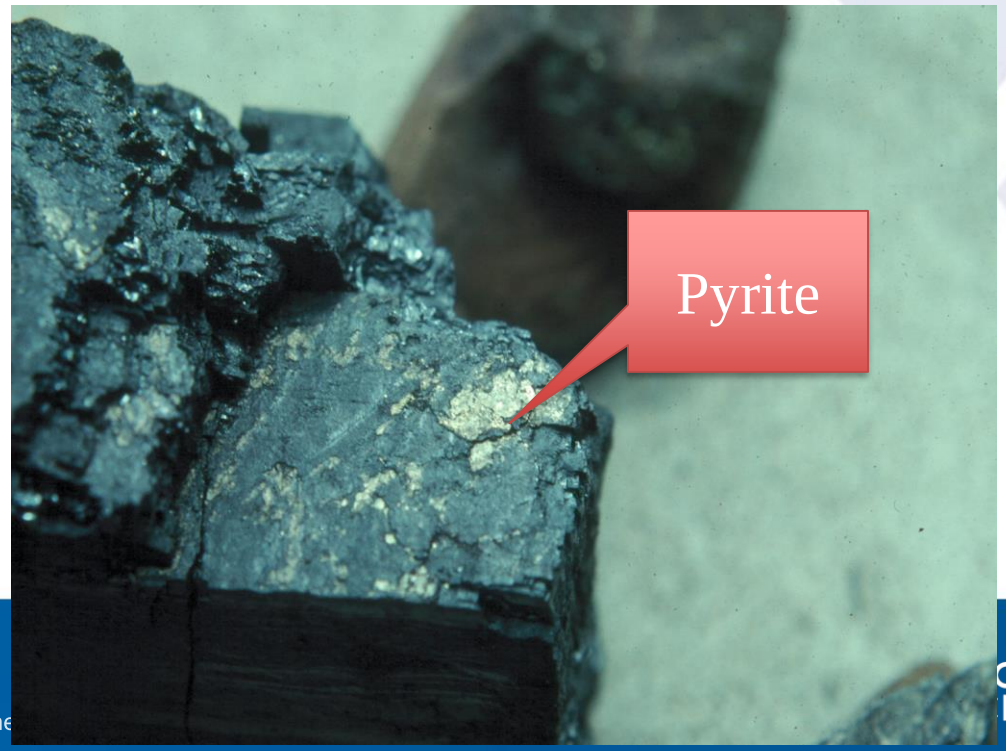


Acid Mine Drainage Chemistry

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

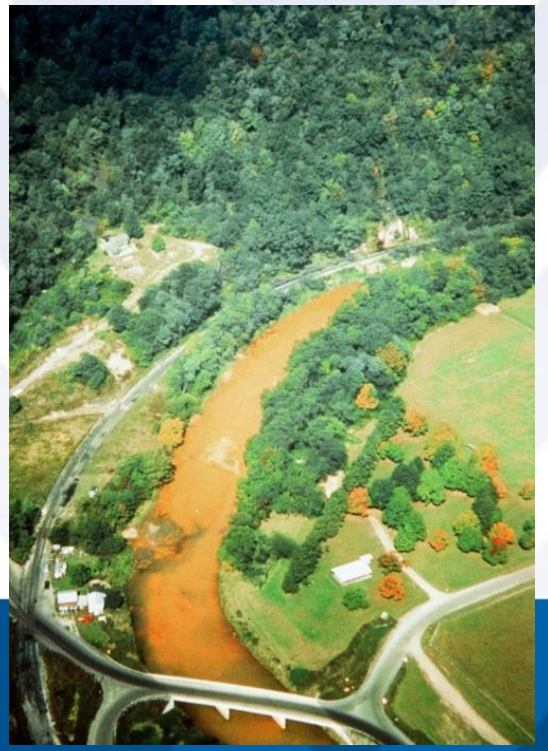
Pyrite + O_2 + H_2O

= Fe^{2+} + H_2SO_4



Fe^{2+} + O_2 + OH^-

= $Fe(OH)_3$



Conventional AMD Treatment

2. Lime for pH adjustment

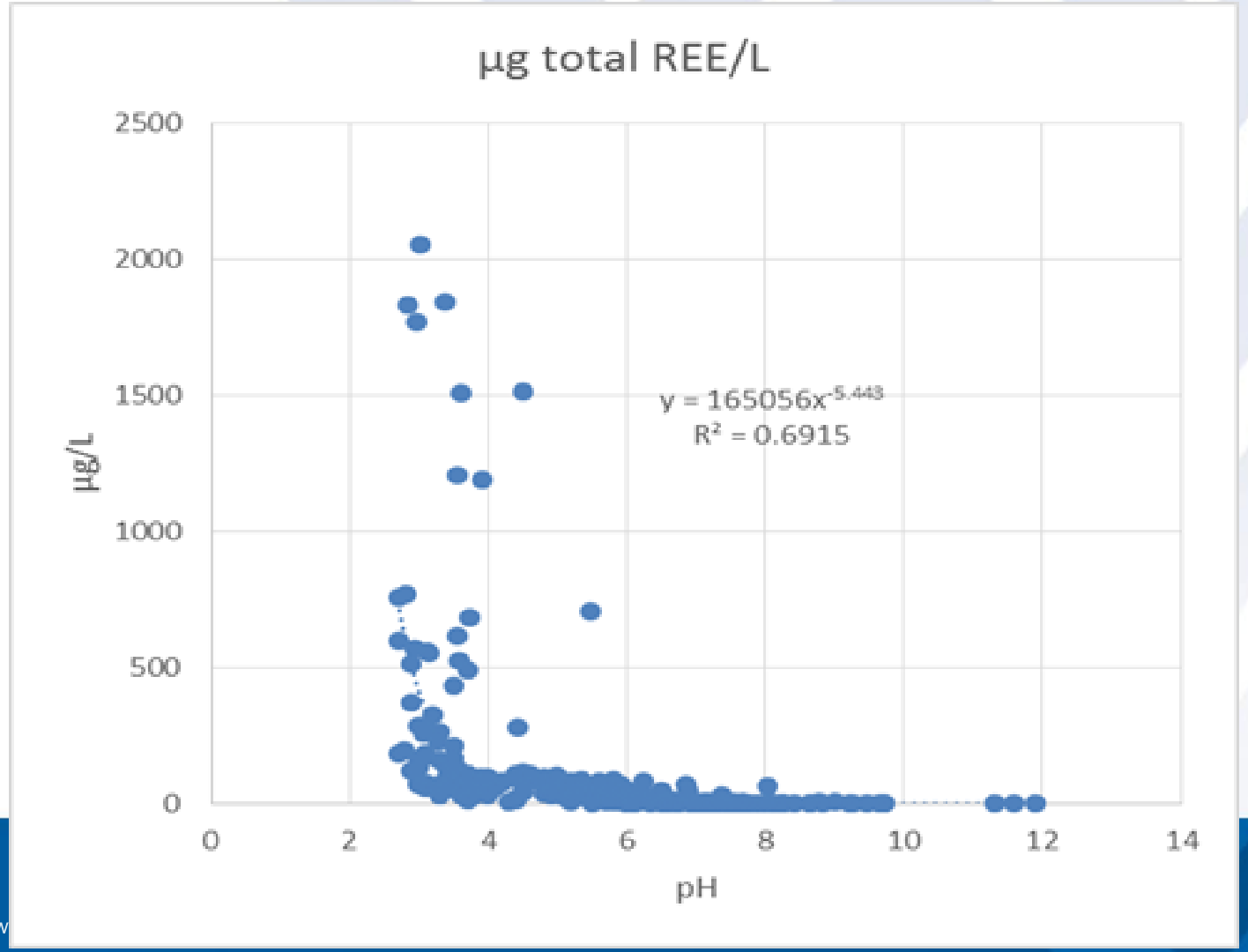
1. RAW AMD= **water** + **major ions (Ss)** + **TREE**

3. AMD treatment: lime mixing/oxidation

5. Treated **water** for surface discharge

4. AMD sludge: precipitation of **major ions (Ss)** + **TREE**

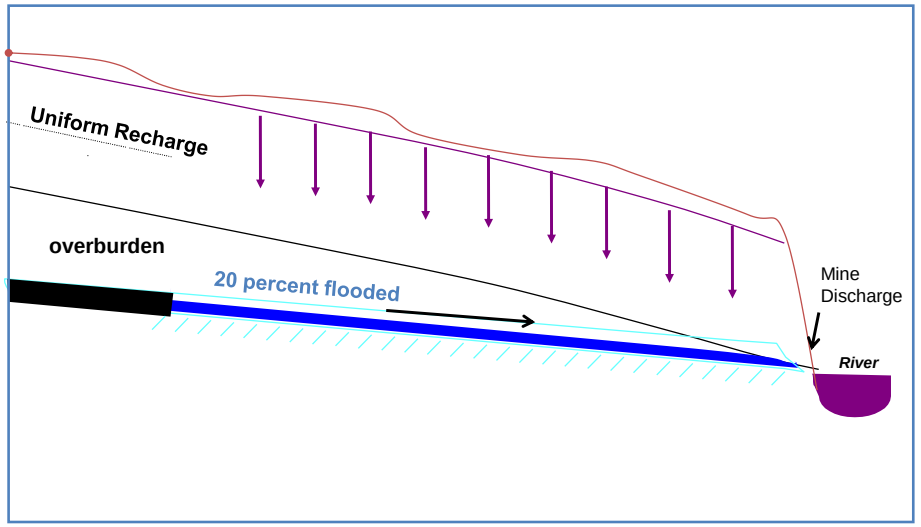
Acid mine drainage:
TREE Concentration vs. raw water pH



The extraction point will control REE concentration

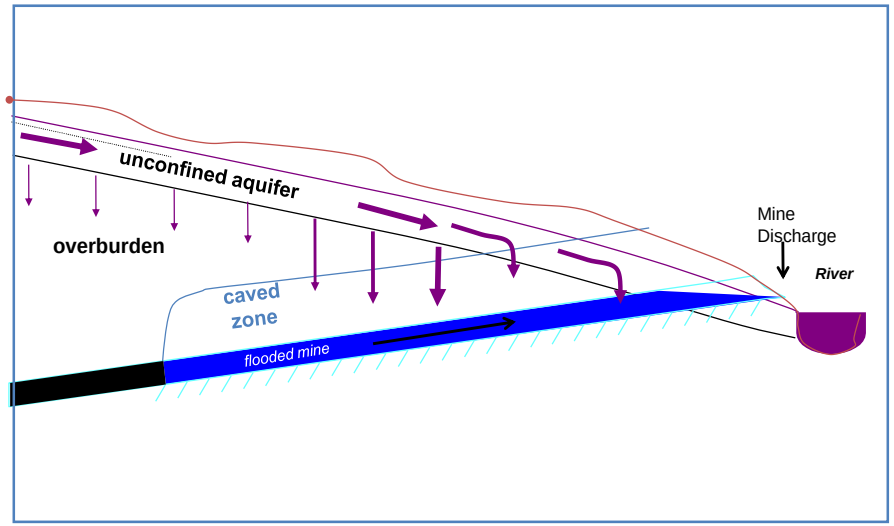
Low pH/high REE

Unflooded, Free Draining

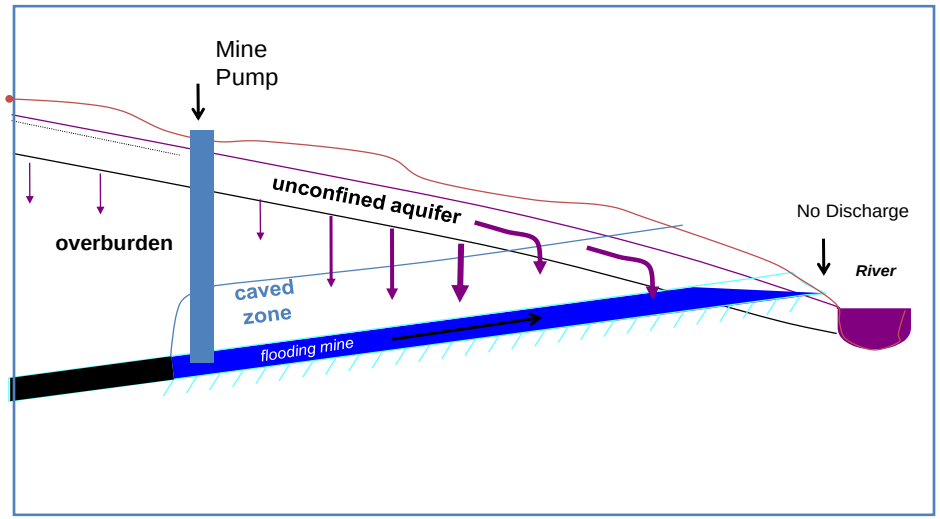


High pH, low REE

Flooded High Dilution



Flooded Mine Low Dilution

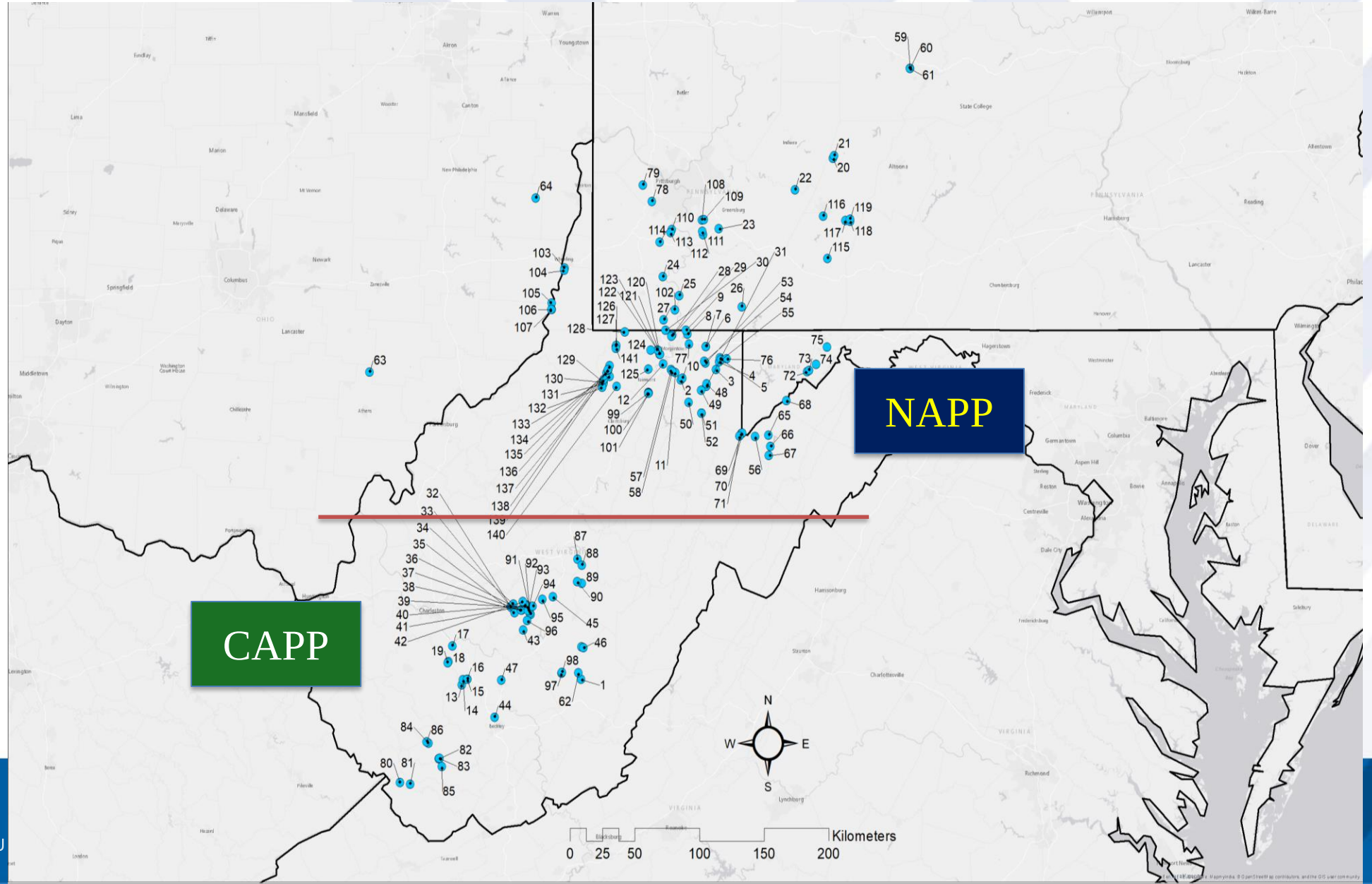


Resource characterization, Valuation

Metal value: $555/kg TREE

We use a conservative inherent value: $225/kg TREE to account for handling and processing

Sampled locations: 140



Central vs. Northern Appalachian coal basins

Little difference between REE distribution or total concentration (g/t)

Sites sampled:

CAPP	42
NAPP	110

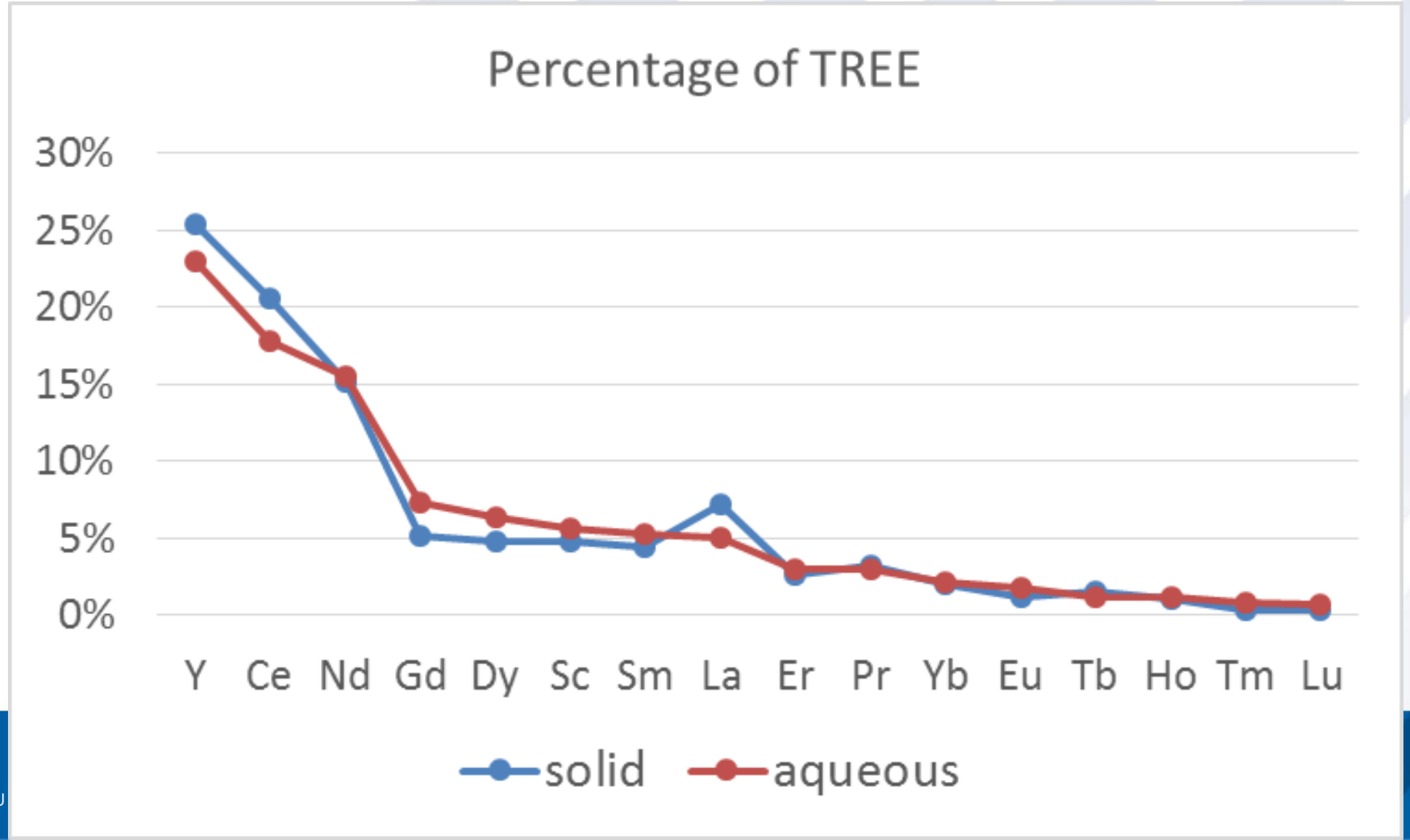
	CAPP	NAPP	All
La	41.4	38.4	39.9
Ce	97.1	95.0	96.0
Pr	14.4	14.0	14.2
Nd	66.5	64.5	65.5
Sm	18.2	17.6	17.9
Eu	4.4	4.5	4.4
Sc	12.8	14.9	13.8
Y	88.6	108.7	98.7
Gd	23.9	24.3	24.1
Tb	3.4	3.7	3.6
Dy	18.8	20.7	19.8
Ho	3.5	4.0	3.8
Er	9.1	10.7	9.9
Tm	1.0	1.4	1.2
Yb	6.7	8.1	7.4
Lu	0.9	1.2	1.0
TREE	410.6	431.6	421.1

LREE

Critical

HREE

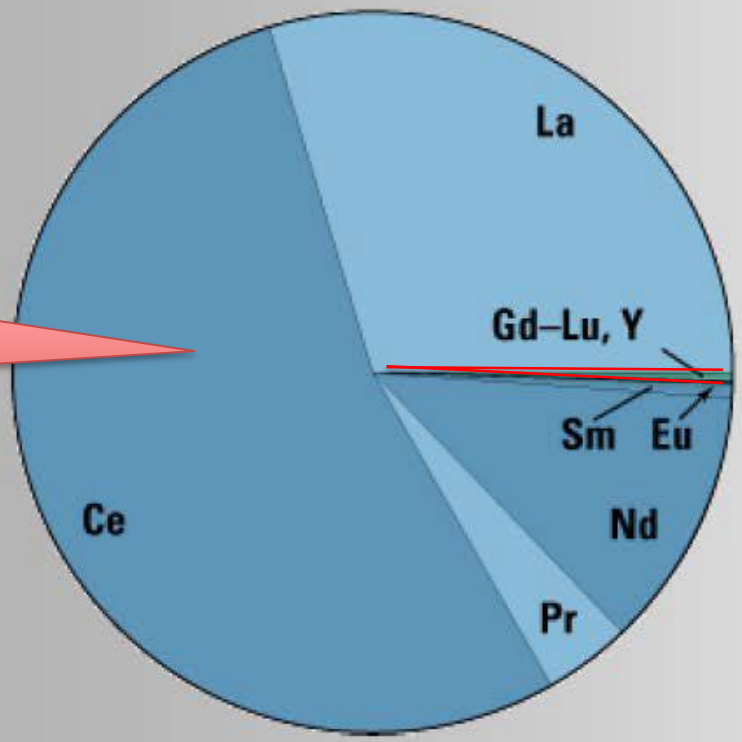
All REEs precipitate to AMDp with nearly equal enthusiasm

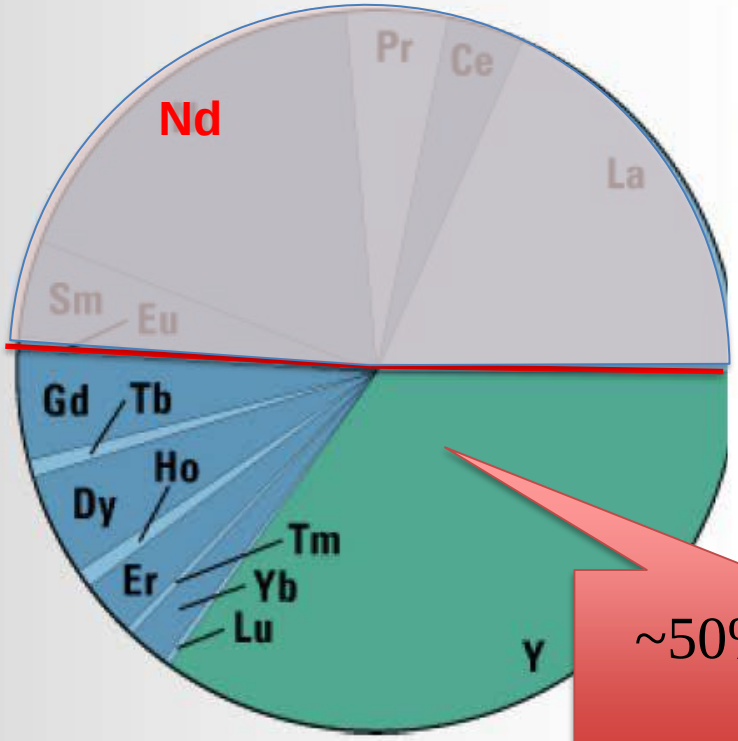


Distribution of HREE in AMD sludge is similar to south China clays

Bayan Obo, Mountain Pass

South China Clay





almost all LREE

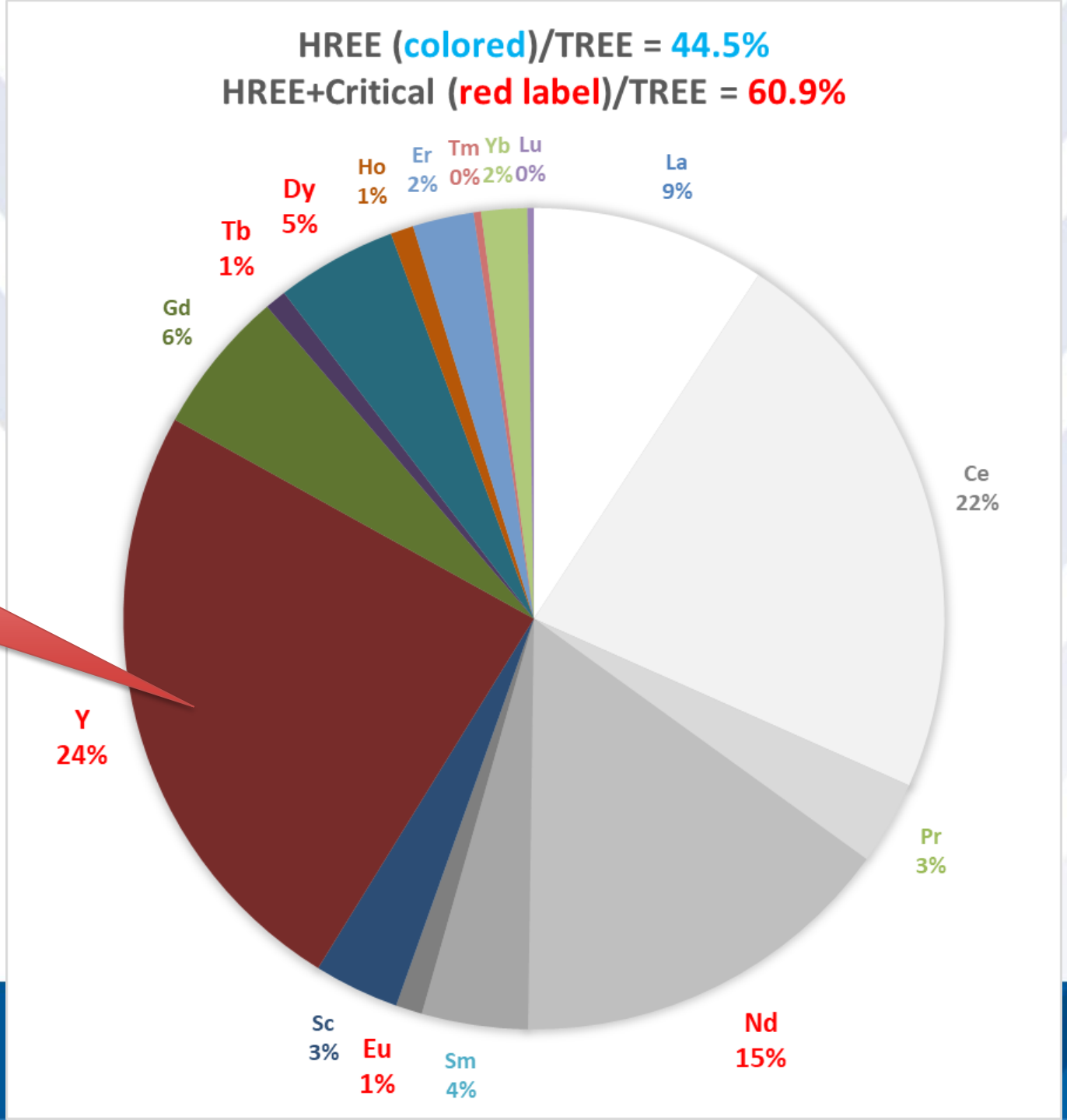
~50% HREE - Sc

USGS facts sheets

Heavy and Critical REEs in Acid Mine Drainage

Very high Yttrium content…

n=155



REE concentrations and weighted in situ value
Scandium represents 91% of weighted value.

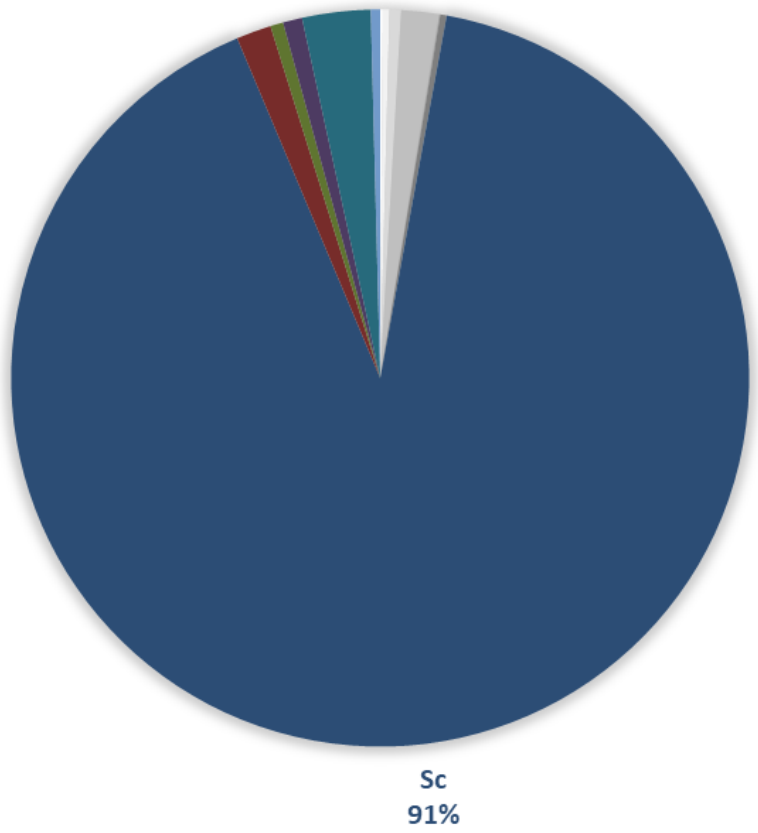
LREE

Critical

HREE

	TREE g/t DW	% TREE	$/kg elemental	weighted value $/kg TREE
La	39.2	9.2%	$ 7.00	$ 0.65
Ce	95.6	22.4%	$ 7.00	$ 1.57
Pr	14.1	3.3%	$ 85.00	$ 2.81
Nd	65.0	15.3%	$ 60.00	$ 9.16
Sm	17.8	4.2%	$ 7.00	$ 0.29
Eu	4.4	1.0%	$ 150.00	$ 1.57
Sc	14.3	3.4%	$ 15,000.00	$ 504.32
Y	103.3	24.2%	$ 35.00	$ 8.49
Gd	24.2	5.7%	$ 55.00	$ 3.12
Tb	3.6	0.9%	$ 550.00	$ 4.68
Dy	20.2	4.7%	$ 350.00	$ 16.62
Ho	3.9	0.9%		
Er	10.2	2.4%	$ 95.00	$ 2.28
Tm	1.3	0.3%		
Yb	7.7	1.8%		
Lu	1.1	0.3%		
sum	425.9			$ 555.56

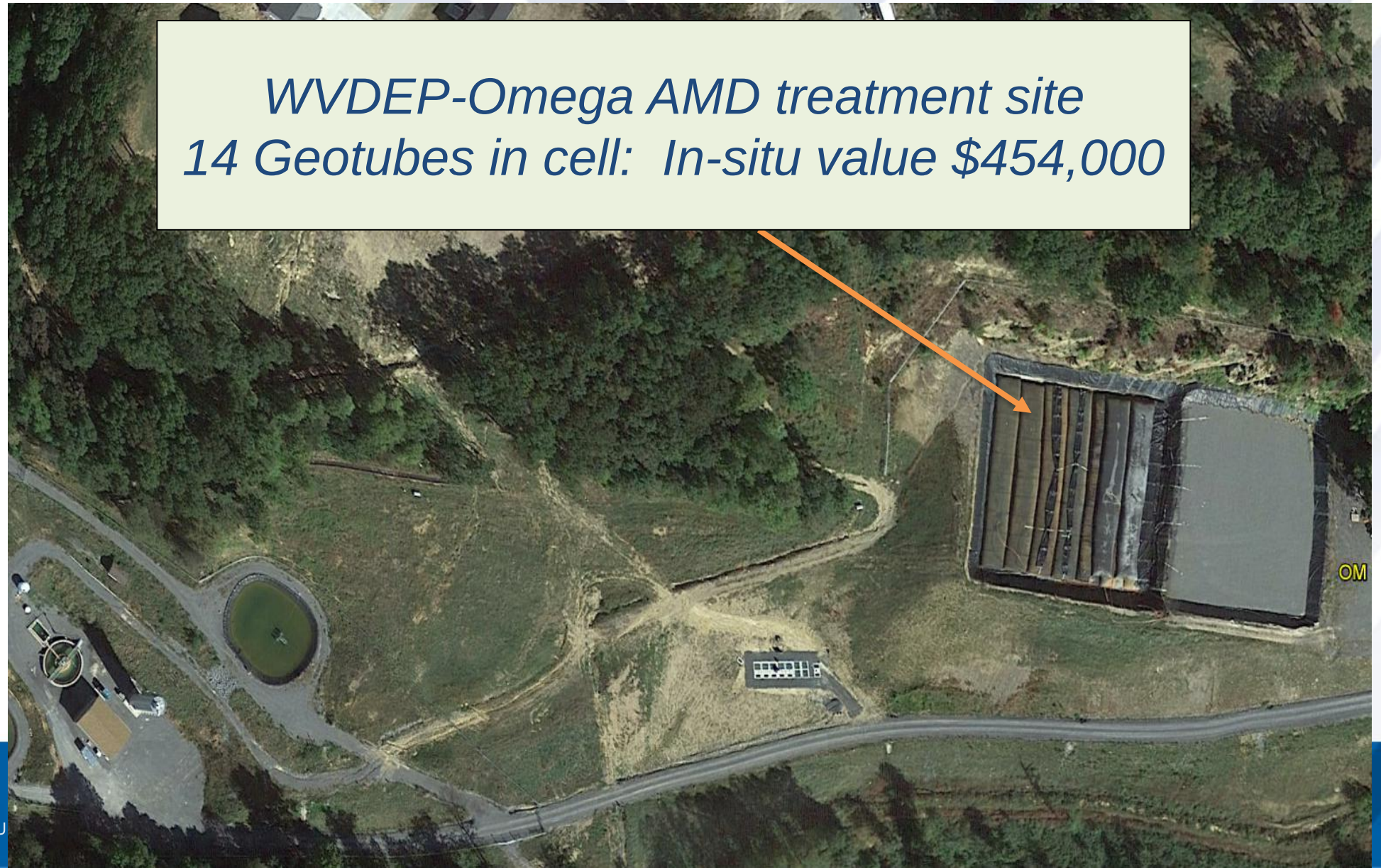
Scandium represents 91% of the metal value in AMD derived REEs



n=155

In situ sludge value=market value of REEs excluding transport and processing

Accessibility/Extractability/Dewatering



Estimated REE production CAPP/NAPP

Sludge cells sampled to date:			**155**
Sludge		2,344,452	m^3
solids content		21%	
Sludge		1,081,660	tons DW
average TREE grade		428	g/t
TREE		**462,950**	**kg**
in-situ value	$	225.00	/kg TREE
in-situ TREE value	**$**	**104,163,841**	

All Sites	Units		sites (n=140)	est. total APP[1]	est. total APP[2]
Total Q	L/sec		6,221	94,838	418,000
% total APP Q				6.56%	1.49%
Total TREE flux	kg/year		41,395	631,059	2,781,412
In-situ value/year @ $/kg TREE	**$**	**225.00**	**9,313,905**	**141,988,220**	**625,817,729**

[1]APP basin AMD discharge (Q) per this study

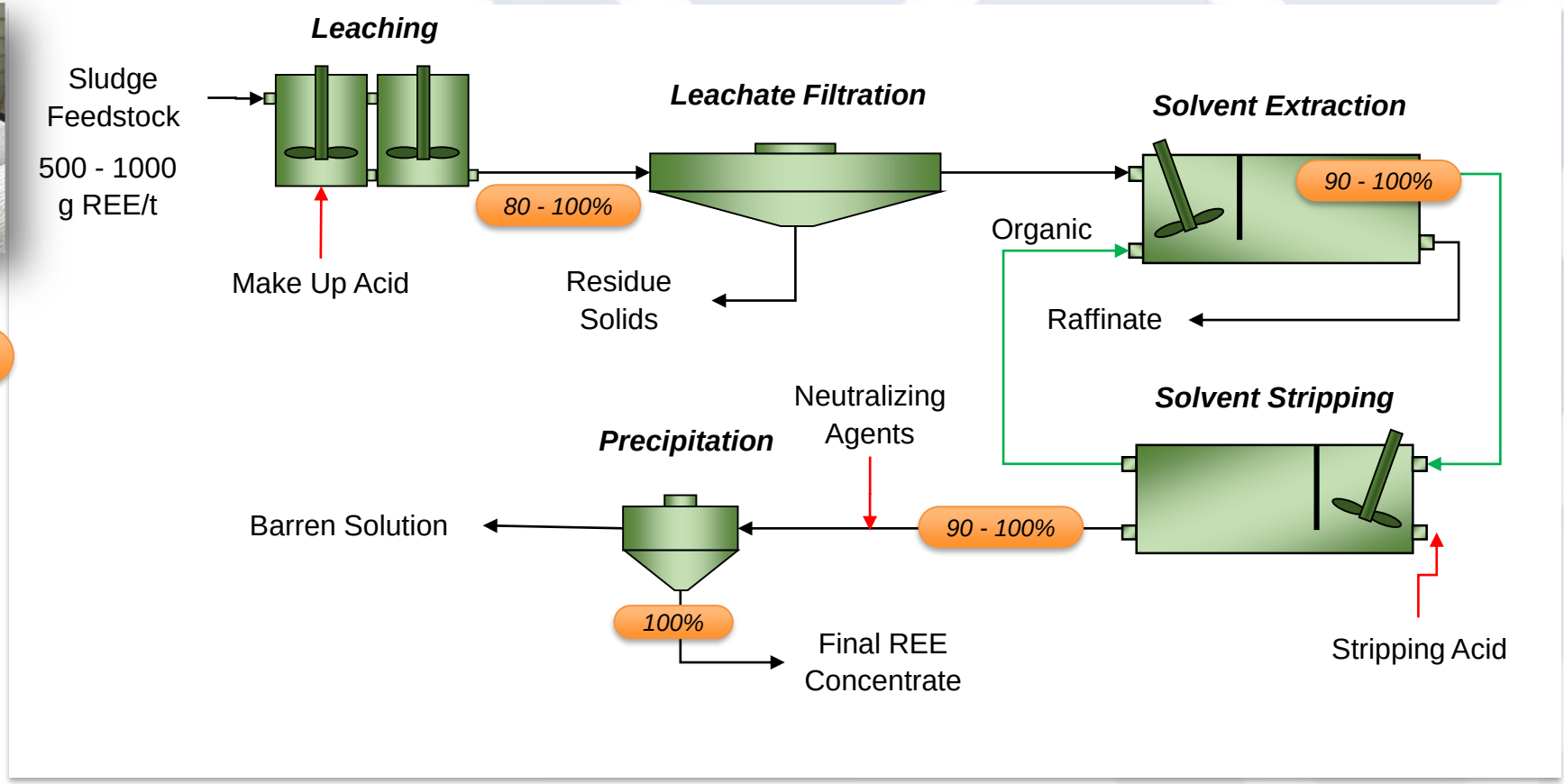
[2]APP basin AMD discharge (Q) per Stewart et al., 2017

PROCESS DESIGN

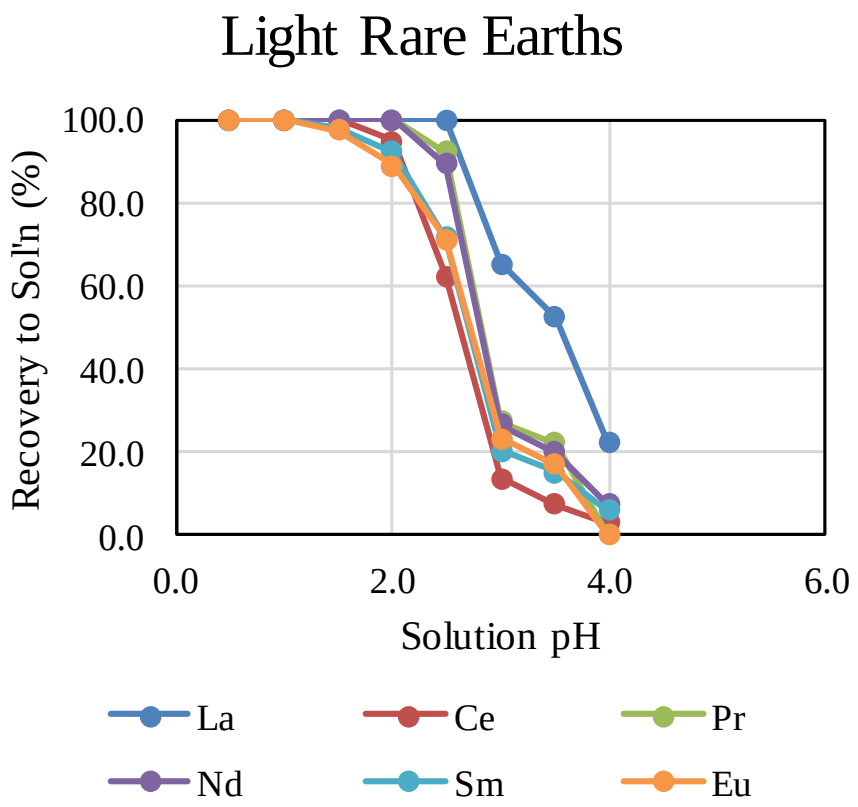
Conceptual Process Flowsheet

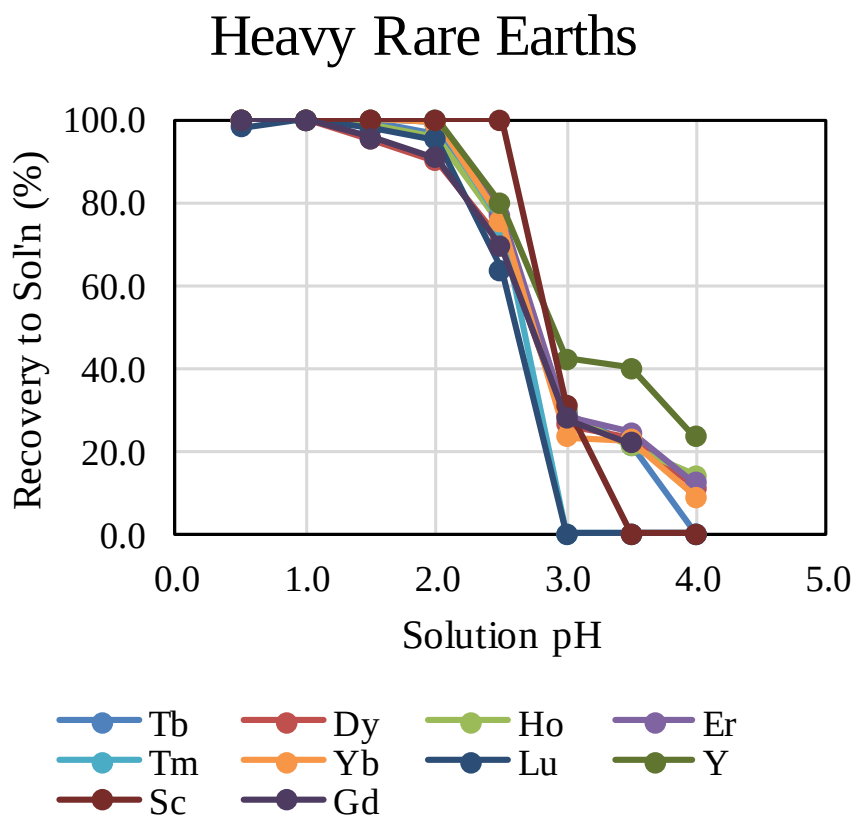
All processes at ambient pressure and temperature

REE recovery



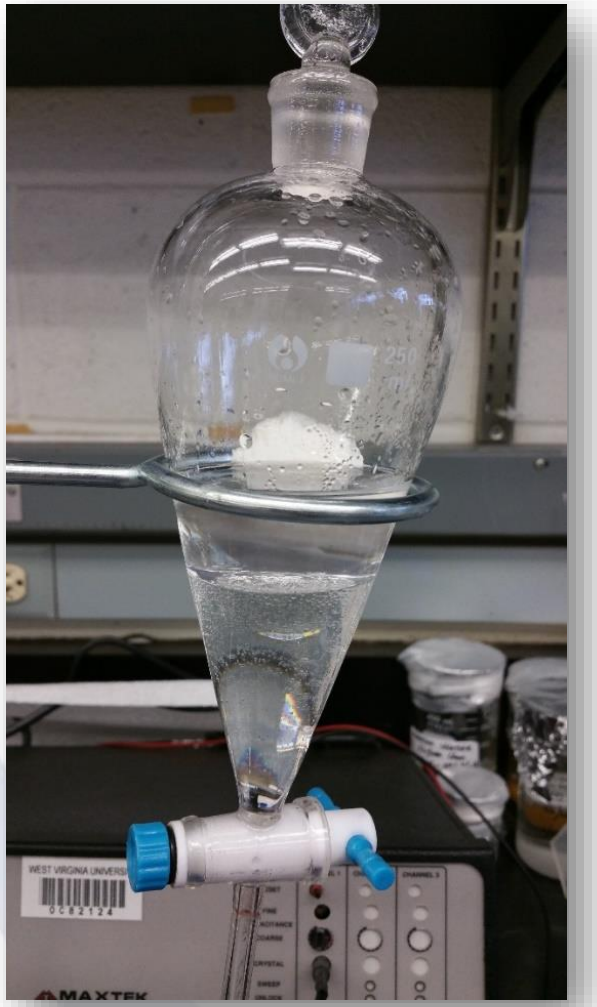
Acid Leaching at Ambient Temperature and Pressure





Feedstock

Solvent Extraction-Batch Tests



Distribution Coefficients (D)

- REE = 17.7 (as high as 100+ for some elements)
- Gangue Metal = 0.023

$$D = \frac{M_O}{M_{Aq}}$$

Separation Factor (SF)

- SF=17.7/0.023=770

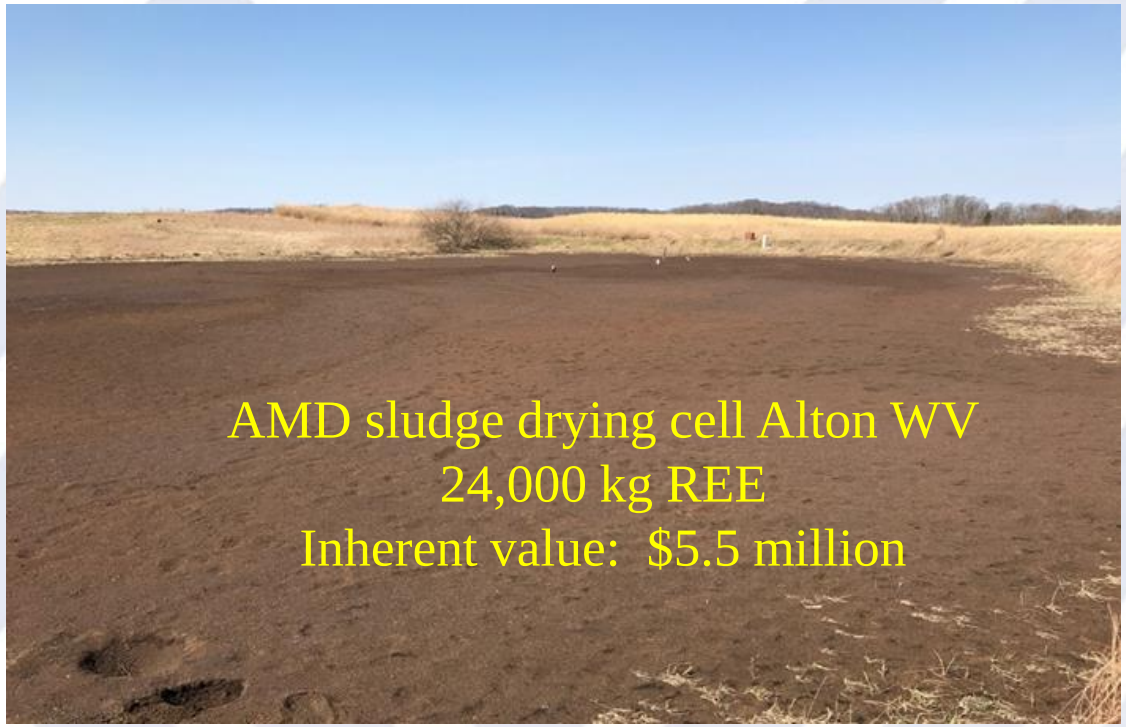
$$SF = \frac{D_{REE}}{D_{gangue}}$$

Construction
Bench-Scale, Continuous Flow Plant

SUMMARY

Summary

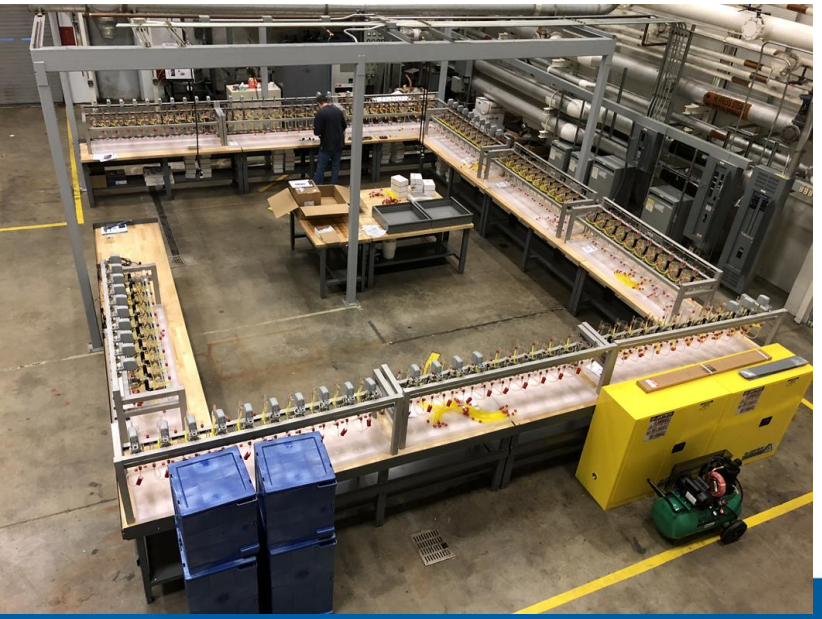
Acid from coal spoils, tailings, and underground mines tends to leach REEs from the surrounding strata.

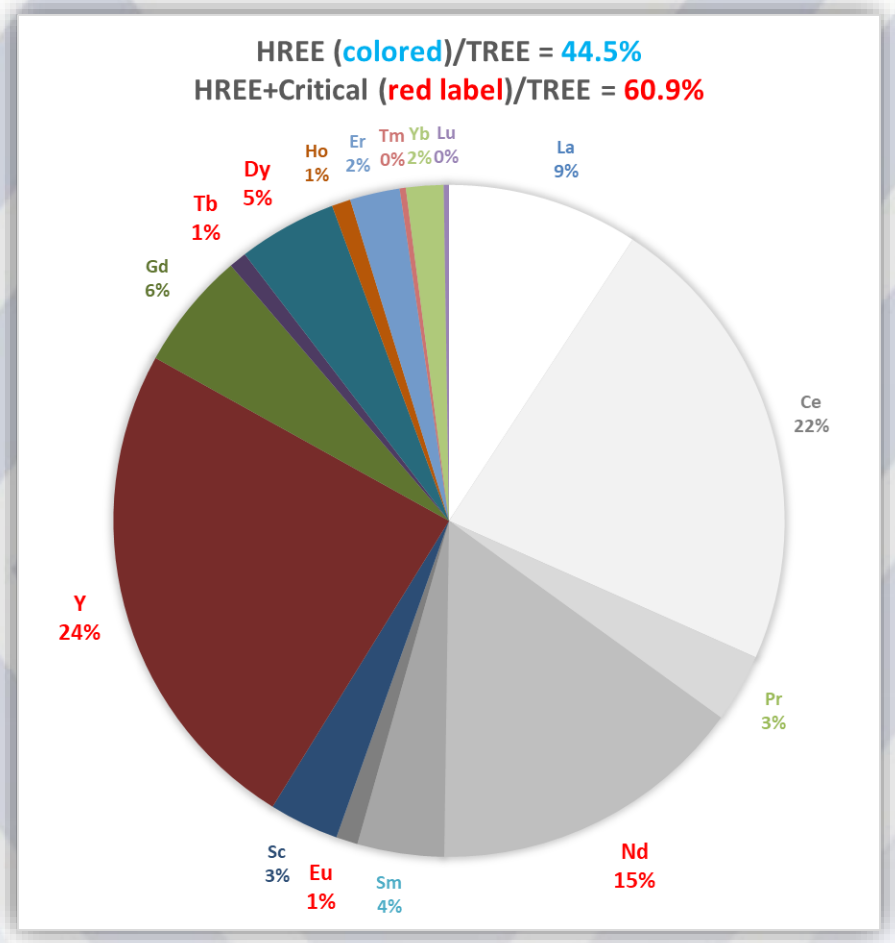


Conventional AMD treatment captures nearly 100% of the REEs and concentrates them by a factor of 2000x.

Summary

AMD sludge has a mean REE concentration of 420 mg/kg, with a fairly consistent elemental distribution





A continuous, bench scale ALSX unit is currently under construction. Operational mid May 2018

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