



Recovery of Rare Earth Elements (REEs) from Coal Mine Drainage

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Acid Mine Drainage Task Force Symposium
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STATEMENT OF PROJECT OBJECTIVES

Phase 1.

1. Development of a cost-effective & environmentally benign process to treat and recover REEs from AMD
2. Preliminary process system design and techno-economic analysis in preparation for pilot-scale testing
3. Down select

Phase 2.

1. Build and operate a pilot plant
2. Report cost/performance

Participants

WVU

- Paul Ziemkiewicz, PhD
  - Director, WVU Water Research Institute
- Xingbo Liu, PhD
  - Professor, Mechanical and Aerospace Engineering
- Aaron Noble, PhD
  - Assistant Professor, Mining Engineering
- Tom He, PhD
  - Chemist, WVU Water Research Institute

External

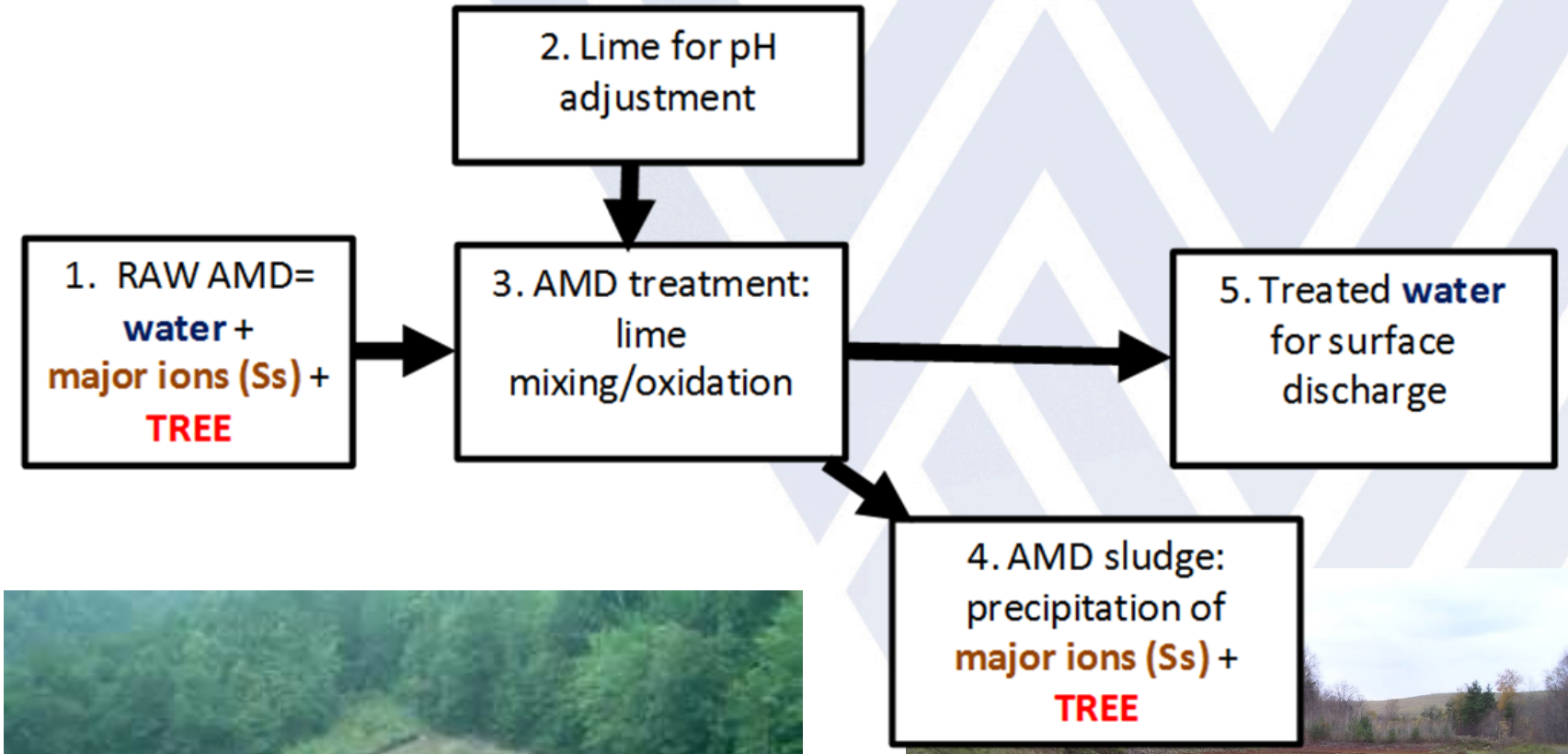
- Consol Energy, Inc.
- Mepco Inc.
- Rosebud Mining Co.
- West Virginia Dept. of Environmental Protection

TECHNICAL BACKGROUND/ MOTIVATION FOR THE PROJECT

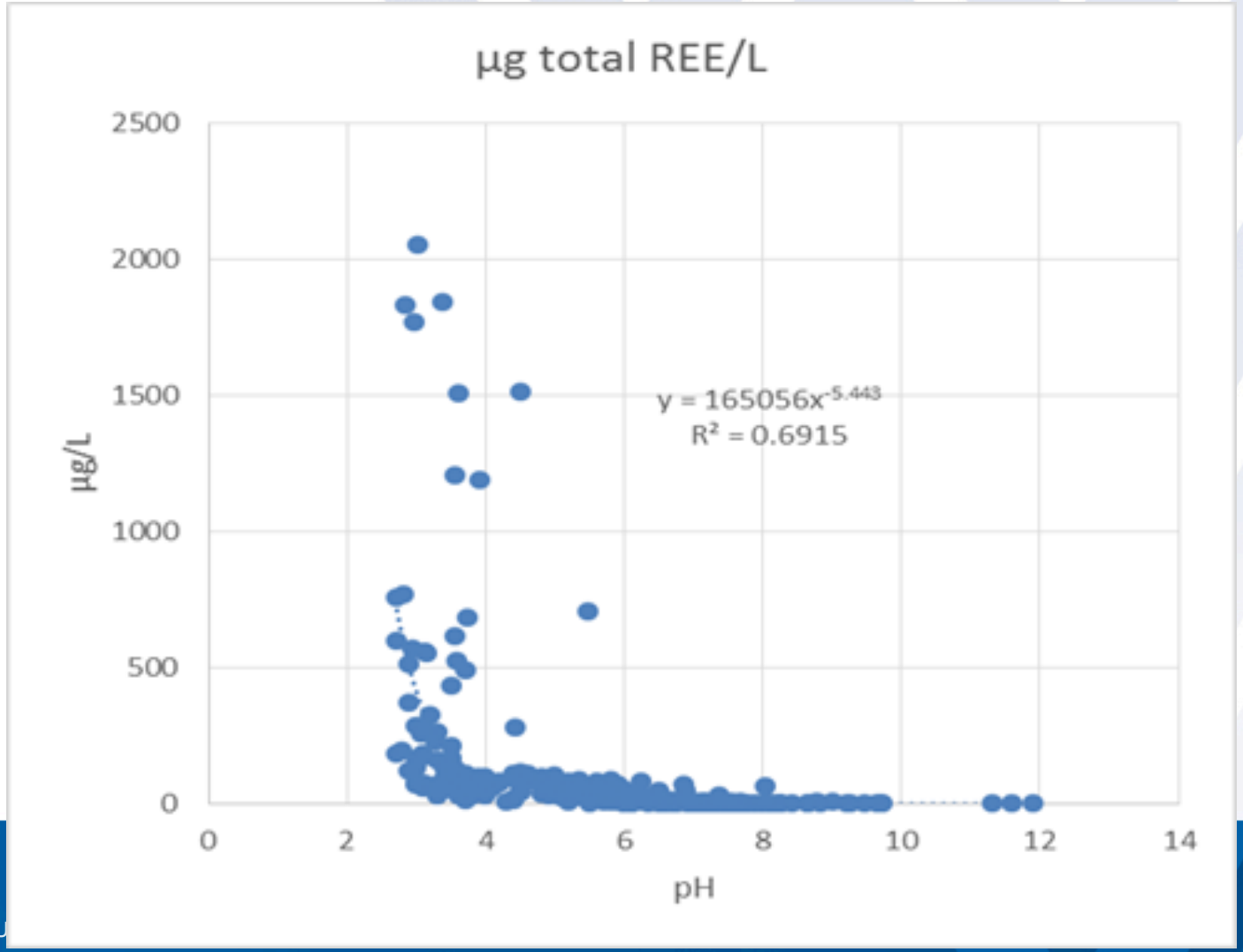
With much thanks to
Chuck Cravotta, PhD
USGS, PA Field Office

This was only possible because he shared his data set

AMD treatment flow diagram



Acid mine drainage: TREE Concentration vs. raw water pH



Early Sludge Samples

Sago/Sawmill-Lime

DLM-Caustic

Sago (A) and DLM (B) AMD sludge samples from WV Freeport and Kittanning coals

REE	AMD sludge (mg/kg) site A	site B
Ce	26.0	160.0
Dy	9.0	34.0
Er	5.0	19.0
Eu	2.0	6.0
Gd	9.0	34.0
Ho	2.0	7.0
La	8.0	59.0
Lu	0.6	2.0
Nd	16.0	90.0
Pr	3.0	19.0
Sc	6.0	9.0
Sm	5.0	23.0
Tb	2.0	6.0
Tm	0.6	2.0
Y	54.0	230.0
Yb	4.0	14.0
TREE actual	152.2	714.0

Ss	AMD sludge (mg/kg) site A	site B
SO4	8,870	40,210
Al	13,400	79,000
Ca	128,000	8,200
Si	19,700	34,700
Fe	98,200	51,800
Mg	20,700	63,600
Mn	8,500	24,200
Ss	297,370	301,710
TREE/Ss	512	2,367
Correction factor	3.36	3.31
Avg. correction factor		3.34
TREEc	153.3	708.8

$$TREEc = \Sigma(\Delta REE)/(Ss \times 3.34) \times 10^6$$

Estimating Sludge REE Concentration

$$TREEc = \Sigma(\Delta REE)/(Ss \times 3.34) \times 10^6$$

- *TREEc = estimated TREE concentration in treated AMD sludge (mg/kg)*
- *ΔREEa = change in AMD REE concentration: pre and post-AMD treatment (mg/L)*
- *Ss = sludge solids: sum of major ions in raw AMD feed water: Ca, SO_4, Si, Fe, Mg, Mn (mg/L)*

AMD vs Sludge

AMD treatment plant	Ss mg/L	AMD mg/L	AMD kg/yr	TREEc mg/kg	Conc. factor
SaxmanRun	67	0.69	2.7	3073	4478
Racic	93	0.77	92.0	2495	3232
Thomas	12	0.09	17.5	2169	24585
CaledoniaPike	42	0.28	80.0	1997	7144
Nittanny	339	2.07	180.6	1824	883
Morris2	111	0.61	292.8	1663	2707
RogersMill	43	0.23	20.1	1595	6949
Nittanny	360	1.85	117.5	1535	831
McVillePile	364	1.83	641.3	1510	823
MtMorris	14	0.07	3.9	1500	21566
PotRidge2	114	0.55	110.2	1462	2635
PotRidge2	119	0.56	13.4	1408	2507
Antrim	72	0.33	467.4	1371	4173
Keener	156	0.71	50.6	1359	1921
HallTallent	26	0.09	5.0	1032	11413

15 AMD sources

			Raw AMD source water				AMD treatment sludge			
		coal		Q	Ss	TREE	TREE/Ss	TREEc	REE load	TREE/Q
type	facility	seam	pH	cfs	mg/L	mg/L	mg/kg		kg/yr	kg/yr/cfs
Refuse	McVillePile	Kittanning	2.83	0.44	363.80	1.83	5042	1510	641	1457
Refuse	CRDA5	Kittanning	2.95	1.31	221.38	0.58	2609	781	601	459
Surface	Antrim	Kittanning	3.20	1.79	71.75	0.33	4580	1371	467	261
Deep	LCN	?	6.00	24.80	22.00	0.02	959	287	416	17
Surface	Trent	?	5.82	5.66	32.72	0.08	2588	775	381	67
Refuse	PBSJob12	Kittanning	3.55	0.37	4052.29	1.21	299	89	356	962
Deep	Porter	?	3.42	7.43	23.17	0.06	2517	754	344	46
Surface	Morris2	?	3.56	0.60	110.60	0.61	5553	1663	293	488
Deep	RauschCr	?	6.47	22.40	14.93	0.01	994	298	264	12
Surface	SteeleShaft	Pittsburgh	6.50	6.79	605.19	0.05	77	23	251	37
Refuse	Renton	Freeport	6.25	3.43	488.81	0.08	169	51	226	66
Deep	Manor44	?	3.08	1.03	319.30	0.26	820	245	214	208
Surface	Nittanny	?	3.01	0.11	339.21	2.07	6091	1824	181	1642
Deep	SilverCr	?	5.88	4.92	28.98	0.04	1264	378	143	29
Surface	PotRidge2	?	3.15	0.25	113.61	0.55	4884	1462	110	441
Average				5.42	453.85	0.52	2563	767	326	413

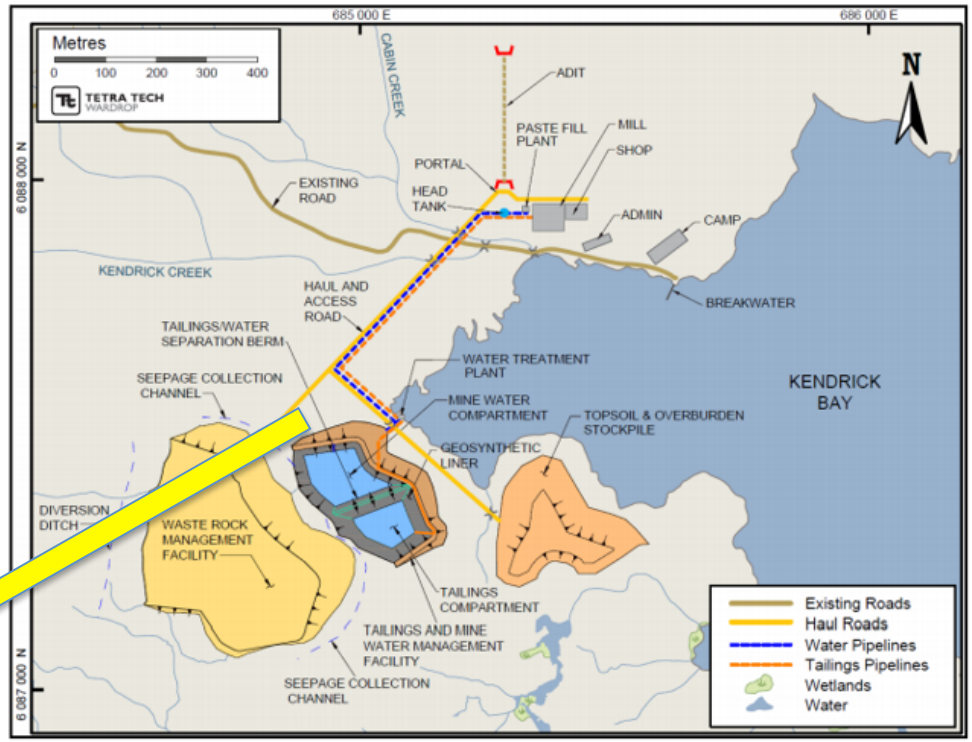
POTENTIAL SIGNIFICANCE OF THE RESULTS OF THE PROJECT

1. Economic development for coal communities
2. Diversify revenue streams for coal industry
3. Create domestic REE supply industry
4. Brownfield, not greenfield industry
5. Incentivize AMD treatment

Global Demand, 2015

REE as oxide	2015 demand tons/year	2015 supply tons/year
total REE	180,000	208,500
cerium	65,500	82,500
neodymium	37,500	32,500
europium	750	600
terbium	475	400
dysprosium	2,750	1,800

Figure 1.2 General Site Layout



Current, proposed developments

% Total REE, Proposed Developments

concentration	mg/kg	basis	location
0.0300%	300	total REE	south China
0.0160%	160	Dysprosium	Kipwa, Canada
0.5800%	5,800	total REE (low)	Dotson Dike, Alaska
1.0540%	10,540	total REE (high)	Dotson Dike, Alaska

Goal: 2% TREE
Range of feedstock quality

TREE		req'd conc.
mg/kg	%	factor to 2%
20,000	2.00%	1
10,000	1.00%	2
5,000	0.50%	4
2,563	0.26%	8
1,282	0.13%	16
714	0.07%	28
357	0.04%	56
152	0.02%	132
76	0.01%	263

Average top 15 PA AMD sites (estimated)

DLM sludge (actual)

Sago sludge (actual)

Valuation: shaded elements are critical materials (2009 prices)

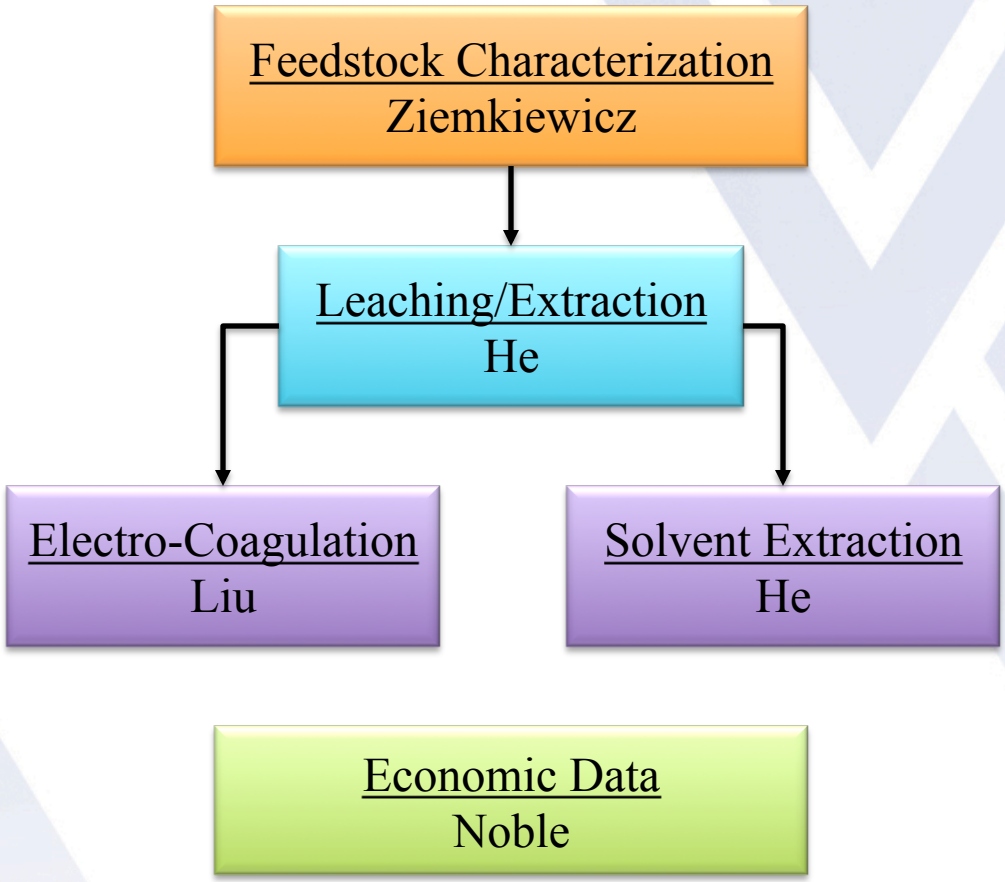
		Average 15 PA AMD treatment sites			
	price*	production		est. value	
REE	$/kg	kg/yr	% TREE***	$/yr	% total
Eu	1600	5.46	1.3%	$ 8,742	18.8%
Y	44	126.82	29.3%	$ 5,580	12.0%
Dy	170	23.35	5.4%	$ 3,969	8.5%
Tb	900	4.39	1.0%	$ 3,955	8.5%
Gd	150	23.69	5.5%	$ 3,554	7.6%
Ho	750	4.38	1.0%	$ 3,288	7.1%
Yb	325	8.77	2.0%	$ 2,850	6.1%
Ce	30	84.81	19.6%	$ 2,544	5.5%
Sm	130	19.35	4.5%	$ 2,515	5.4%
Lu	1800	1.30	0.3%	$ 2,349	5.1%
Nd	42	55.59	12.8%	$ 2,335	5.0%
Tm	1500	1.45	0.3%	$ 2,178	4.7%
Er	100	11.79	2.7%	$ 1,179	2.5%
La	30	31.77	7.3%	$ 953	2.1%
Pr	38	12.50	2.9%	$ 475	1.0%
Sc**	?	17.36	4.0%	?	?
total		432.78	100.0%	$ 46,464	100.0%

* UGSS, 2009

** no price given for Sc

*** no data available for Pm

Data Inputs



Interpret all data using n^{th} order kinetics, with respect to experimental conditions and feedstock characterization.

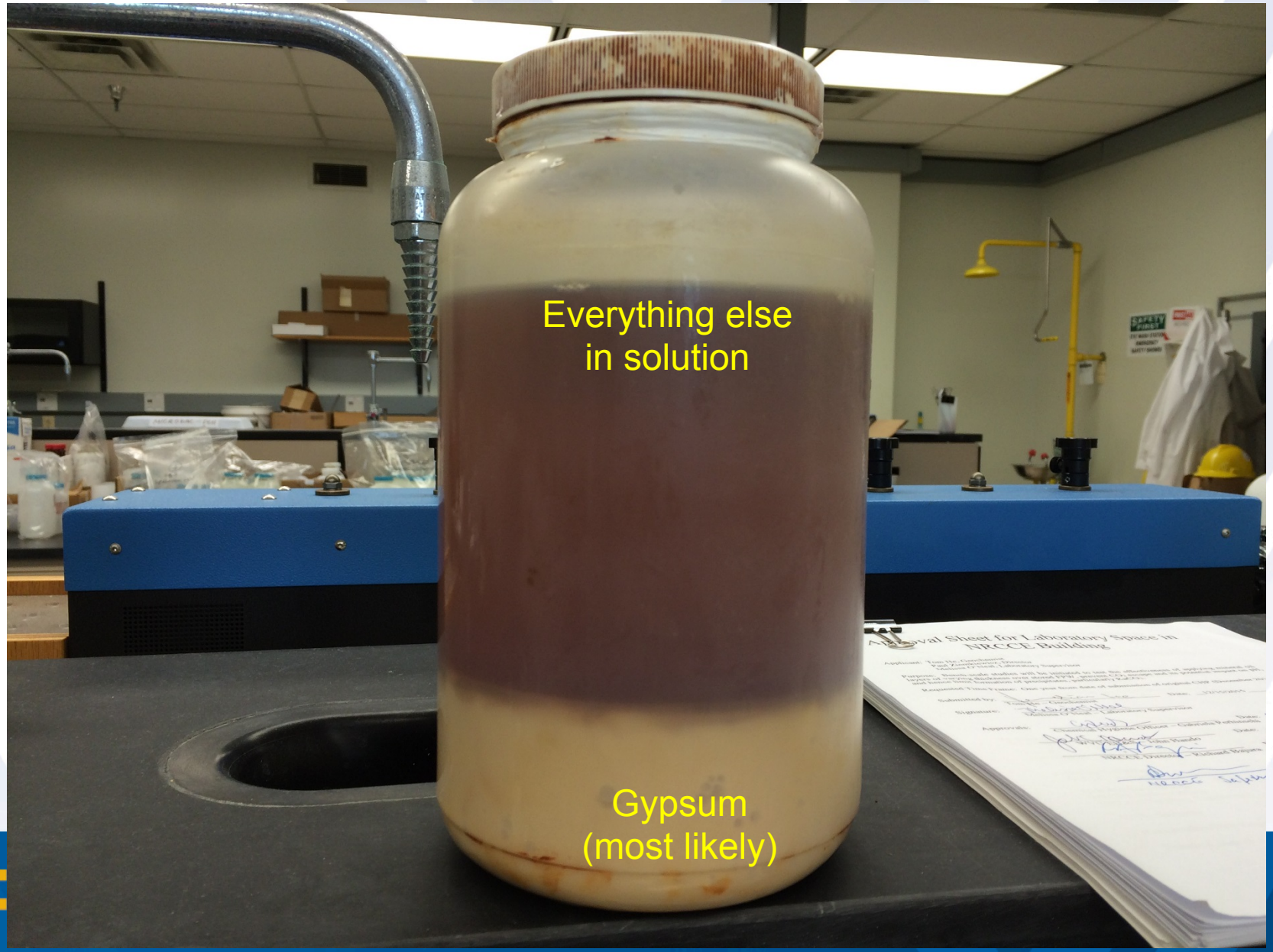
Develop and maintain database.

PROJECT STATUS

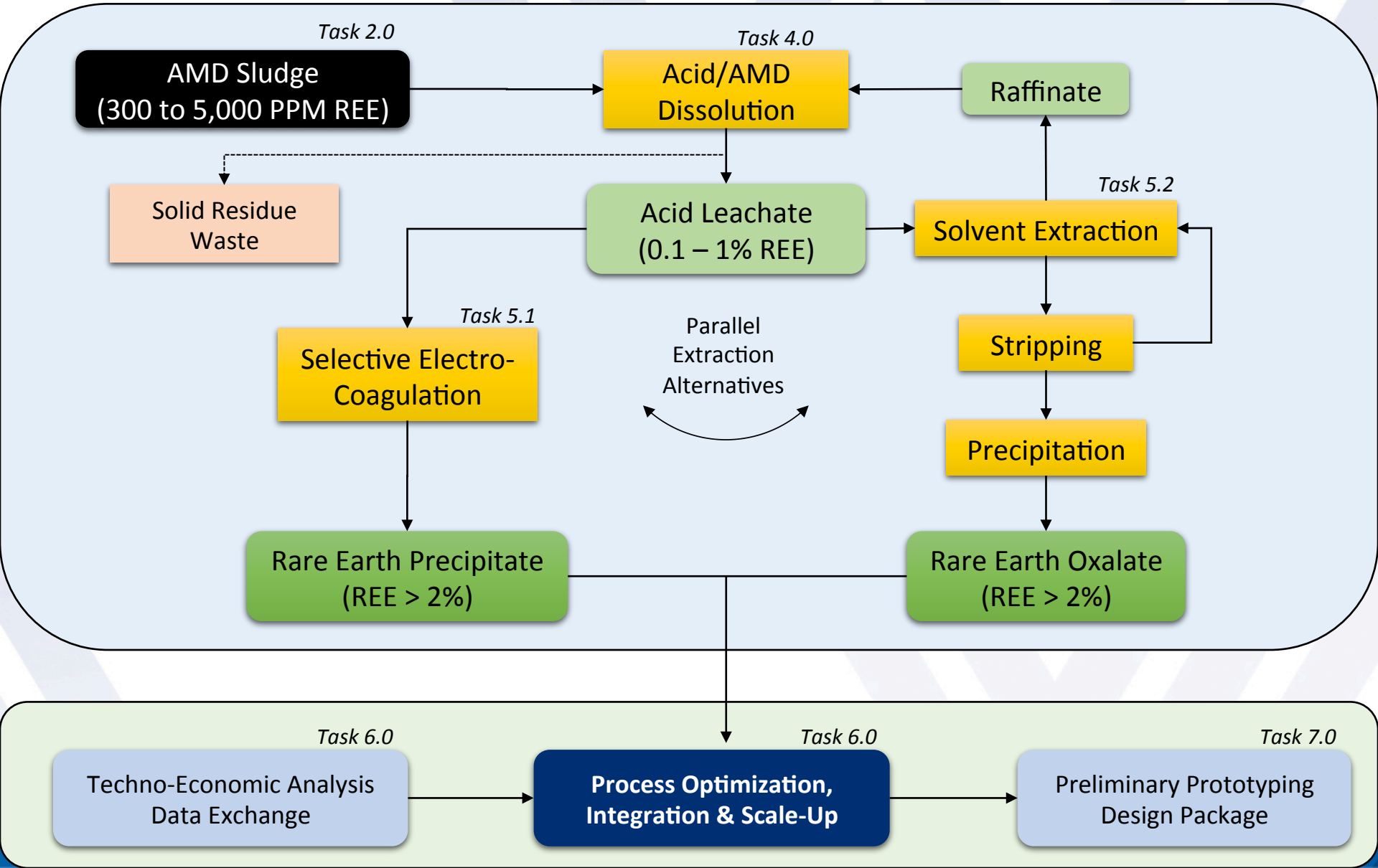
- AMD sludge samples collected from
  - Rosebud Mining:
    - McVille Refuse, Freeport PA
    - St. Michael UG discharge, St. Michael PA
  - Mepco Inc.
    - Steel Shaft HDS plant, Greene Co. PA
- Acid extraction on those three samples
  - Complete dissolution of solids at pH1 and 2 in H_2SO_4
- Presentation to WV AMD Task Force
  - Morgantown 29 Mar 16

Rosebud Mining: McVille Refuse

Steel Shaft sludge dissolved in H_2SO_4, pH 1



Conceptual Process Flowsheet



FOR MORE INFORMATION PLEASE CONTACT

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