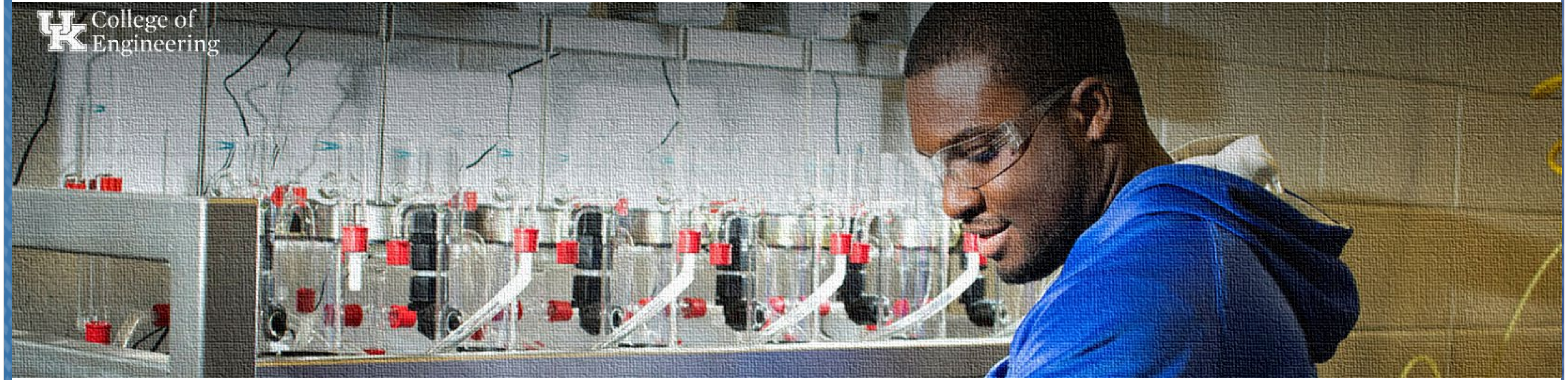

Demonstration of Scaled-Production of Rare Earth Oxides and Critical Materials from U. S. Coal-Based Sources

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DOE Award Number: DE-FE0031827
Period of Performance: 10/1/2019–6/30/2022
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Acknowledgement & Disclaimer

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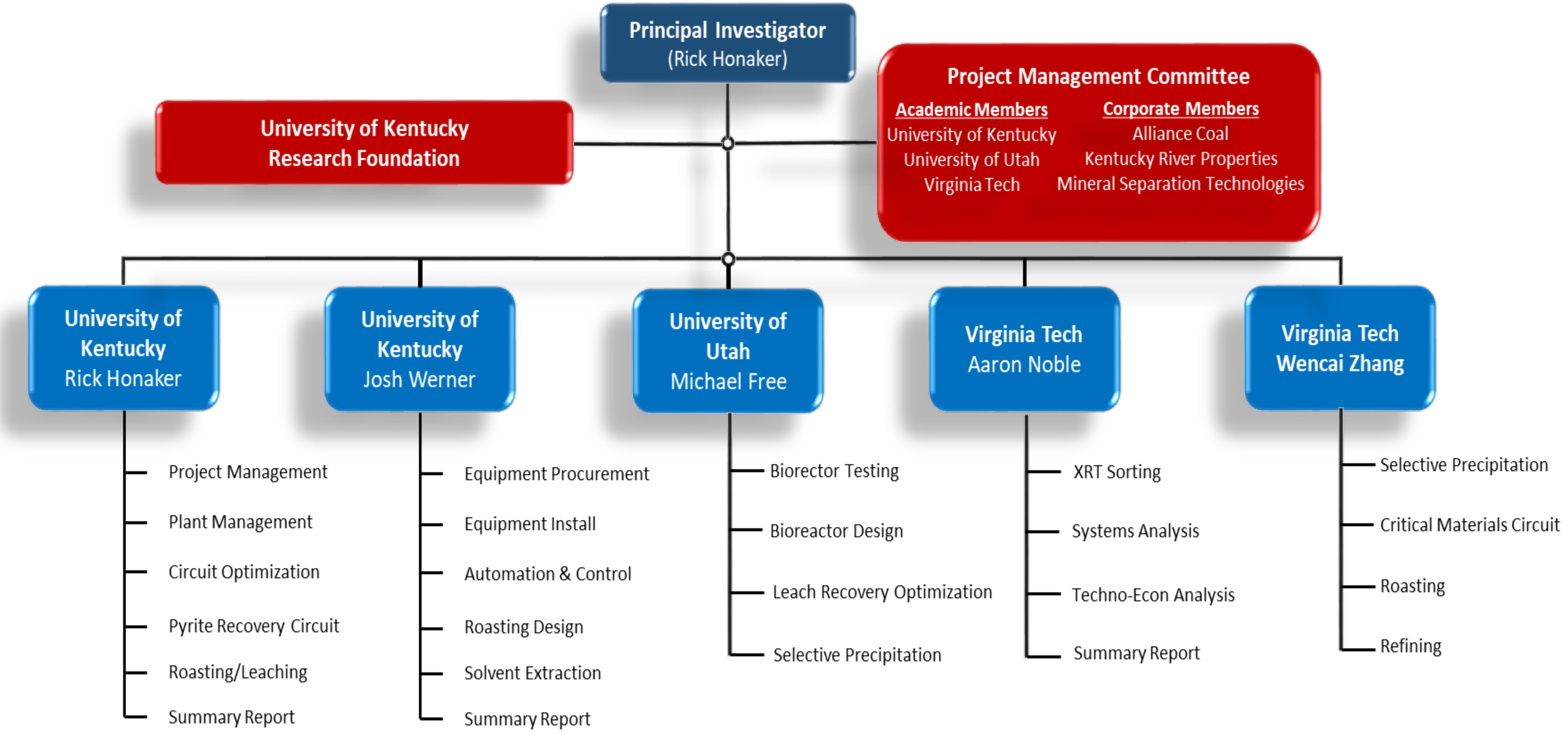
Project Organization Chart



Project Goals & Objectives

- Demonstration of scaled production of high purity rare earth oxide mix from coal refuse sources using innovative technologies that will reduce cost and improve environmental outcomes.
- Performance objectives:
  - >90% REO mix purity
  - 200 g/day product rate
  - Co, Mn and Sc products >2% purity
  - Cost reduction per kg of REO produced by 50%
- Bituminous coarse coal refuse sources will be the primary feedstock.

Fire Clay Coarse Refuse

Category	Element	Content (ppm)	Resource (tonnes)	Market Value ($*10^6)
Light	Sc	17	1554	$5,441.88
	La	53	4808	$24.04
	Ce	122	10937	$54.69
	Pr	14	1296	$115.70
	Nd	51	4632	$277.93
	Sm	11	994	$16.47
	Eu	2	155	$4.66
Heavy	Y	25	2276	$76.40
	Gd	10	867	$173.32
	Tb	0	44	$33.35
	Dy	6	530	$183.59
	Ho	2	159	$9.07
	Er	5	417	$11.54
	Tm	1	83	$124.99
	Yb	3	273	$27.34
	Lu	0	2	$1.40
Other CM	Co	23	2106	$66.48
	Li	174	15625	$146.87
	Mn	278	25033	$25.03
	V	140	12557	$138.13

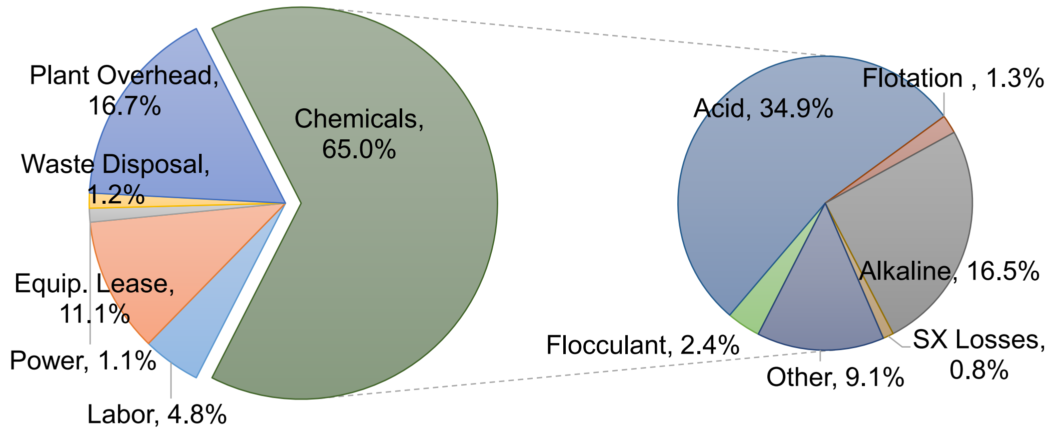
- 90 million tons in surface storage
- 29,000 metric tons of REEs
- 55,000 metric tons of other critical metals
- **$6.9 billion in total metal value**

Project Justification Statement

Economic Issues Being Addressed

- Prior analyses have shown that chemical costs (acid and base) are a major impediment to an economically viable process.

- Low feed grade, poor leaching recovery, low PLS concentration, and waste disposal are other concerns of note.



OPEX breakdown for a hypothetical coal-based REE recovery facility.

Associated Mineral Advantage

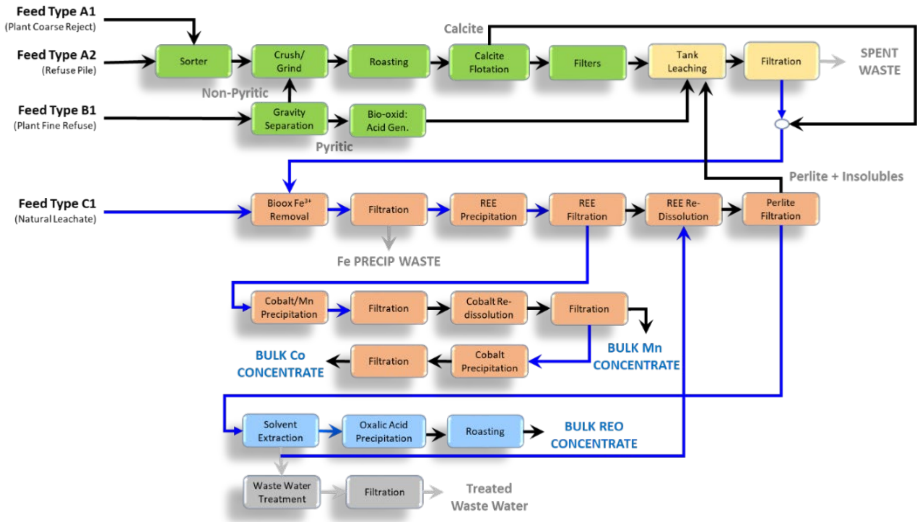
- Coal is associated with minerals that provide natural acidity and alkalinity:
    - Pyrite
    - Calcite
- Both minerals have physical properties that allow low cost recovery and concentration.

Size Fraction (mesh)	Weight (%)	Major Minerals (%)			
		Pyrite	Silica	Calcite	Kaolinite
+100	8.84	6.3	6.4	68.2	4.9
100 x 200	43.72	20.0	14.1	62.8	3.1
200 x 325	14.88	43.3	12.2	35.4	1.1
-325	32.56	30.1	44.8	21.0	3.7
Total	**100.00**	**25.5**	**23.1**	**45.6**	**3.2**

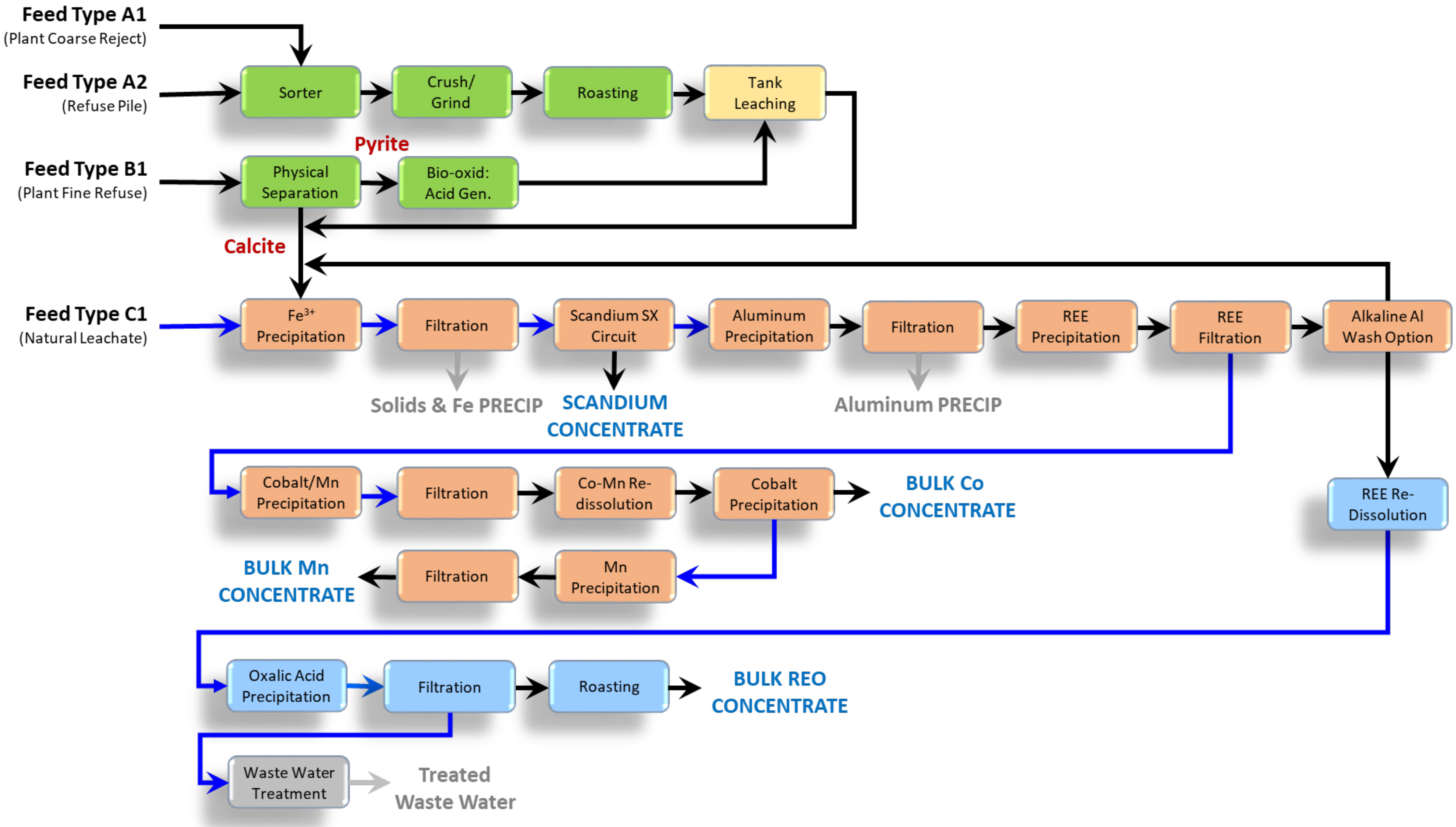
Project Justification Statement

Technical Solutions

- Utilize pre-concentration sorting to maximize REE concentration entering the leaching tanks.
- Utilize roasting to improve leach recovery and reduce acid consumption.
- Utilize low cost-physical separation to isolate acid-generating and base-generating constituents
- Utilize bio-oxidation to maximize acid production.
- Integrate process components in a novel flowsheet configuration to maximize technical and economic outcomes.



Block Flow Diagram



Project Schedule: Budget Period 1
(Four Month No-Cost Time Extension: BP1 end date April 2021)

ID	Task	Project Month																	
		2019			2020												2021		
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
	DOE Required Tasks																		
1	Project Management & Planning*																		
2	Finanical Plan for Commercialization*																		
3	Techno-Economic Assessment*																		
4	Provide Split Samples*																		
5	Feasibility Study*																		
	Laboratory Support Tasks																		
6	Optimization of Physical Separaitons *(crush, grind, sort,calicte float)*																		
7	Optimization of Acid Generation *(pyrite recovery, bioreduction* **)**							X	X	X									
8	Optimizaton of Roasting & Leaching							X	X	X									
9	Optimization of REE Recovery (*selective precip and/or SX*)							X	X	X									
10	Optimization of CM Recovery (*Co/Mn/Sc Precip or SX*)							X	X	X									
	Pilot-Scale Tasks																		
11	Environmental Monitoring and Management																		
12	Pilot Plant Upgrades and Modification *(Design, Bidding, procurement, fabrication, installation)*						X	X	X	X									X
13	Feedstock Collection and Preparation						X	X	X	X									
14	Pilot Plant System Shakedown									X									X
15	Pilot Plant Operation and Continuous Improvement																		
16	Operational Cost Analysis, Refinement and Optimization																		
17	Secondary Feedstock Testing																		
18	Decommissioning and Disposition																		

** = DOE Required Task*

X = one month delay in activity

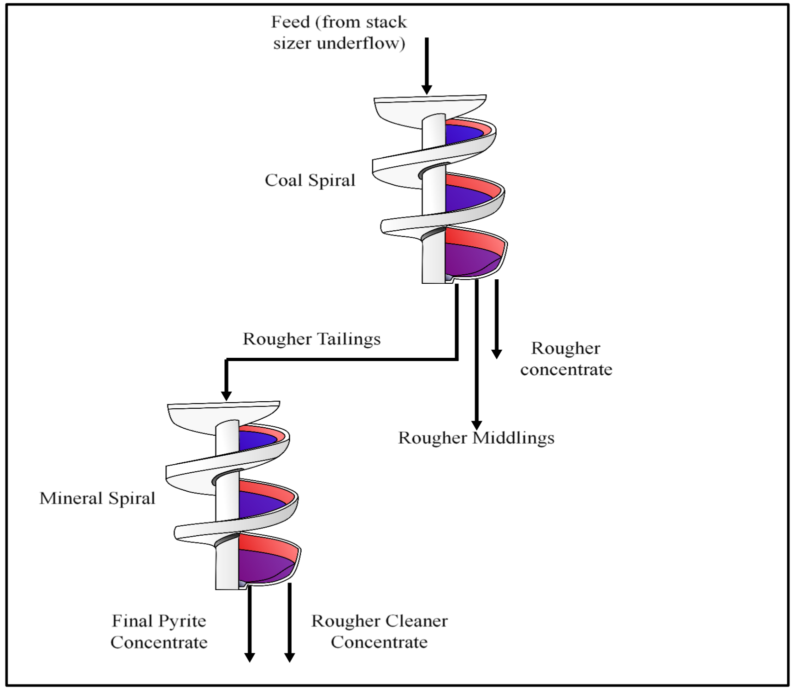
Project Schedule: Budget Period 2
(Project end date June 30, 2022)

ID	Task	Project Month														
		2021									2022					
		A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
	DOE Required Tasks															
1	Project Management & Planning*															
2	Finanical Plan for Commercialization*															
3	Techno-Economic Assessment*															
4	Provide Split Samples*															
5	Feasibility Study*															
	Laboratory Support Tasks															
6	Optimization of Physical Separaitons *(crush, grind, sort,calicte float)*															
7	Optimization of Acid Generation *(pyrite recovery, bioreduction* **)**															
8	Optimizaton of Roasting & Leaching															
9	Optimization of REE Recovery (*selective precip and/or SX*)															
10	Optimization of CM Recovery (*Co/Mn/Sc Precip or SX*)															
	Pilot-Scale Tasks															
11	Environmental Monitoring and Management															
12	Pilot Plant Upgrades and Modification *(Design, Bidding, procurement, fabrication, installation)*															
13	Feedstock Collection and Preparation															
14	Pilot Plant System Shakedown															
15	Pilot Plant Operation and Continuous Improvement															
16	Operational Cost Analysis, Refinement and Optimization															
17	Secondary Feedstock Testing															
18	Decommissioning and Disposition															

** = DOE Required Task*

Physical Separations

Pyrite-Calcite Concentration



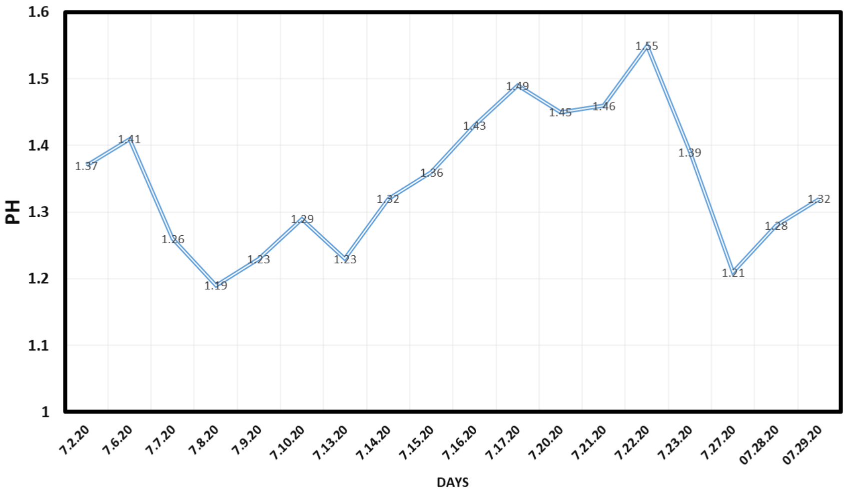
Size Fraction	Weight (%)	Percentage						
		Pyrite	Silica	Calcite	Kaolinite	Barite	Montmoril.	Bohmite
+100 mesh	8.84	6.3	6.4	68.2	4.9	---	---	14.2
100 mesh x 200 mesh	43.72	20.0	14.1	62.8	3.1	0.0	---	---
200 mesh x 325 mesh	14.88	43.3	12.2	35.4	1.1	0.6	7.4	---
-325 mesh	32.56	30.1	44.8	21.0	3.7	0.3	---	---
Total	100.00	25.5	23.1	45.6	3.2	0.2	1.1	1.3

Calcite-Pyrite Circuit Analyses

Sample	Density (g/cm^3)	Ca (ppm)	Fe (ppm)	Si (ppm)	% Pyrite	% Calcium Carbonate
CYC.100920.OF.X20.	2.24	2.400	4.310	0.670	8.83	5.74
CYC.102020.OF.X20.	2.70	4.28	7.85	0.275	16.21	10.31
CYC.SOLID(2.0).O/F.3.X20.	2.65	6.696	9.924	0.188	21.06	16.57
CYC.SOLID(2.0).O/F.2.X20.	2.65	7.530	10.585	0.149	22.35	18.55
CYC.101420.OF.X20.	2.65	9.632	12.722	0.191	26.06	23.02
CYC.SOLID(2.0).FEED.2.X20.	3.28	4.800	16.471	0.069	35.01	11.90
SCREEN.OF.LMT.FLOAT.X20.	2.86	15.462	18.860	0.286	39.97	38.23
CYC.101520.OF.X20.	3.29	7.668	19.601	0.126	41.46	18.92
CYC.100920.FEED.X20.	2.94	7.526	21.177	0.286	41.94	17.39
CYC.101420.FEED.X20.	2.83	7.05	21.078	0.118	44.81	17.49
CYC.101620.FEED.X20.	3.23	6.035	22.506	0.099	45.07	14.10
CYC.BARREL.2.X20.	3.12	8.611	22.682	0.114	45.64	20.21
CYC.101620.UF.X20.	3.42	7.724	23.679	0.091	47.47	18.06
CYC.BARREL.3.X20.	3.42	8.218	24.106	0.071	50.05	19.91
CYC.102020.FEED.X20.	3.43	6.579	24.709	0.119	50.62	15.72
CYC.101520.FEED.X20.	3.47	5.38	26.232	0.111	51.66	12.36
CYC.100920.BARREL.1.X20.	3.38	8.535	25.495	0.091	52.08	20.34
CYC.SOLID(2.0).FEED.3.X20.	3.10	7.252	26.671	0.119	52.97	16.80
CYC.BARREL.1.X20.	3.54	6.536	27.062	0.053	55.28	15.58
CYC.100920.UF.X20.	3.45	7.499	26.941	0.102	55.72	18.10
CYC.102020.UF.X20.	3.79	5.884	27.968	0.067	58.47	14.35
CYC.101320.UF.X20.	4.07	6.115	28.104	0.074	59.10	15.00
CYC.101520.UF.X20.	3.89	4.161	29.38	0.069	60.83	10.05
CYC.101420.UF.X20.	3.64	6.431	29.432	0.035	62.63	15.97
CYC.SOLID(2.0).U/F.3.X20.	3.85	6.689	30.719	0.042	64.60	16.41
CYC.SOLID(2.0).U/F.2.X20.	3.76	5.506	32.096	0.030	65.50	13.11
SCREEN.OF.LMT.SINK.X20.	4.12	3.077	36.800	0.016	77.62	7.57

Sulfuric Acid Generation by Biooxidation

- Concentrated pyrite is used as feed to a bio-oxidation reactor.
- Bacteria is used to drive the oxidation reaction converting Fe^{2+} to Fe^{3+}.
- Tests have indicated that 0.2M sulfuric acid can be consistently produced with a pH value around 1.0 – 1.2.
- Acid cost reduction is anticipated to be 75% or greater.



Bioreactor operating procedure and performance

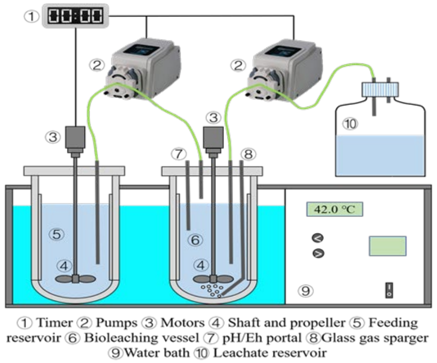


***Figure**: (a) Schematic Diagram of Bioreactor system; (b) Digital image of Bio-Reactor*

- *The bioreactor was filled with 300ml of stored bioleaching solution containing bacterial culture along with 1 L 9K medium that was already prepared to make the total volume to 1.3L in the bioleaching reactor.*
- *Overhead stirrer speed was set up at 680 rpm, and gas flow was set up at 0.5 l/min, which was changed to 0.2 l/min later. After that, when Eh reached to 600mV, pyrite feeding was started.*
- *The pyrite feeding slurry was made with 5 grams of pyrite concentrate (approximately 60% pyrite) and 100ml of 9k medium and was added into the feeding vessel.*

Bioreactor restarting procedure

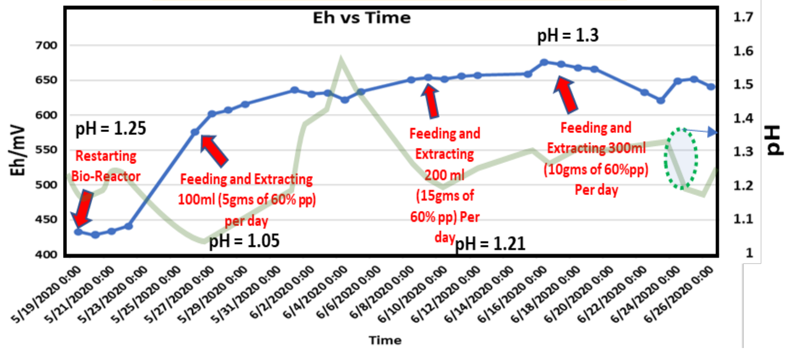
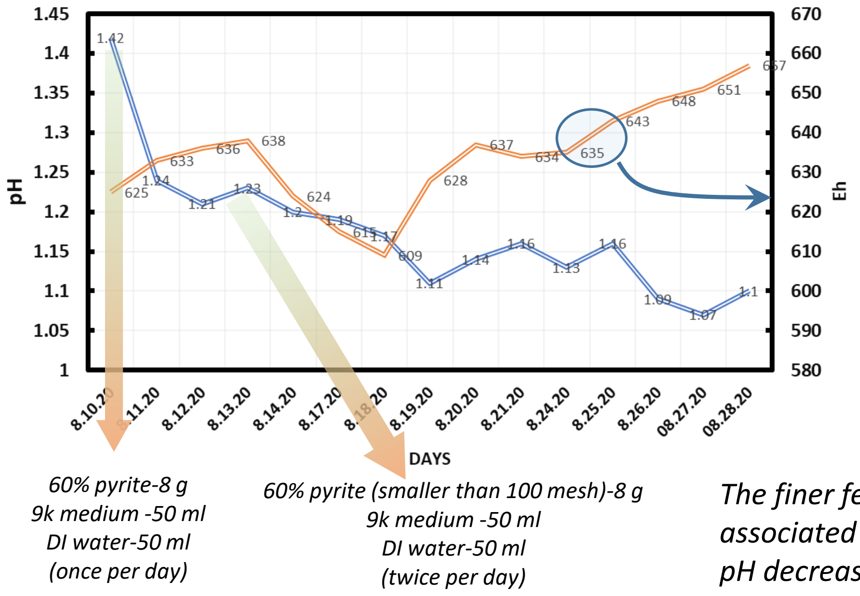


***Figure** : Eh and pH values vs. time for different amount of Feeding solution*



The finer feed is associated with a pH decrease.

***Figure** : Eh and pH values vs. time (most recent)*

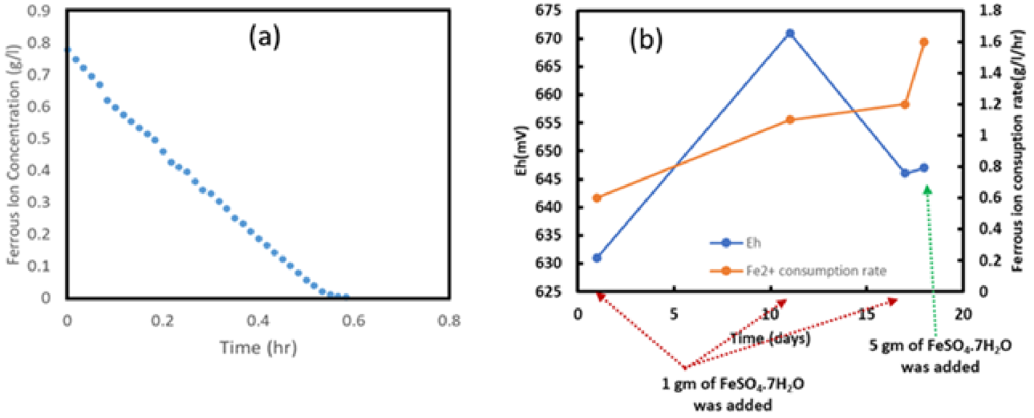
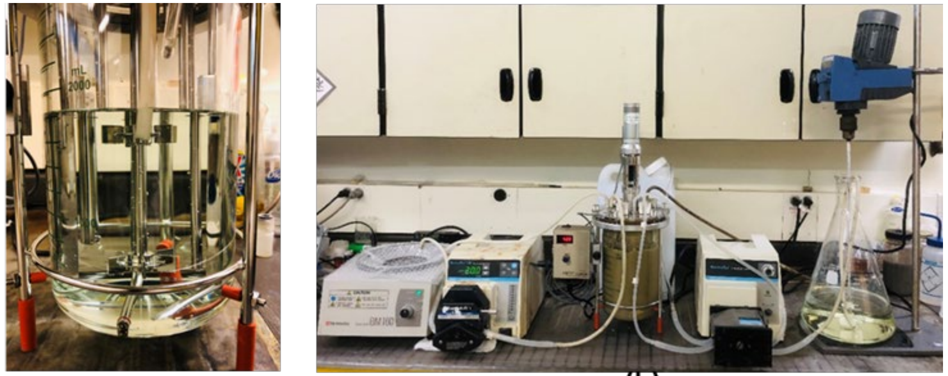


***Figure**: (a) Bio-oxidation rate assessment after addition of 5g $FeSO_4{\cdot}7H_2O$ on 06.23.2020 at Eh 647 mV; (b) overall comparison of bio-oxidation rate for different days and at different Eh values*

New 3L Bioreactor



(a) (b)

***Figure**: (a) Digital image Bioreactor system; (b) overall setup in action*

- *A new 3L bioreactor was purchased from Chemglass Life Sciences (See Figure), and other accessories, such as the circulating water heating, air injection, and the automatic feeding system, that were connected to the new reactor.*
- *Overhead stirrer speed was set up at 680 rpm, and gas flow was set up at 0.5 l/min, which was changed to 0.2 l/min later. After that, when Eh reached to 600mV, pyrite feeding was started.*
- *Other restarting parameters were similar to previous one.*

Bioreactor restarting procedure

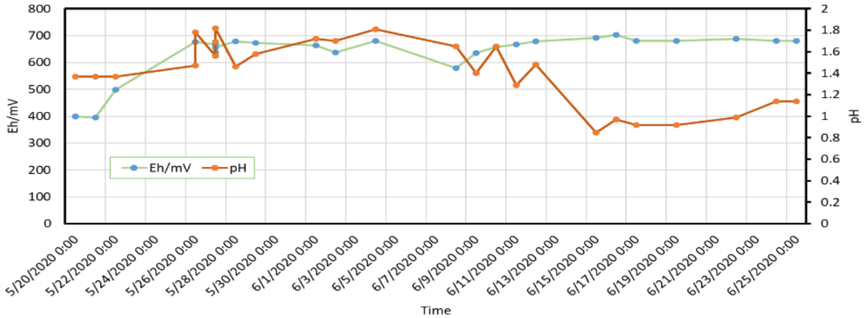
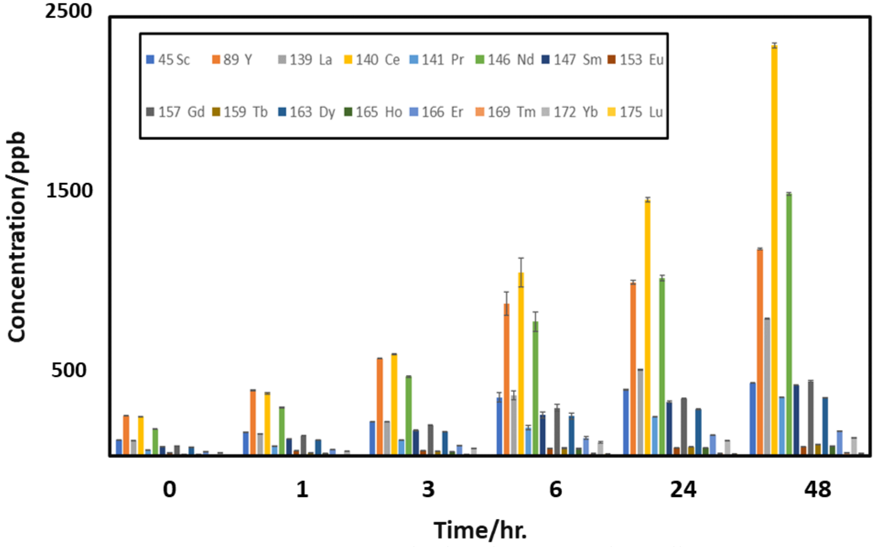


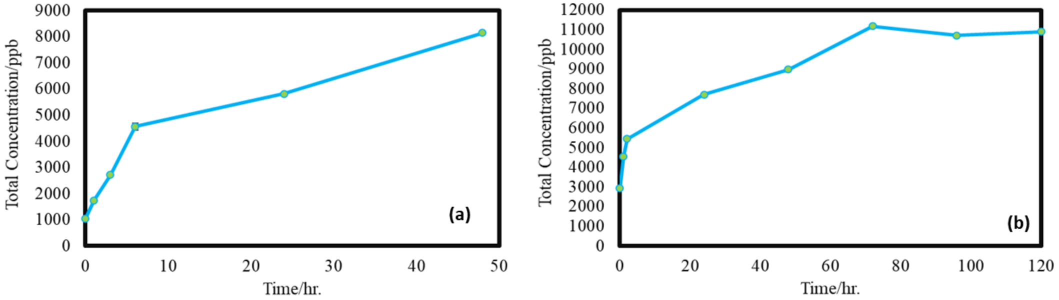
***Figure** : Eh and pH values vs. time (for new 3L bioreactor)*

Coal Waste Bioleaching

Two samples of coal waste (Fire Clay coarse refuse roaster feed and WK 13 coarse refuse roaster feed) were tested to evaluate their potential for heap bioleaching using bioleaching solution accumulated from other bioreactors.



REEs concentrations in the leaching samples collected during the leaching process of Fire Clay refuse.



Total REEs concentration vs. time in the (a) Fire Clay refuse leaching test and (b) WK 13 refuse leaching test.

Bio-oxidation Reactor Scaling

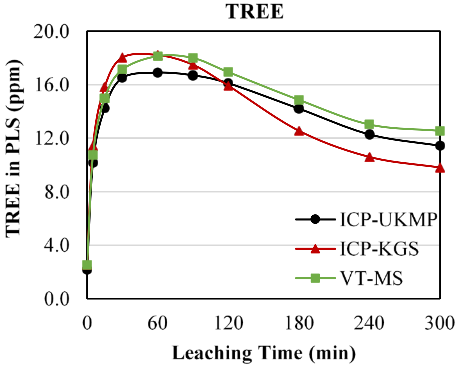
3-liter Biooxidation Reactor

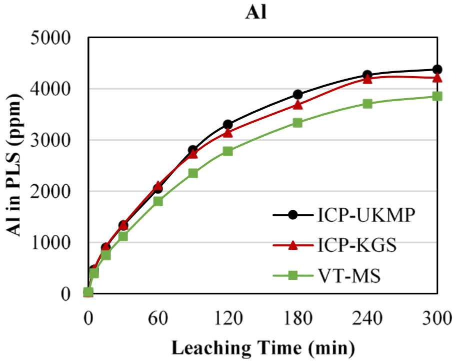
250-gallon Biooxidation Reactor

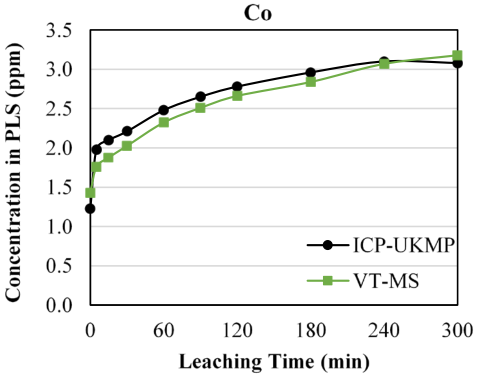
Three 3000-gallon Biooxidation Reactors

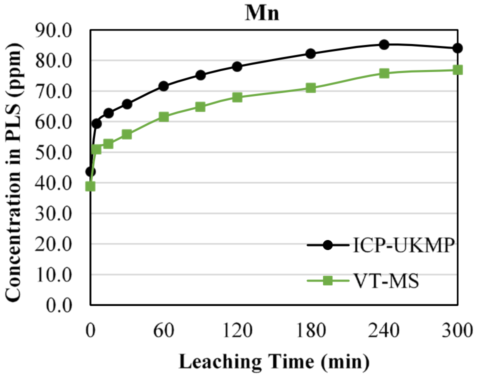
Leaching Characteristics of Bio-oxidation Acid

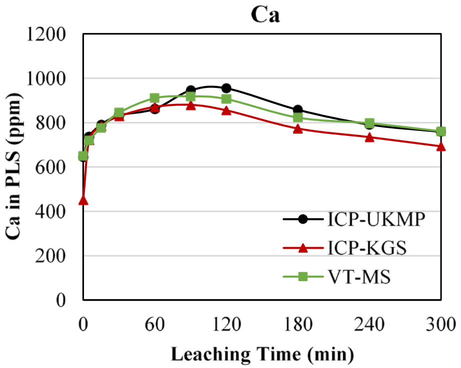
- Leaching performed
- Peak recovery of TREES achievable in short leaching time.
- Prevents Al leaching thus reduce downstream chemical consumption.
- Reduction of Na and Fe indicated the formation of Na-jarosite (XRD confirmed).
- Data comparison between ICP-OES and ICP-MS.

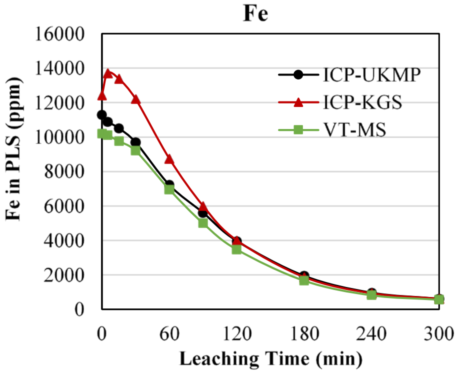


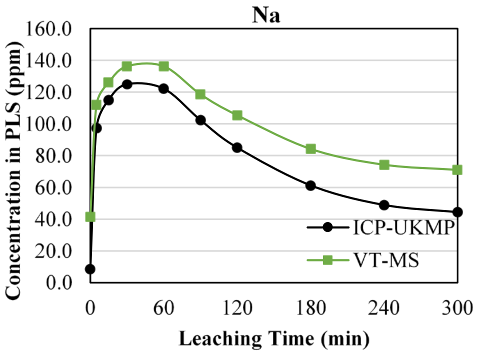


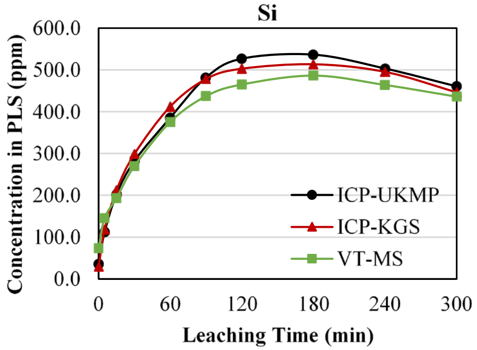






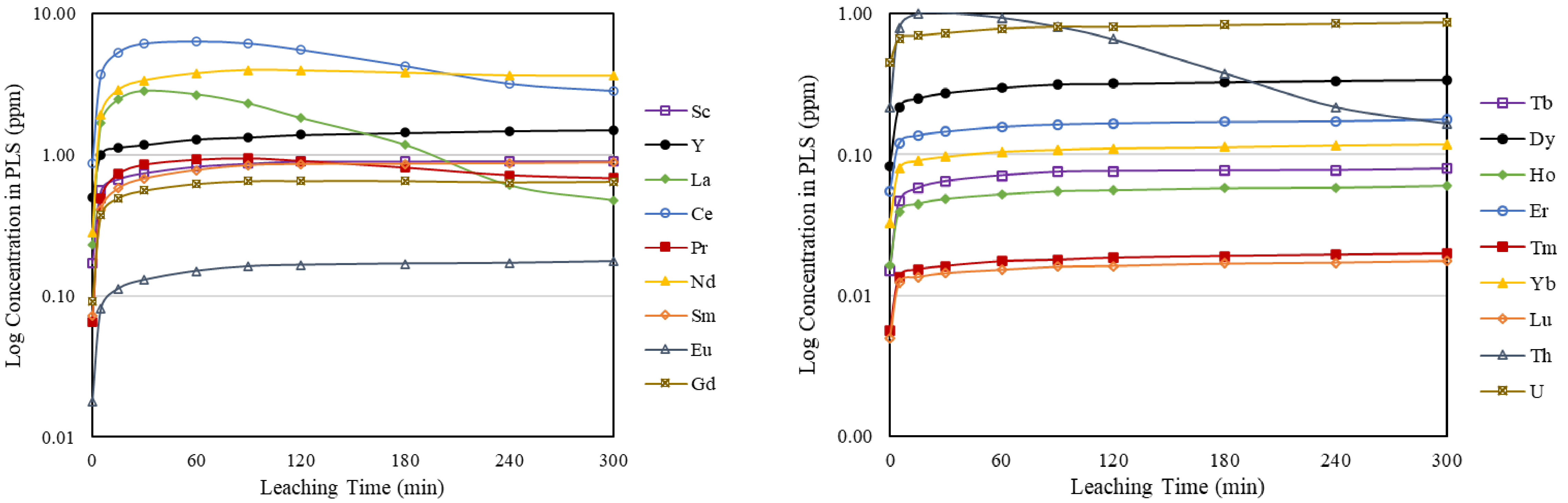






Leaching condition: Bioleach Acid, S/L=1/5 (w/v), 75 °C. Solid feed: Dotiki pile minus 1.5-inch, hammer milled, roast at 600 °C 20 minutes. Solid weight gained 12% after 5 hours leaching.

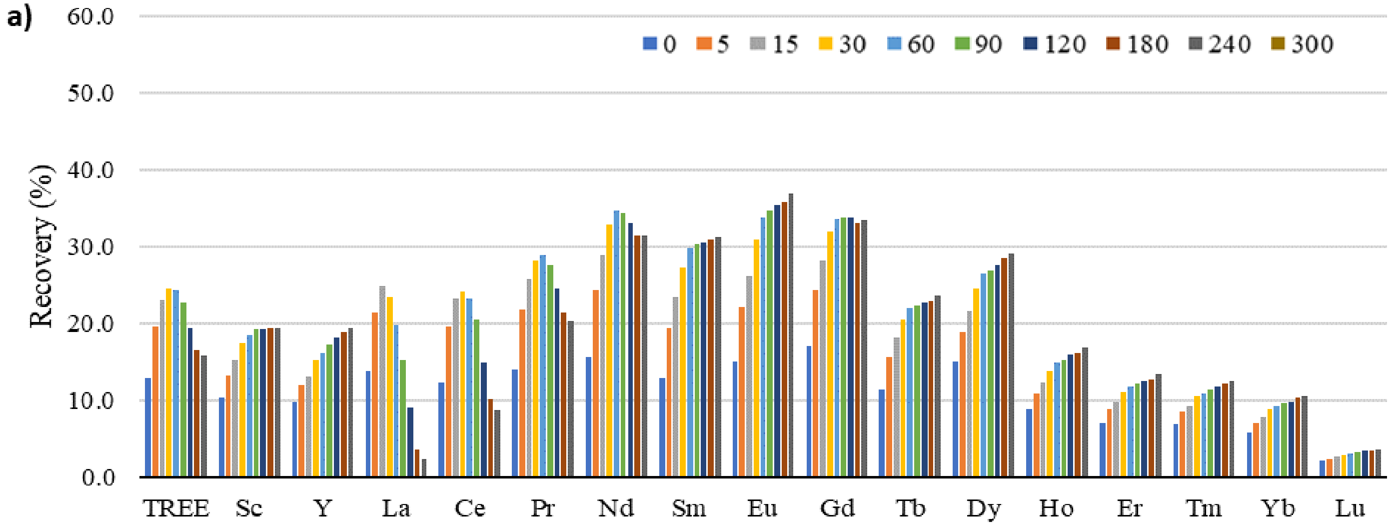
Leaching Characteristics of Bio-oxidation Acid



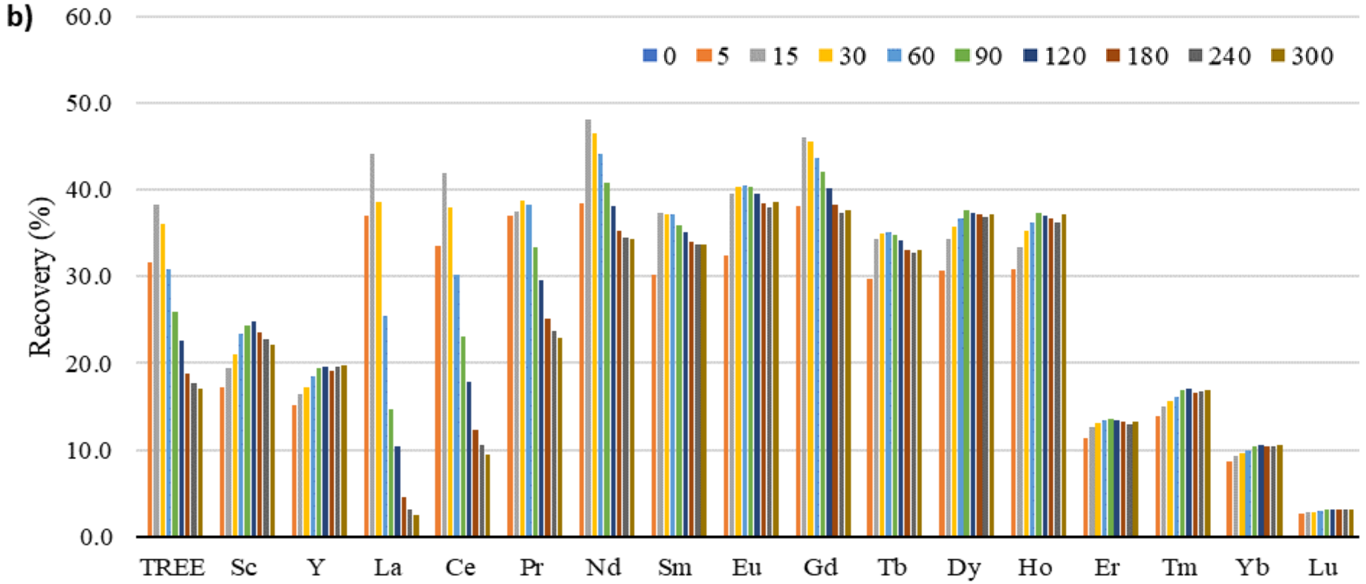
- Ce peak occurs at 1 hour, La peak occurs at 30 minutes.
- Pr and Nd showed a slightly head down after 90 minutes of leaching.
- Light REEs coprecipitation occurred with the formation of gypsum (CaSO4).
- Heavy REEs not affected.
- REE recovery reached peak at 30-60 minutes, whereas recovered value of REEs and critical elements increased with prolonged leaching time.

Leaching Characteristics of Bio-oxidation Acid

Particle Size Effect



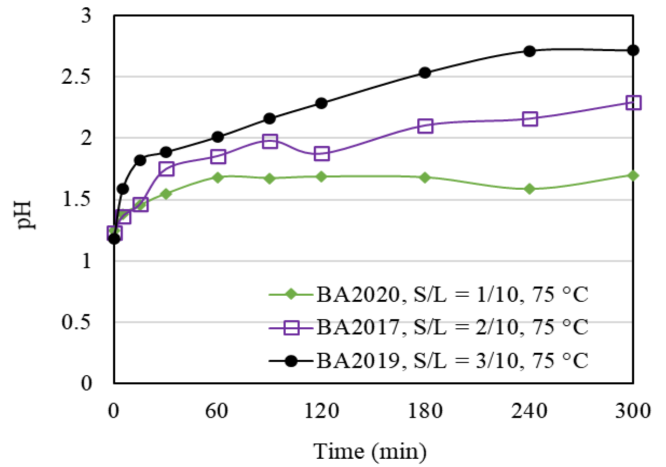
- *Lixiviant: Bioleach acid;*
- *S/L:1/5 w/v;*
- *Temperature: 75 ℃.*
- *Feed size: 2 mm top size*
- *Roasting: 600 ℃ for 20 minutes;*
- *Ending pH: 2.35*

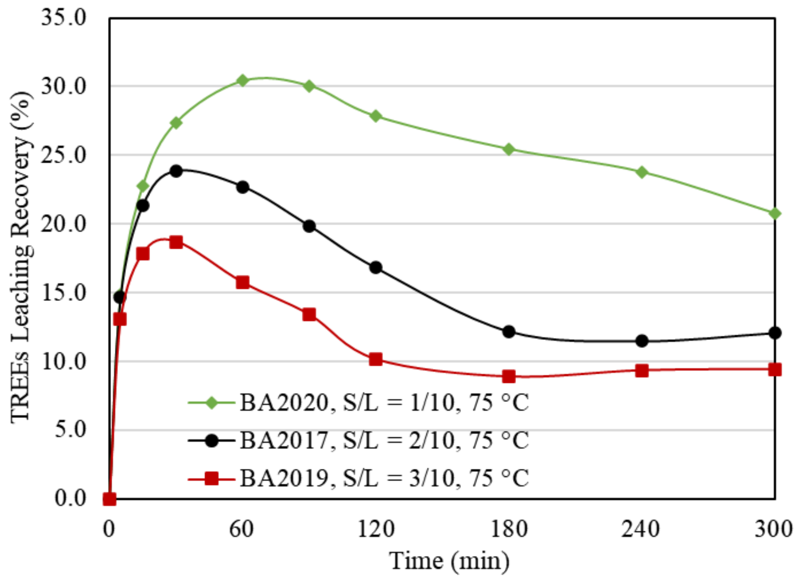


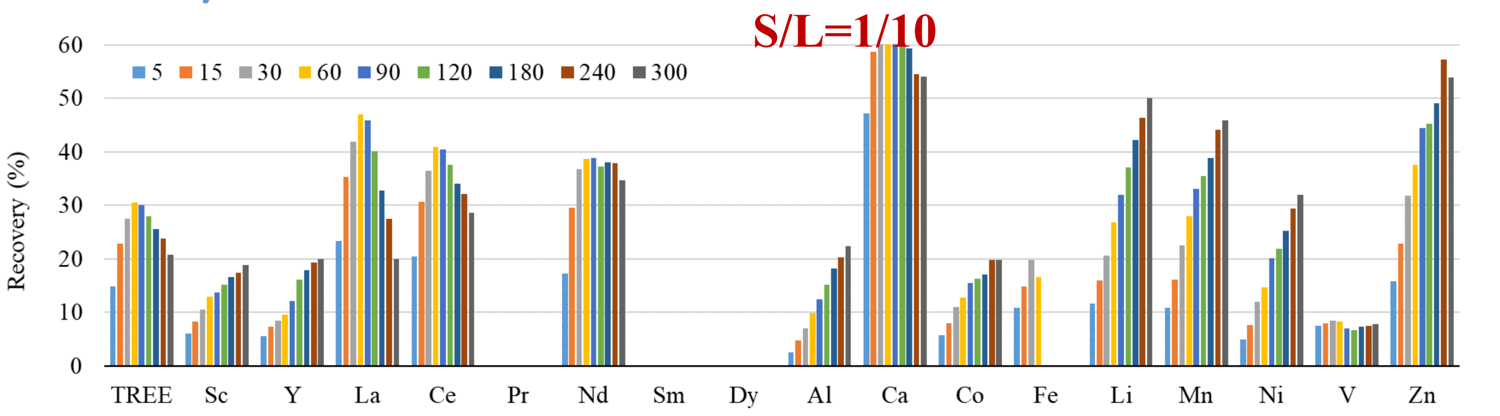
- *Lixiviant: Bioleach acid;*
- *S/L:1/5 w/v;*
- *Temperature: 75 ℃.*
- *Feed size: 177 microns top size*
- *Roasting: 600 ℃ for 2 hours*
- *Ending pH: 2.5*

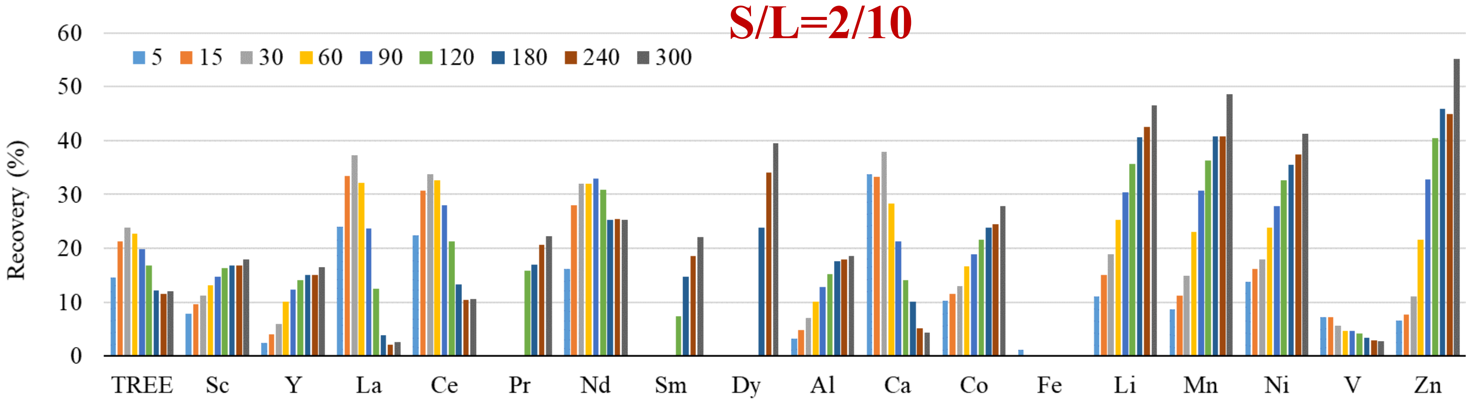
Leaching Characteristics of Bio-oxidation Acid

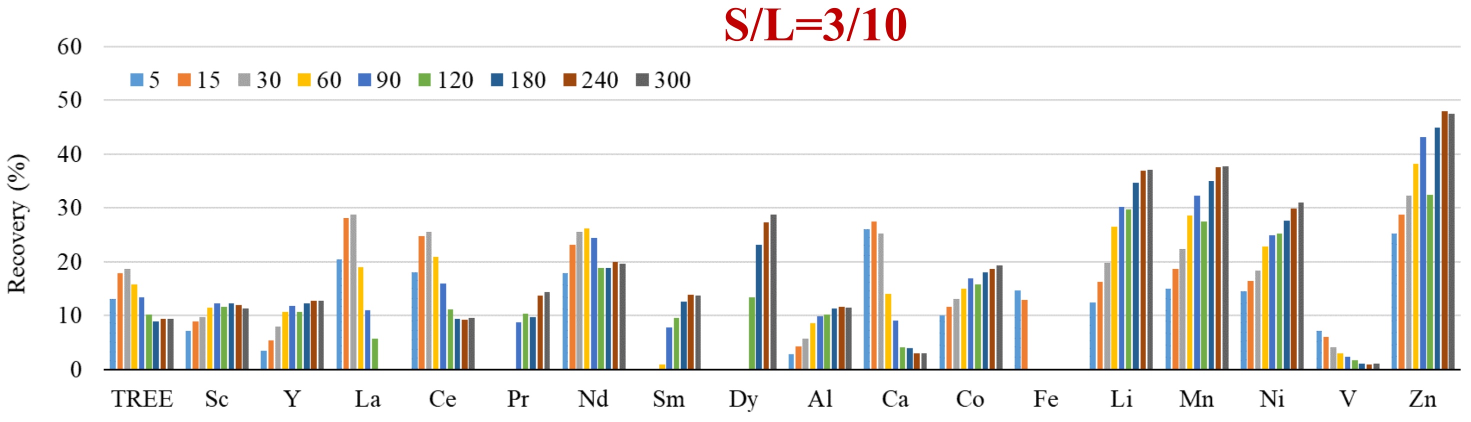
Solid-to-liquid Ratio Effect





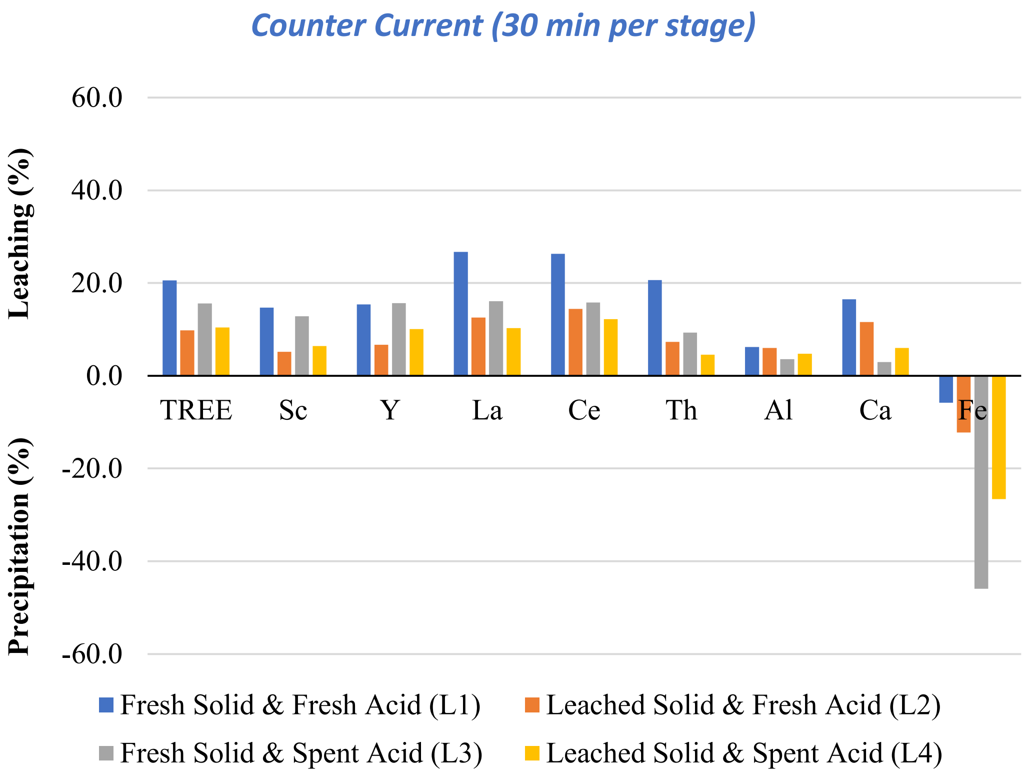


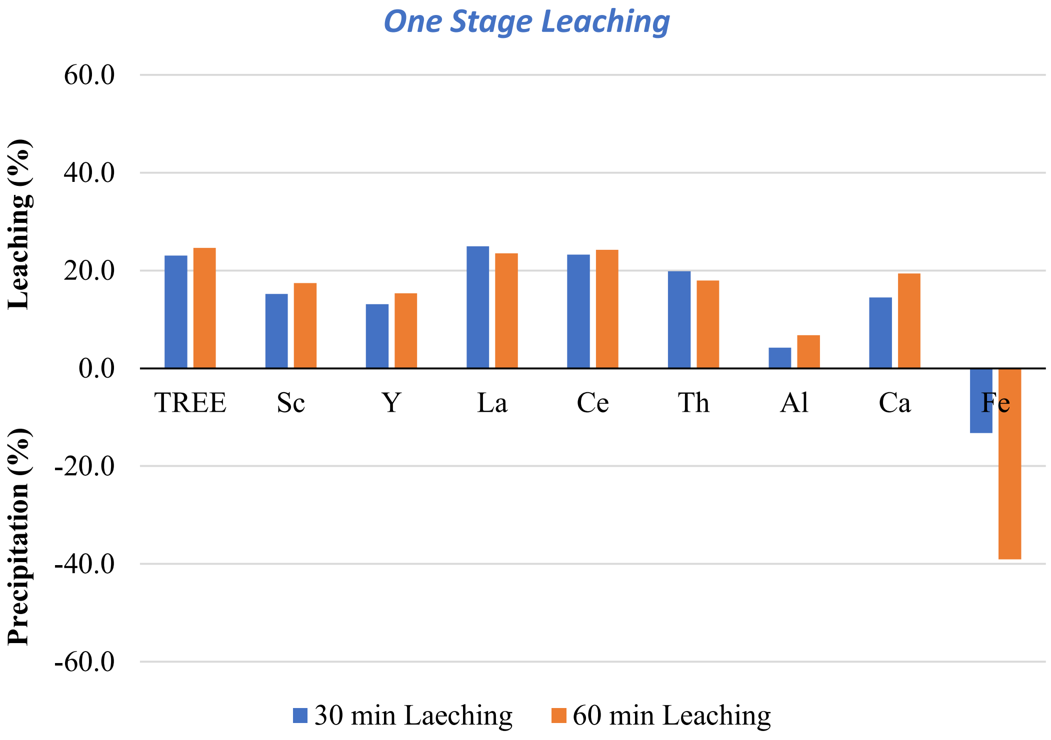


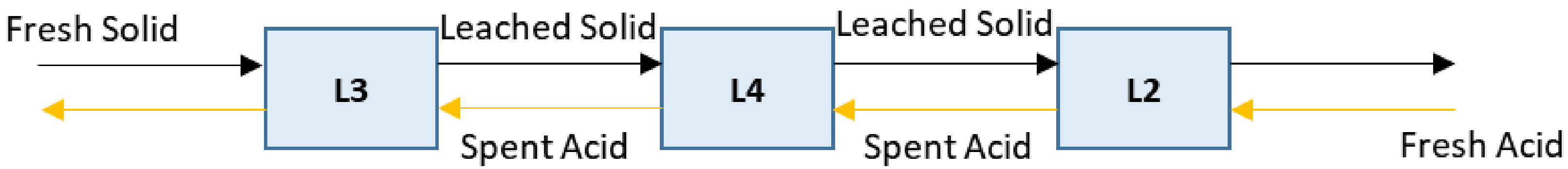


Leaching Characteristics of Bio-oxidation Acid

Counter Current Leaching



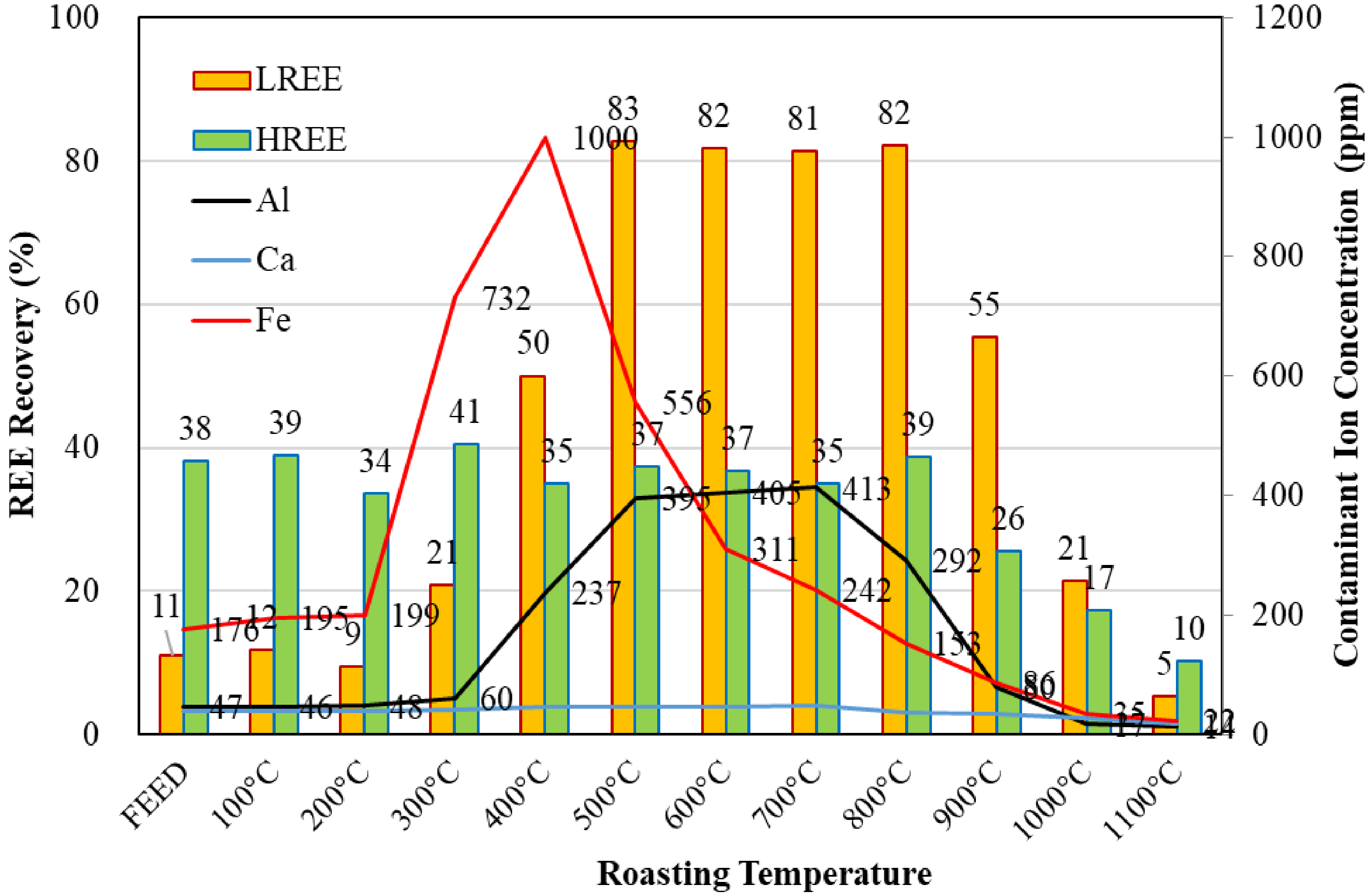




Simulated Stage Recovery%: ***15.6%*** ***10.4%*** ***9.8%***

Optimization of Rare Earth Recovery by Pre-Leach Roasting

TGA-DSC Studies



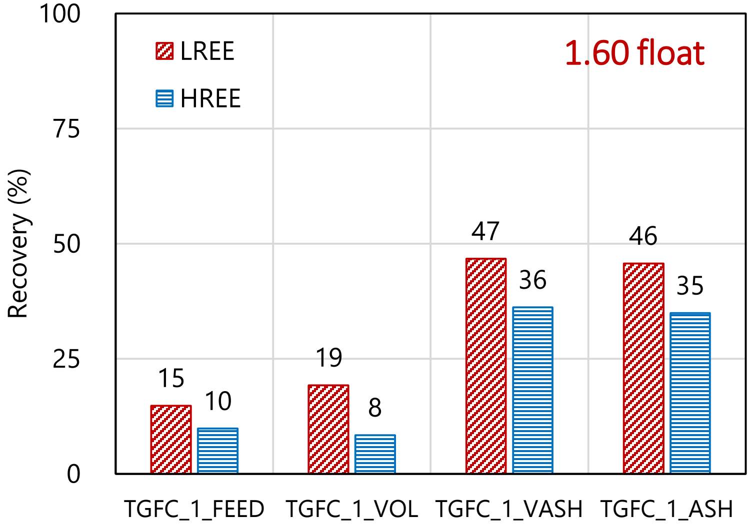
REE leaching recoveries for roasting products of 2.20 sink density fraction of WK No.13 material. (1.2 M H2SO4, 75°C for 5 hours)

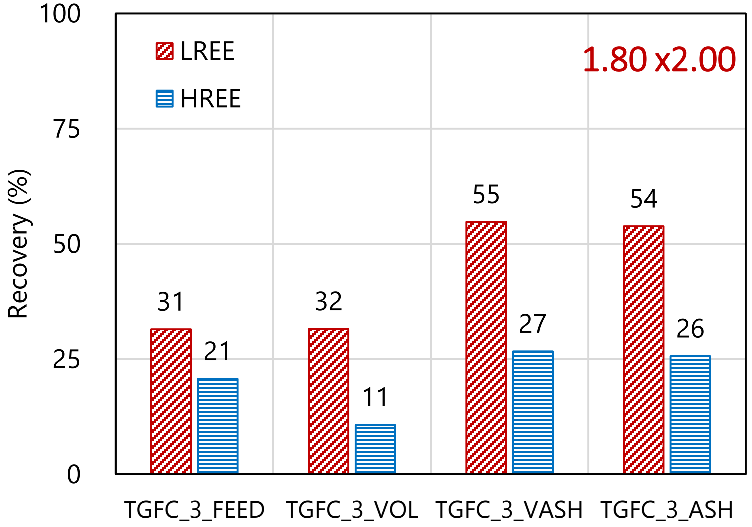
- Leaching Recovery by Roasting Temperature
- Pronounced Effect on Light Elements
- Fe Reduction by Magnetic Material Removal

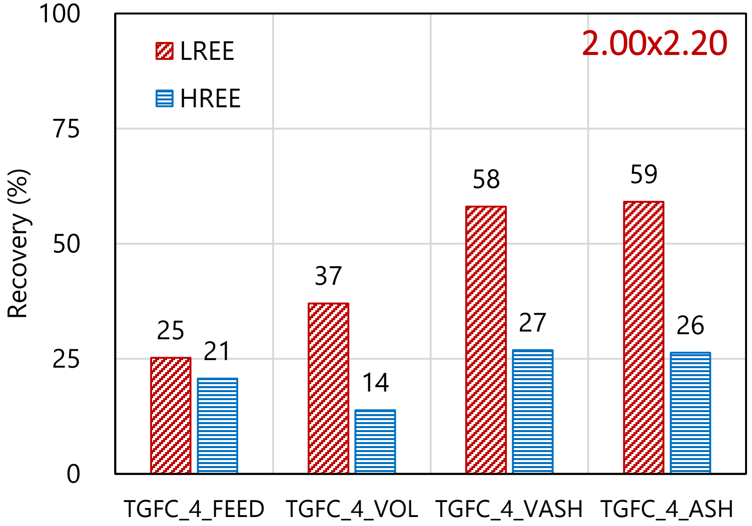
Optimization of Rare Earth Recovery by Pre-Leach Roasting

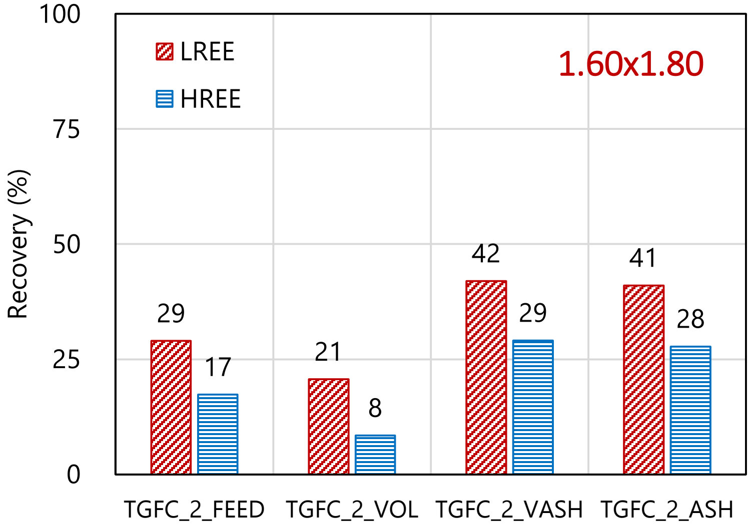
LECO TGA-Fire Clay (volatiles removed at 600°C, ashed at 600°C)

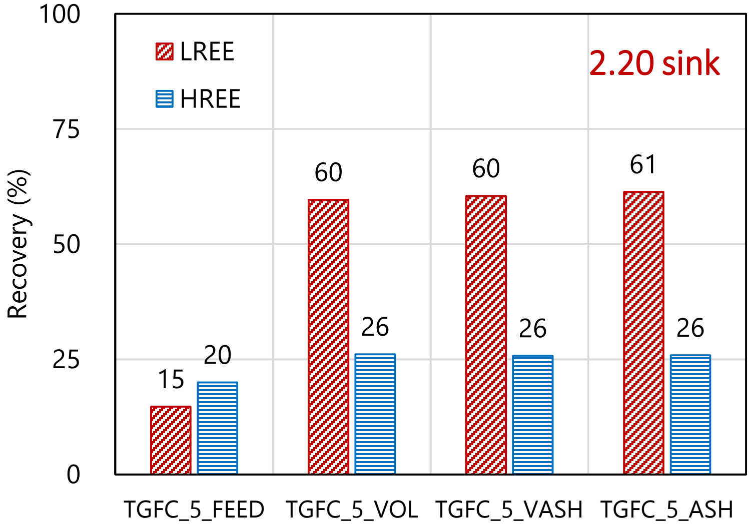
Leaching at 1.2M sulfuric acid at 75°C for 1 hours at 1% solids







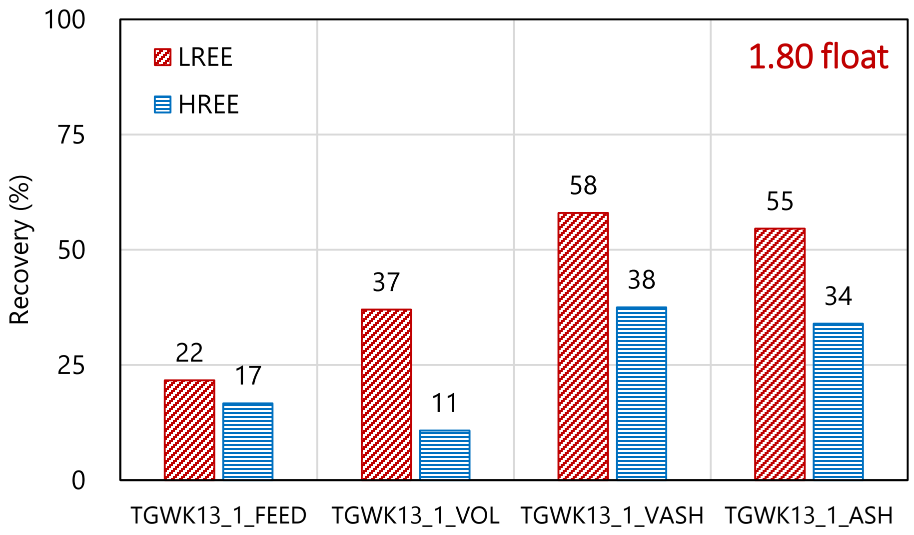


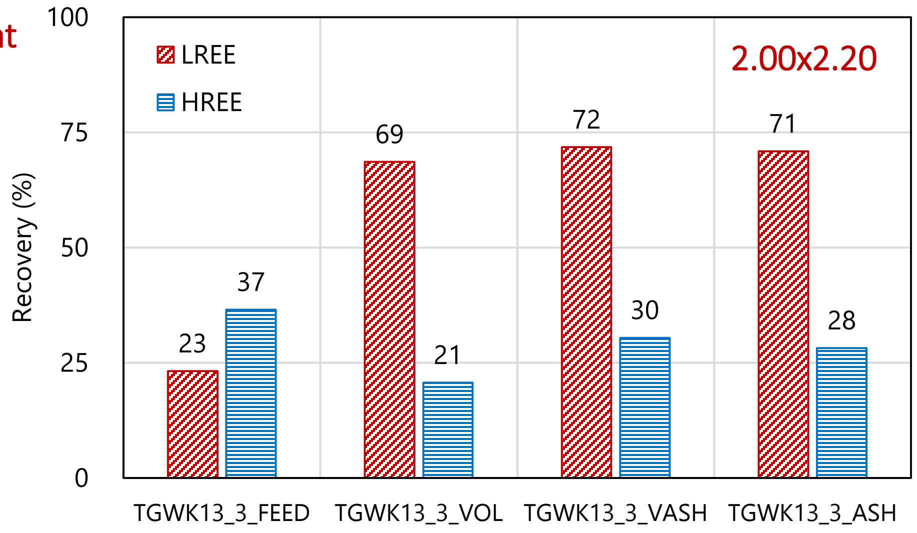


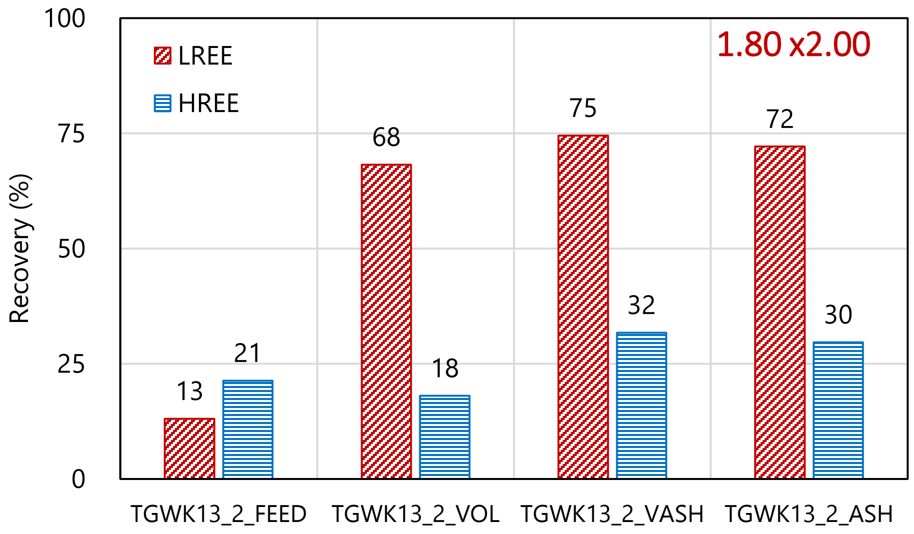
Optimization of Rare Earth Recovery by Pre-Leach Roasting

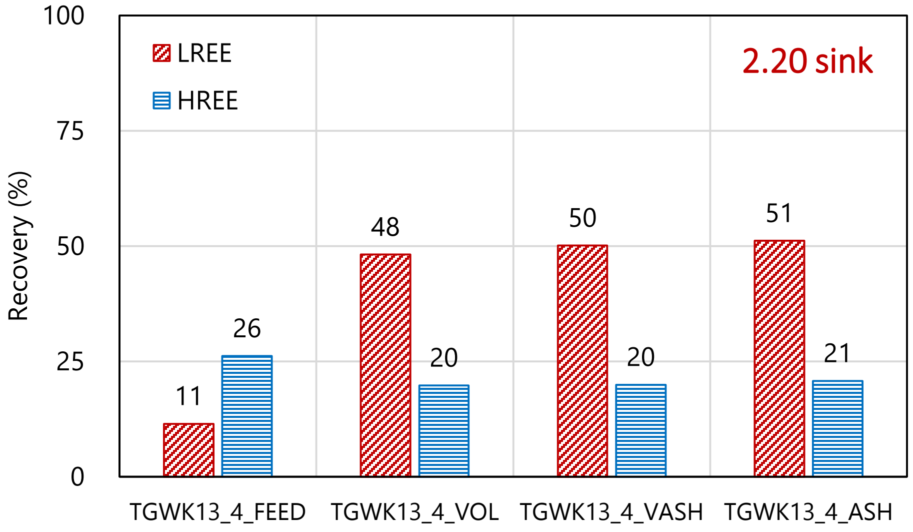
LECO TGA-WK-13 (volatiles removed at 600°C ashed at 600°C)

Leaching at 1.2M sulfuric acid at 75°C for 1 hours at 1% solids





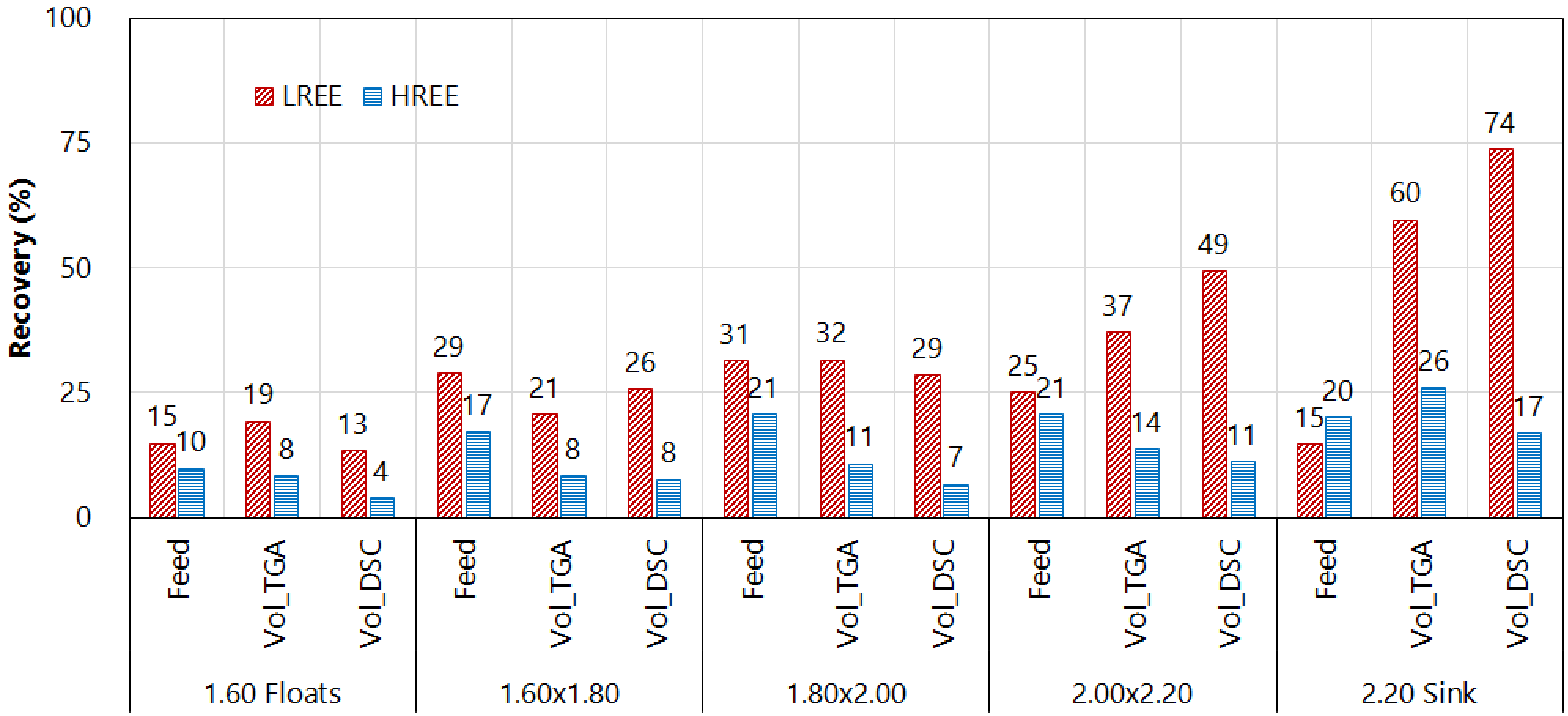




Optimization of Rare Earth Recovery by Pre-Leach Roasting

Inert Roasting Effects at 1000^{O}C: Fire Clay

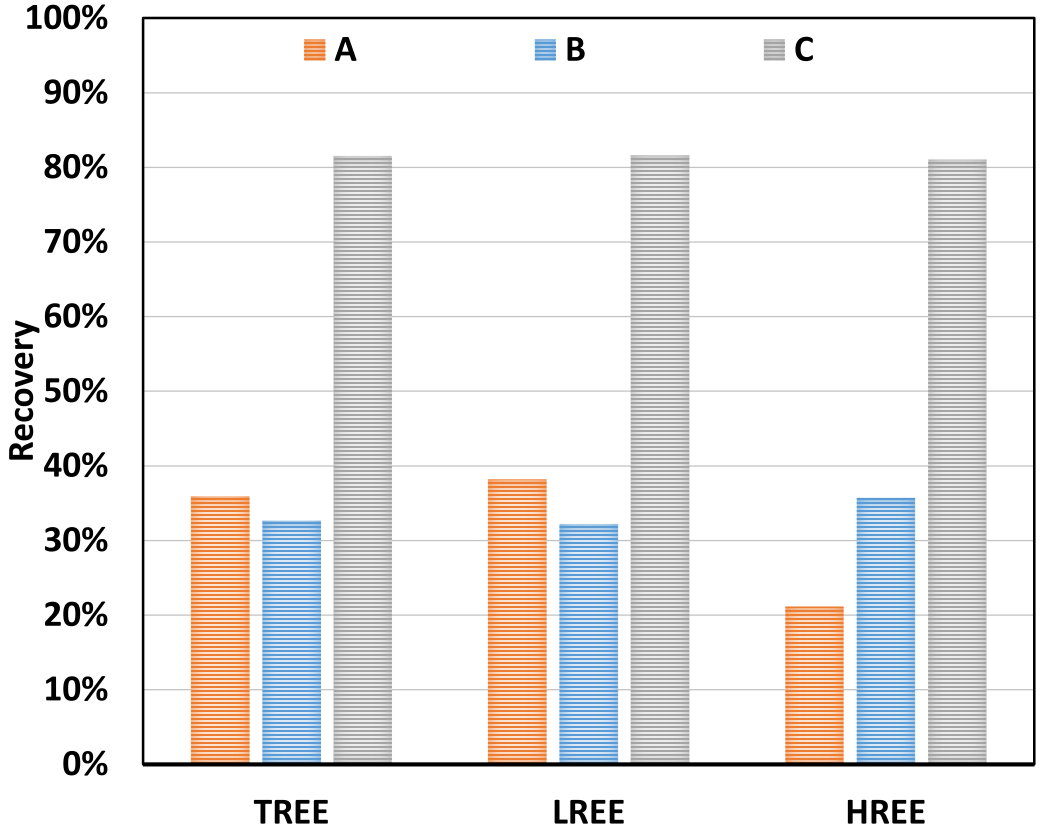
Leaching at 1.2M sulfuric acid at
75°C for 1 hours at 1% solids



Optimization of Rare Earth Recovery by Pre-Leach Roasting

Acid Baking using sulfuric acid

- The results shown in the figure compare the recoveries obtained from 1st and 2nd stage acid baking with the blank roasting using the same acid molarity in leaching.
- The blank roasting performed at 600°C yields only 35.92% REE recovery, with HREEs being approximately 22%.
- The acid baking performed at 250°C recovered approximately 33% TREEs while obtaining 35.68% in HREEs.



A: Blank roasting at 600°C followed by 0.5M H_2SO_4 leaching, **B:**1st stage acid baking using 1:1 acid to coal ratio and leaching with DI water, **C:**Two-Stage acid baking at 250°C using 1:1 acid to coal ratio and leaching with DI water (Each leaching operation was performed at 5% S/L, 75 °C, and 2hrs)

Optimization of Rare Earth Recovery from PLS

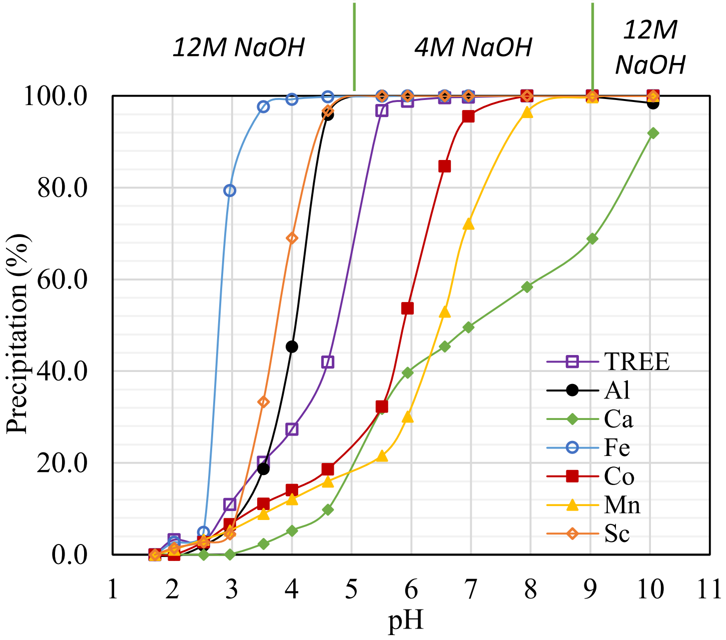
Precipitation using NaOH

50 min leaching filtrate

Leachate Solution
pH: 1.708
Eh: 717.9 RmV

TREE: 14.41 ppm
Al: 1650 ppm
Ca: 747 ppm
Fe: 6723 ppm

NaOH Dose at pH 4.5: 22.49 g/L

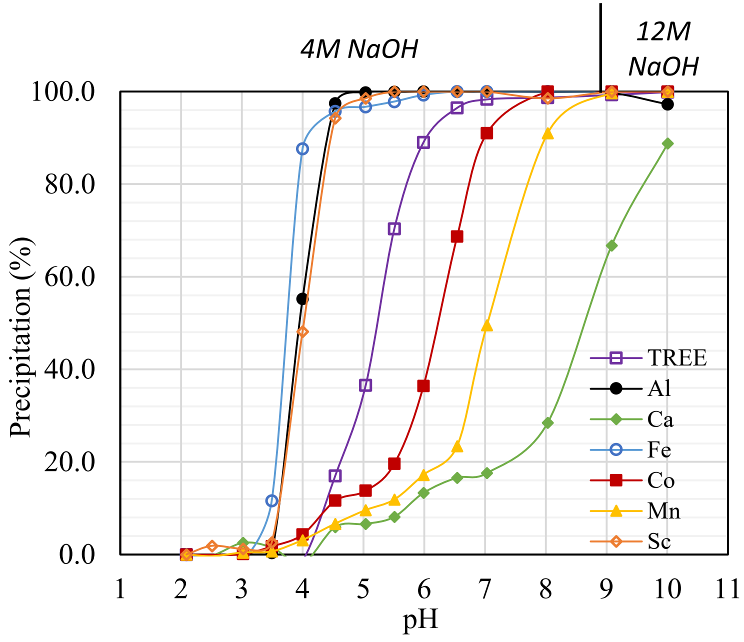


3 hour leaching filtrate

Leachate Solution
pH: 2.091
Eh: 691.6 RmV

TREE: 12 ppm
Al: 3595 ppm
Ca: 718 ppm
Fe: 1071 ppm

NaOH Dose at pH 4.5: 15.25 g/L

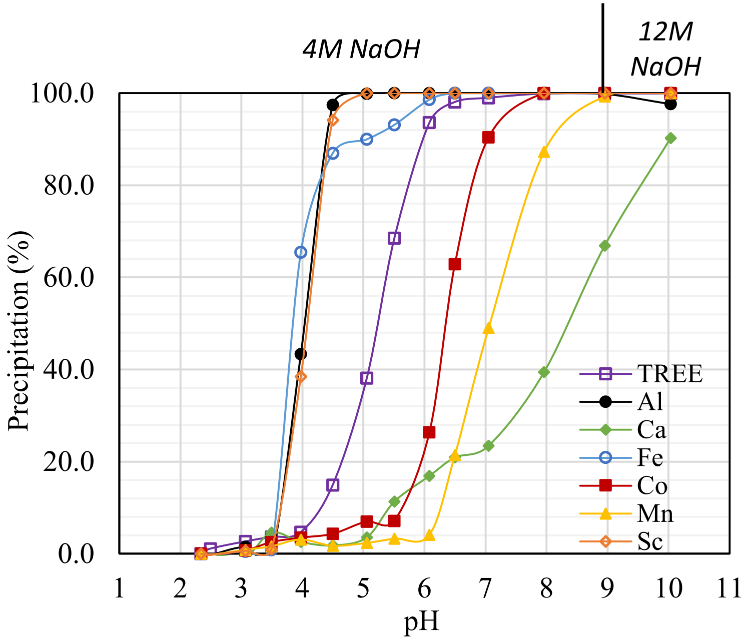


5 hour leaching filtrate

Leachate Solution
pH: 2.339
Eh: 412.1 RmV

TREE: 10.69 ppm
Al: 4033 ppm
Ca: 775 ppm
Fe: 538 ppm

NaOH Dose at pH 4.5: 14.62 g/L



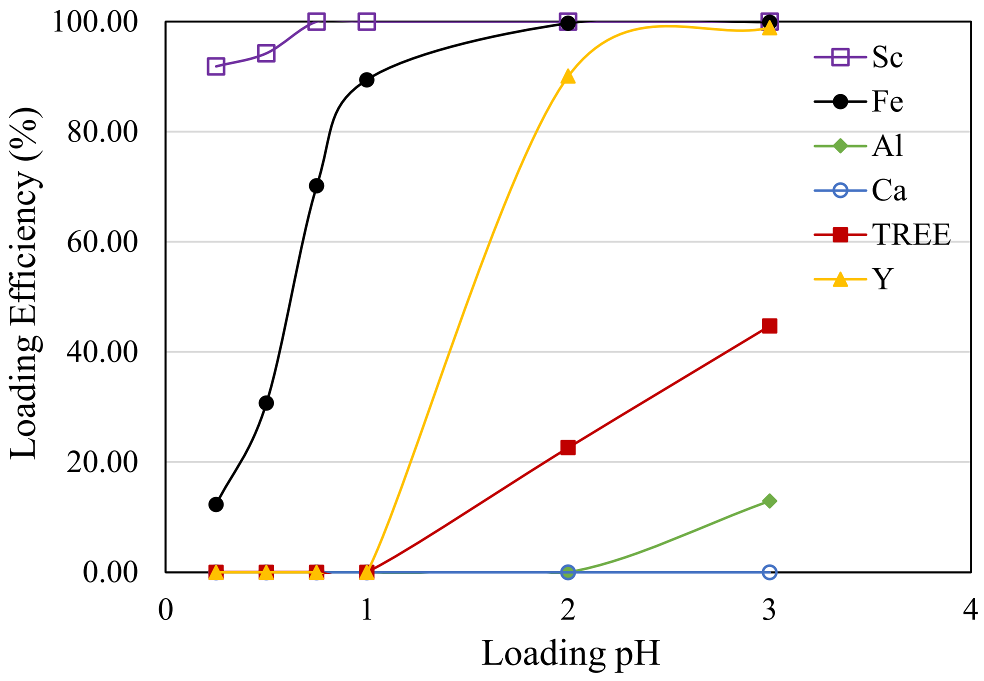
Rare Earth Recovery from PLS
Scandium SX Recovery

Objective:

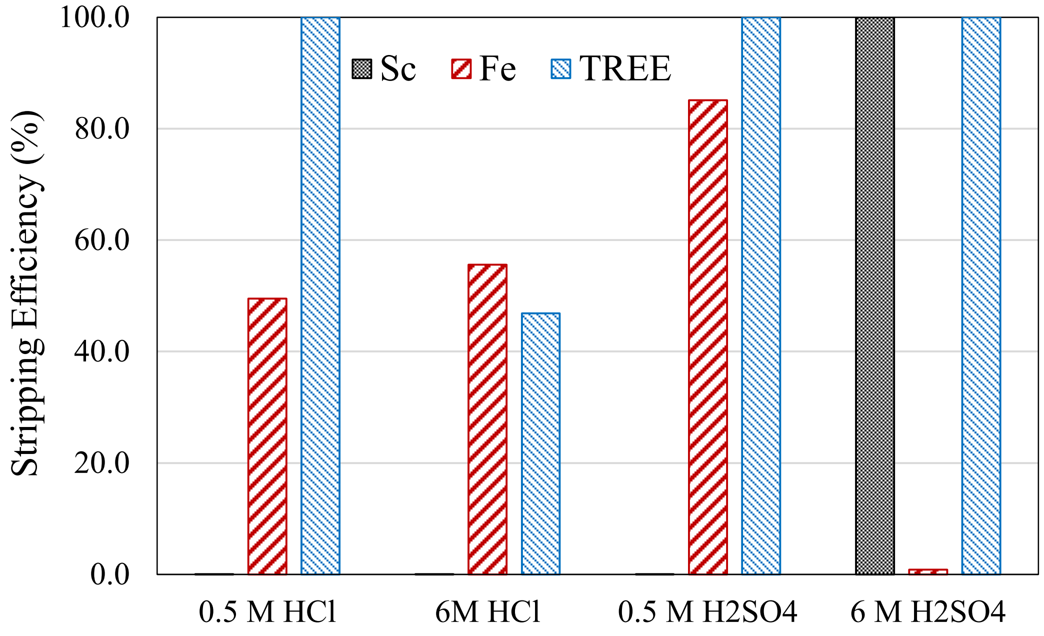
To extract Sc before Al precipitation using solvent extraction (SX).

Extractant: Cyanex 272

Feedstock PLS: Acid Mine Water received from West Kentucky No. 13 coal refuse pile.



(Condition: 1% Cynex 272 in Orfom, Aqueous to organic ratio= 1:1, Contact Time = 15 min.)

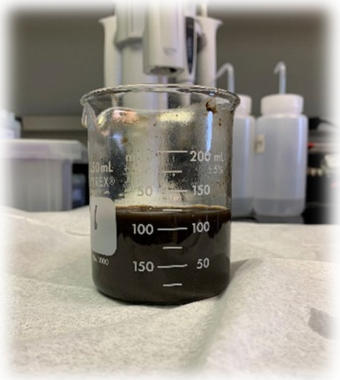


Scrubbing: *0.5M H_2SO_4 to remove Fe;*
Scrubbing solution reports to downstream process for RE recovery.

Stripping: *6M H_2SO_4 to recover Scandium.*

Optimization of Critical Material Recovery

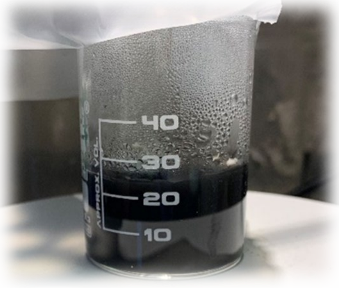
Pre-concentrated Slurry Prepared from AML in the Laboratory



Re-dissolution (pH 1.5)

Solid/Liquid Separation → Undissolved Precipitates (Mn)

Solution

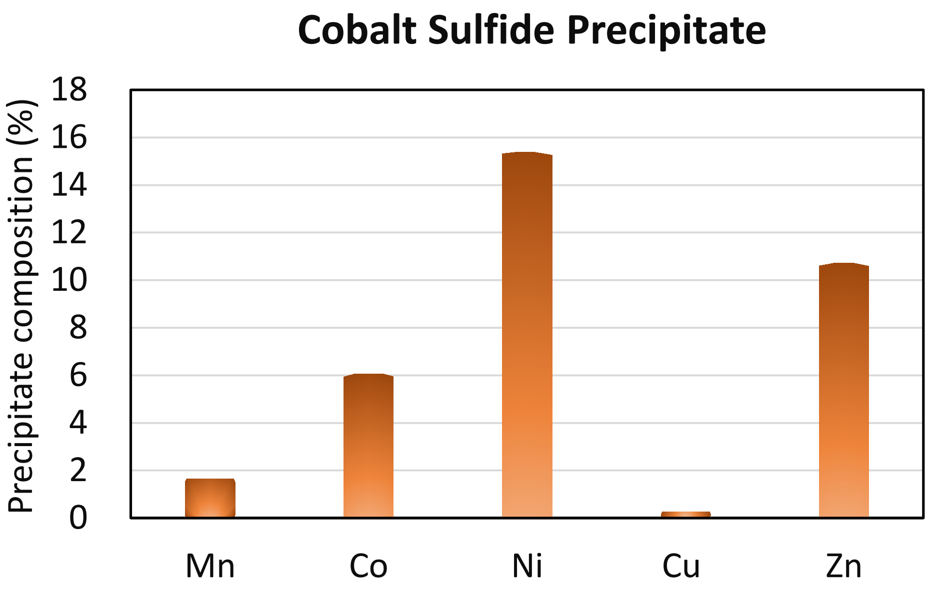


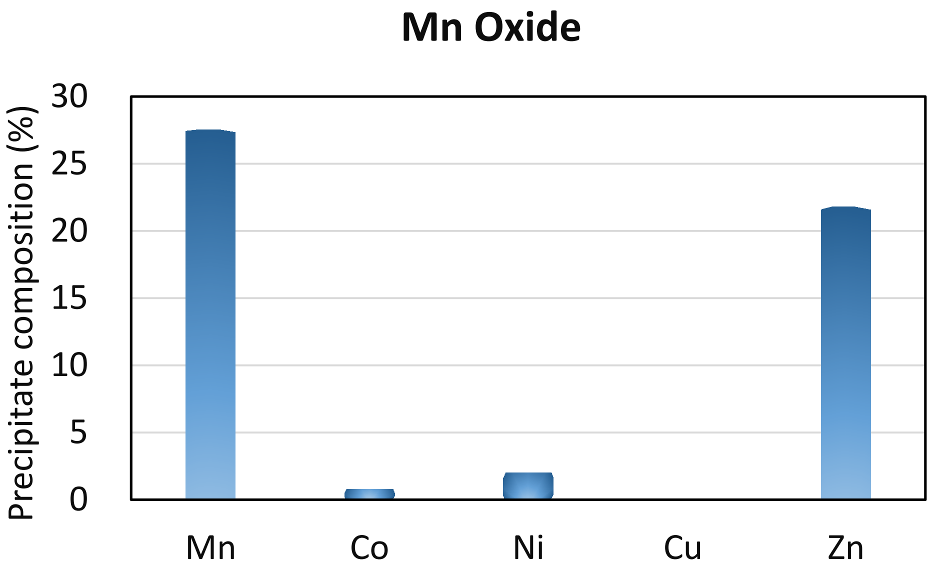
Na_2S Precipitation (pH 3.0)

Solid/Liquid Separation → Cobalt Sulfide Precipitate

Solution

NaOH Precipitation (pH 10) → Mn Oxide

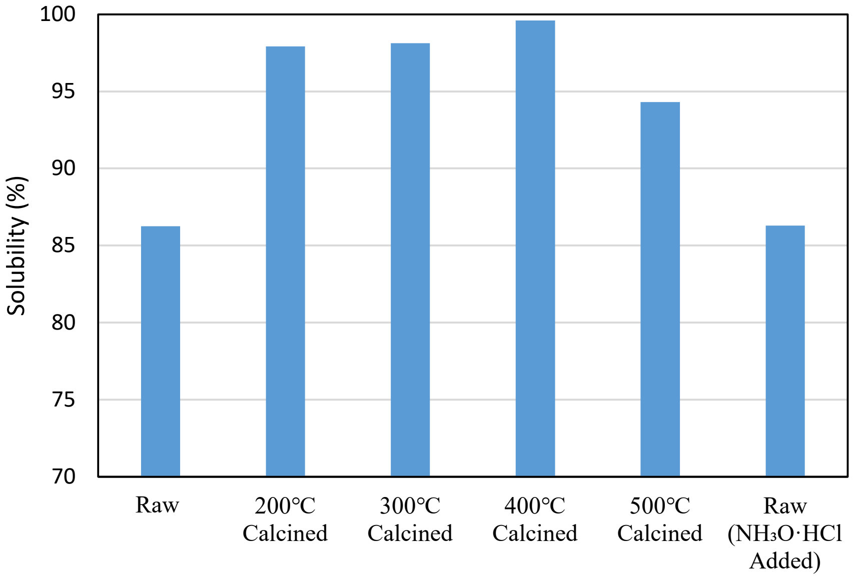




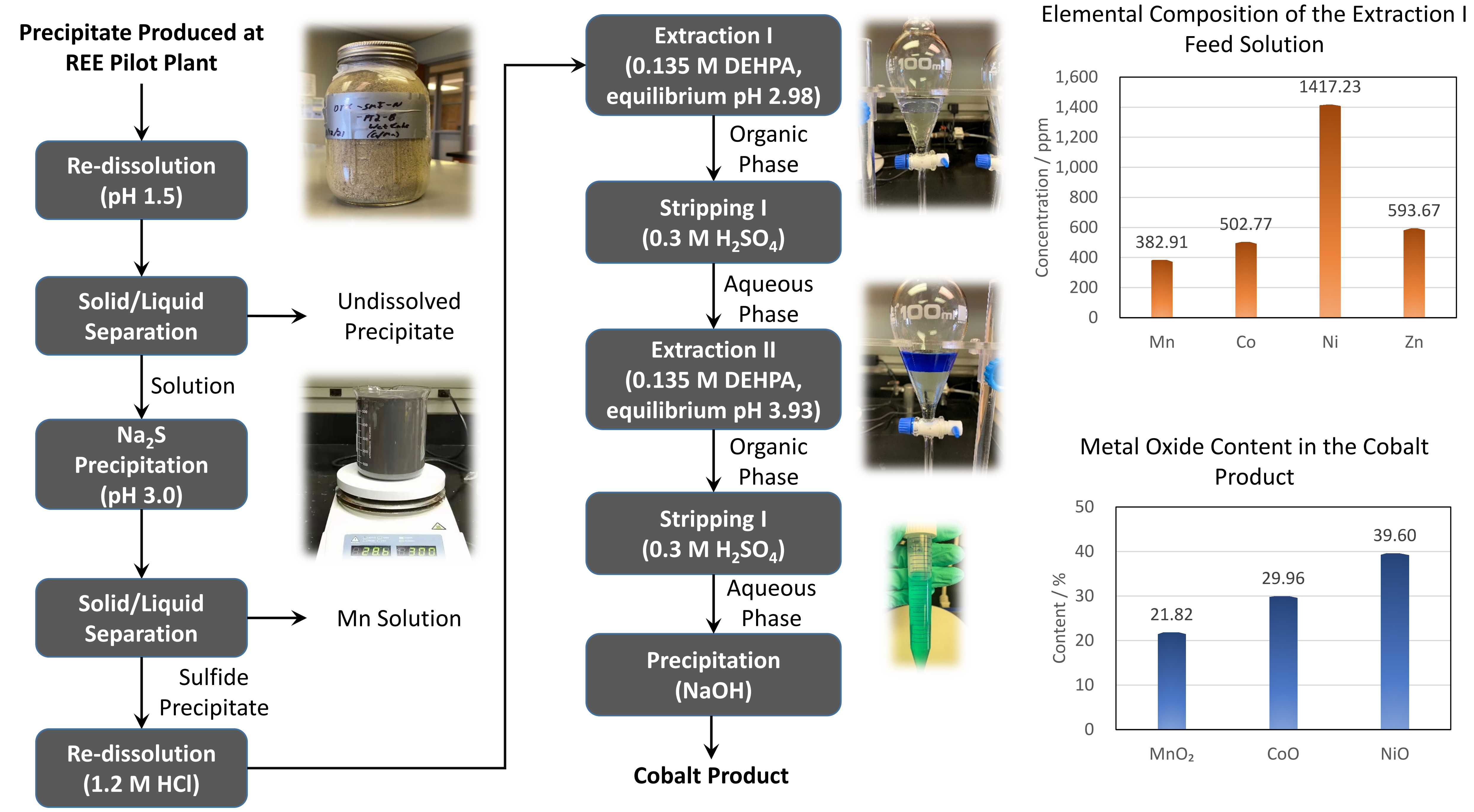
CoS Precipitate Re-dissolution

CoS Precipitate

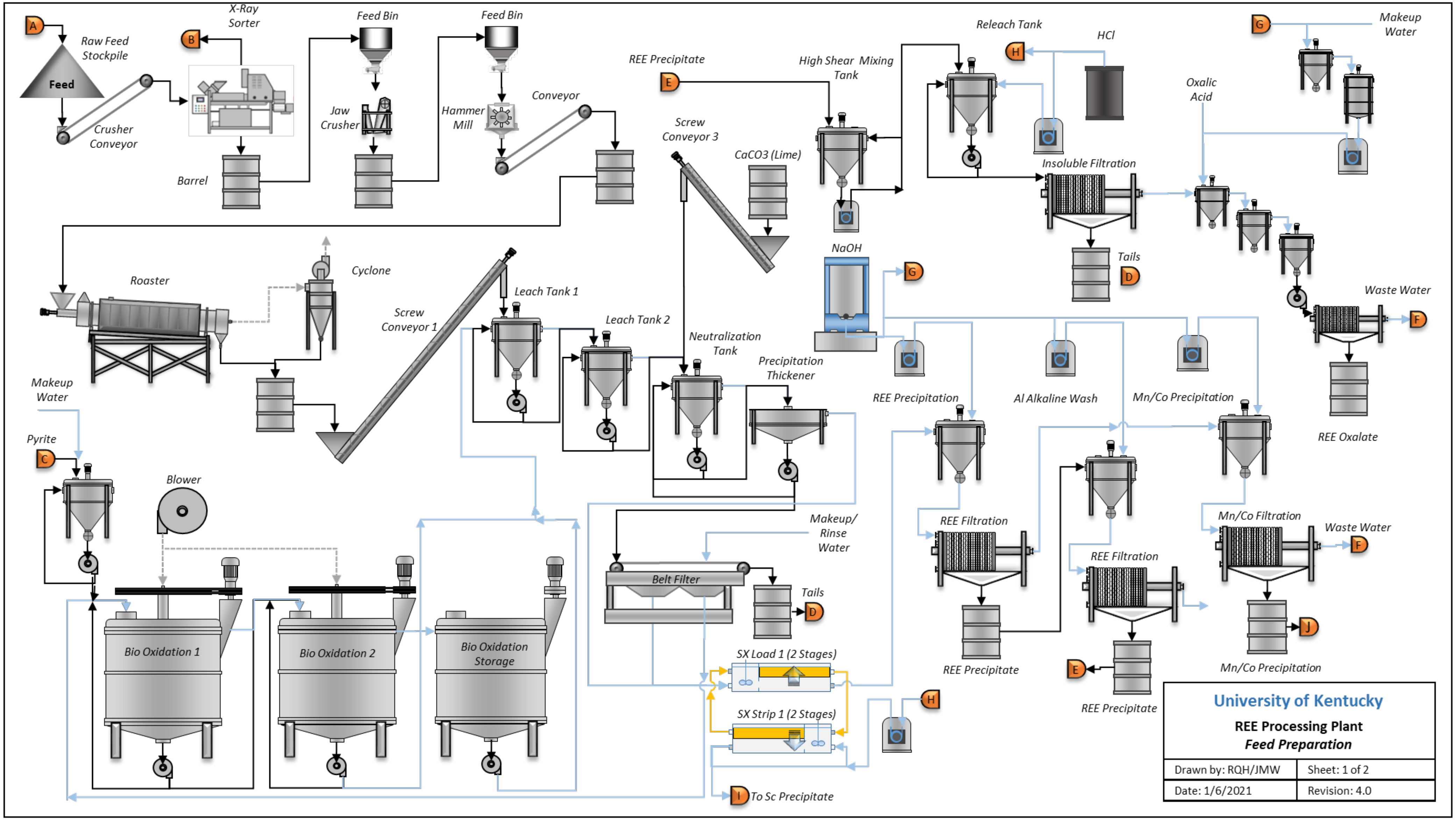
Dissolution tests (calcination impact)
1.2 M HCl; room temperature



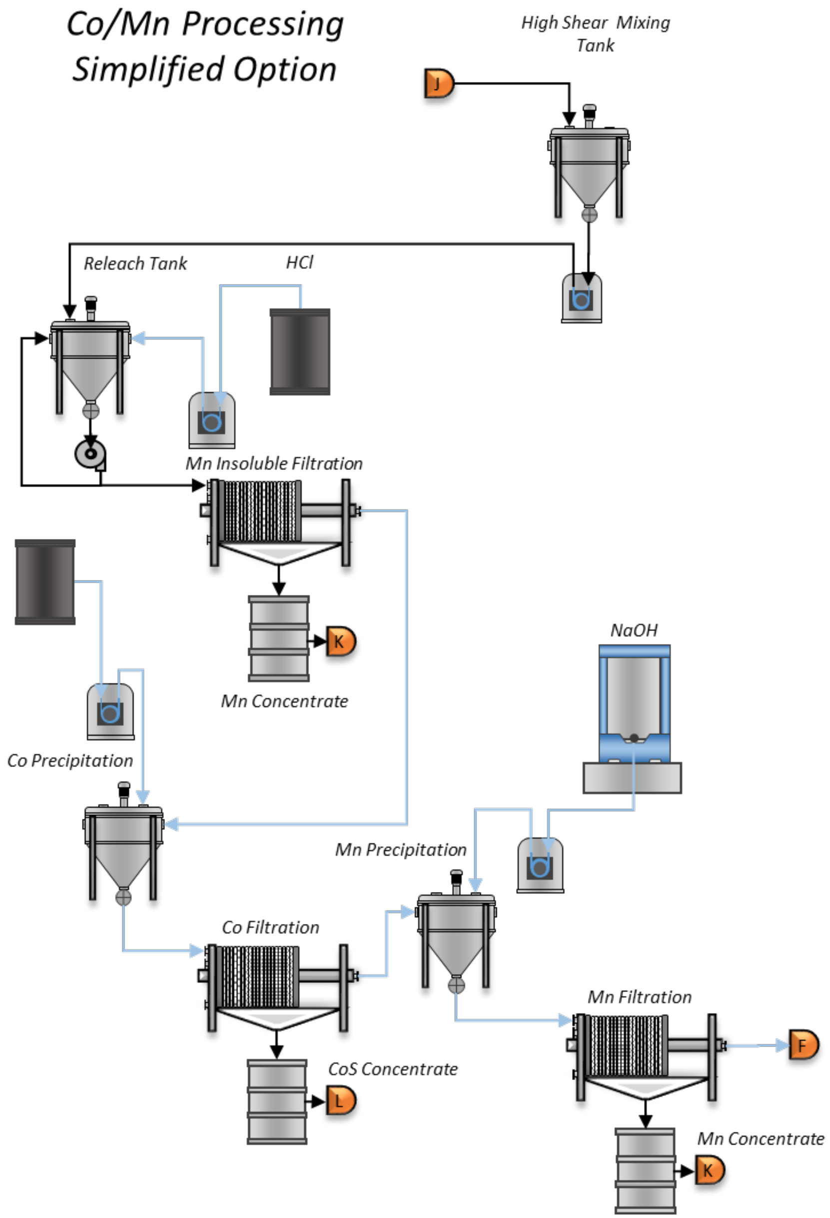
Roasting at appropriate temperature increased the dissolution of cobalt sulfide.


Precipitate Produced at REE Pilot Plant
Re-dissolution (pH 1.5)
Solid/Liquid Separation
Undissolved Precipitate
Solution
Na_2S Precipitation (pH 3.0)
Solid/Liquid Separation
Mn Solution
Sulfide Precipitate
Re-dissolution (1.2 M HCl)
Extraction I (0.135 M DEHPA, equilibrium pH 2.98)
Organic Phase
Stripping I (0.3 M H_2SO_4)
Aqueous Phase
Extraction II (0.135 M DEHPA, equilibrium pH 3.93)
Organic Phase
Stripping I (0.3 M H_2SO_4)
Aqueous Phase
Precipitation (NaOH)
Cobalt Product
Elemental Composition of the Extraction I Feed Solution
Concentration / ppm
1,600
1,400
1,200
1,000
800
600
400
200
0
382.91
502.77
1417.23
593.67
Mn
Co
Ni
Zn
Metal Oxide Content in the Cobalt Product
Content / %
50
40
30
20
10
0
21.82
29.96
39.60
MnO_2
CoO
NiO

Process Flow Sheet



Process Flow Sheet (Co/Mn Flowsheet)

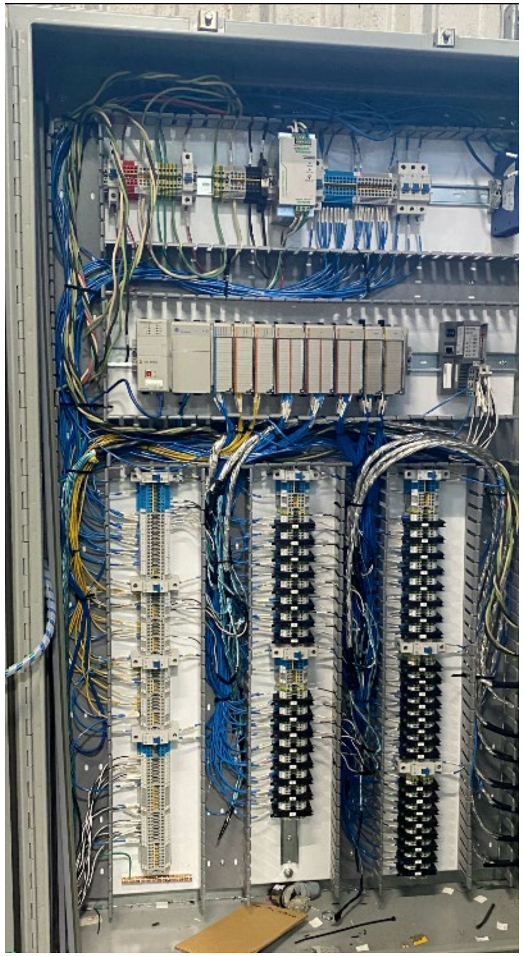


Completed REE/CM Pilot Plant

Production Parameter	FOA 2003
Designed Feed Rate (kg/hr)	113.5
Capable Daily REO Production (kg/day)	0.44
Capable Annual REO Production (kg/yr)	110

Pilot Plant Upgrades and Modification

PLC



Both PLC Control Panels are wired and labeled. (Shown 1 of 2 PLC Control Panels).

PLC and power boxes installed on all associated equipment.

Complete PLC and power box shown.

Process Economics

Feasibility Study

- Feasibility study analyzed the commercial production of REEs and CM from coarse refusing (500 tph feed) utilizing technology components from the project:
  - Roasting
  - Biooxidation
  - Selective Precipitation
  - Dedicated Scandium Recovery
  - Dedicated Co and Mn Recovery
- Output production is estimated at around 300 Mt annually of total rare earth oxide, 18 Mt Sc, 32 Mt Co and 405 Mt Mn.

REE-Econ: Techno-Economic Assessment Tool for Coal-Based REE Recovery

Analysis Information

Case:	Process Model Simulation	Date:	12/29/2020
Feedstock Material:	Coarse Refuse	Performed by:	an
Project	DE-FE0031827	Checked by:	cv

Operational Information

	Total Plant		
Nominal Plant Size	500 TPH	REE Feed Grade:	350 PPM
(unit conversion)	12000 TPD	Project NPV:	(335,709,839)
(unit conversion)	1000000 lb/hr		

Page 1

Document Information

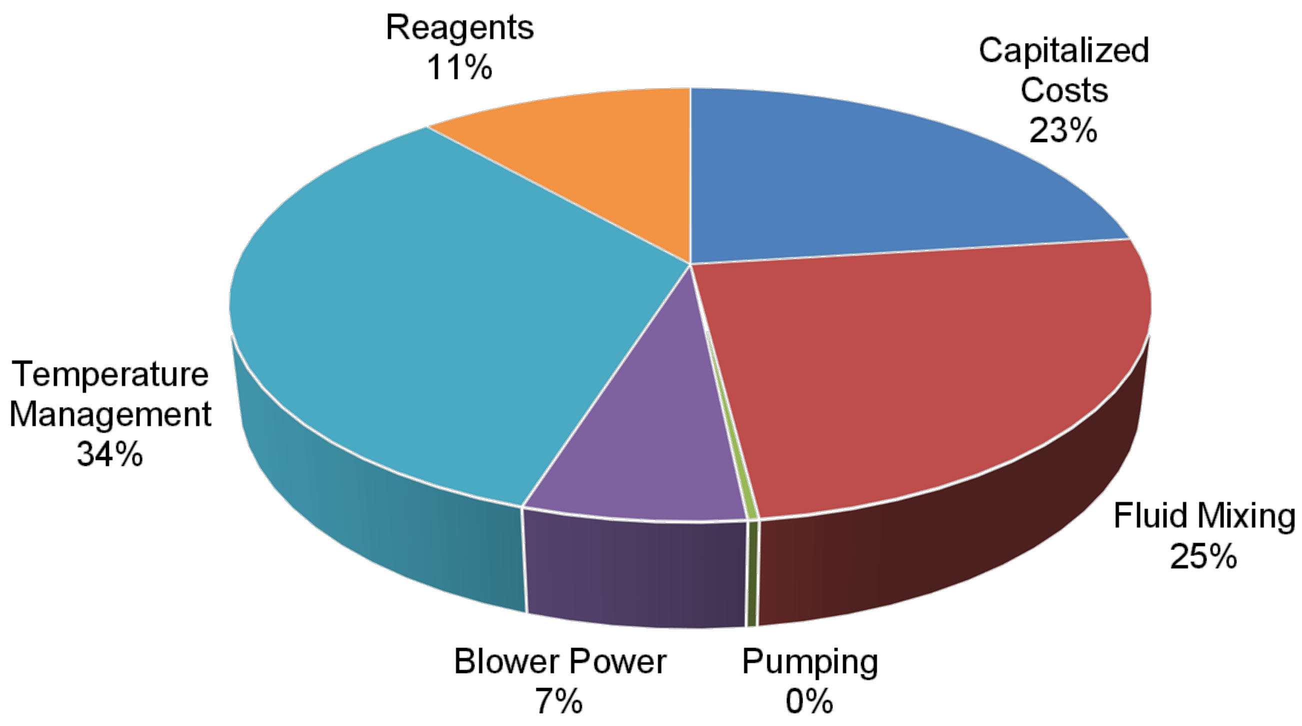
	Process Codes		*Accounting Codes*
PM1	Feed Preparation	OL	Operating Labor
PM2	Roasting	TL	Technical Labor
PM3	Leaching	PR	Power/Utilities
PM4	Al Precipitation	LS	Lease Agreements
PM5	REE Precipitation	CR	Consumables/Reagents
PM6	Al Wash	WD	Waste Disposal
PM7	RE-Redissolution	OH	Plant Overhead
PM8	REE Oxalate Precipitation	GSA	General Sales, and Administration
PM9	Biooxidation Circuit		
PM10	Sc SX Separation		
PM11	CM Recovery Circuit		
PM12	Reserved		
PM13	Reserved		
PM14	Reserved		
PM15	Reserved		

Excel-Based TEA Model

Process Economics
Biooxidation Cost Analysis

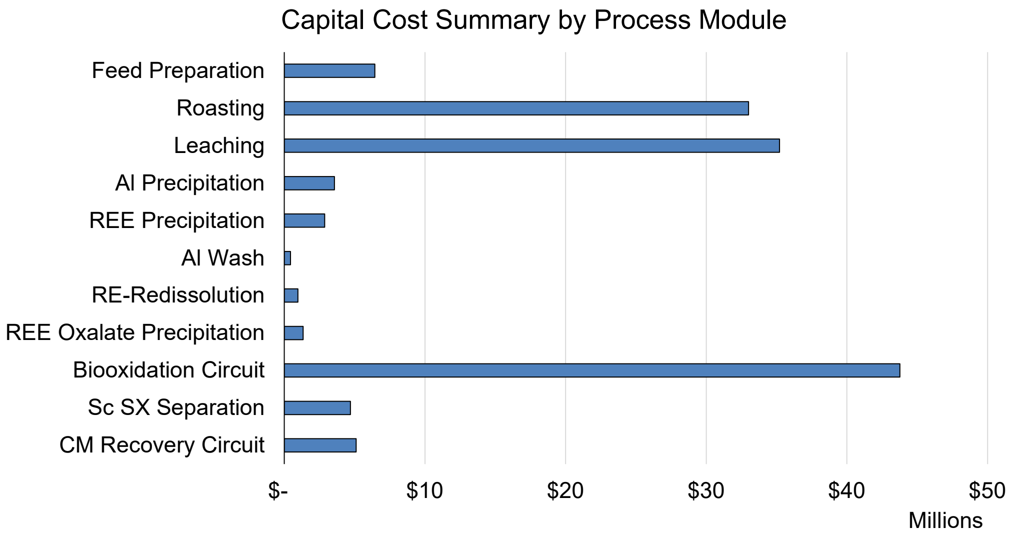
Total cost = $0.05 / kg H_2SO_4 equivalent

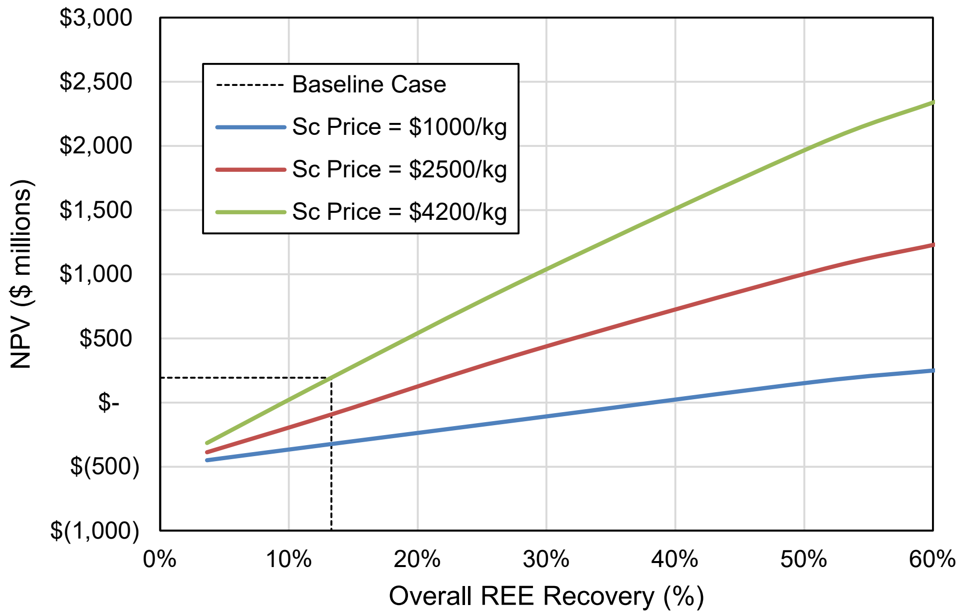
- The biooxidation unit is a large cost component, but it shows notable cost advantages over raw acid leaching.
- Total acid production cost = $0.05 /kg, a reduction of approximately 75% vs. bulk sulfuric acid.
- Largest cost components = mixing, temperature management, capitalization costs (~81% of total).



Process Economics
Feasibility Study

- Key Findings:
  1. Plant capital cost = $137 million. Biooxidation circuit = ~1/3 of total capital expenditure.
  2. Achieved project objective of 50% operating cost reduction versus existing pilot plant. Contributing factors = bioxidation, use of coal calcite, and use of Al wash.
  3. Highest single line item cost = neutralization base.
  4. Under the baseline conditions evaluated, the project was found economically viable; however, this viability is very sensitive to the scandium price.
  5. The overall system recovery is very low, and even modest improvements to recovery could greatly increase the economic robustness of the process.





Summary

- Biooxidation using concentrated ultrafine coal pyrite can produce a 0.2 M H_2SO_4 solution at 25% of the cost of commercial acid.
- Biooxidation acid can be used to effectively leach REEs and CMs from coarse coal refuse.
- Magnetic iron oxide can be produced by roasting at $400^{O}C$.
- Acid baking after roasting provides leach recoveries of HREEs and LREEs greater than 80%.
- Sc and Co/Ni/Zn/Mn circuits have been developed providing well over 2% product grades.