Integrated Treatment of Acid Mine Drainage and Rare Earth Production

DE FE 0032296

ETD112 p1

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U.S. Department of Energy

National Energy Technology Laboratory

Resource Sustainability Project Review Meeting

April 2-4, 2024

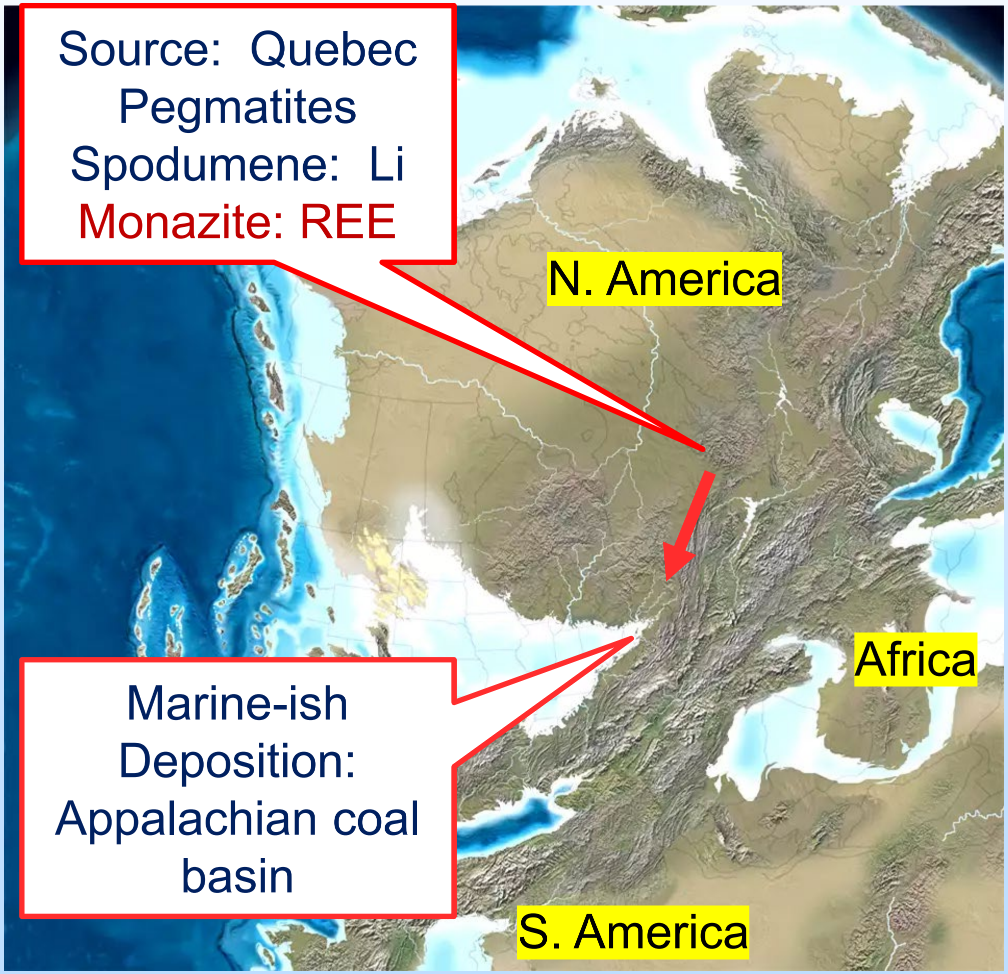
Project Overview

- Funding
  - $8,000,000 DOE
  - $3,704,182 Cost Share
- Overall Project Performance Dates
  - 1 Aug 2023 to 31 Oct 2024
- Project Participants
  - West Virginia University
  - Virginia Tech
  - WVDEP
  - Rockwell Automation
  - L3 Process Development
- Project Objectives
  - Conduct a feasibility study to assess the production of 1-3 t REE/CM oxides and metals from an AMD-based feedstock.
  - Components:
    - Front End Engineering Design (FEED) Study
    - Class 3 Cost Estimate
    - NEPA Approvals and Permits
    - Financial Plan
    - Disposition Plan/Offtake Agreements
    - Derisking and Optimization Testwork

Technology Background*

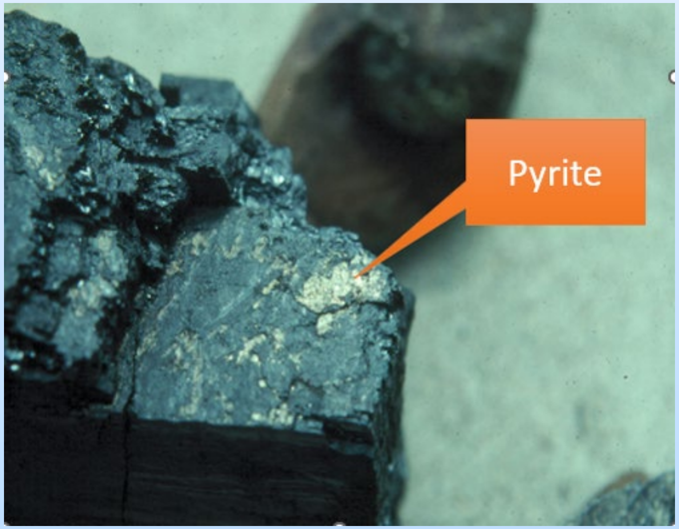
***Paul's unified field theory**

Late-Pennsylvanian time

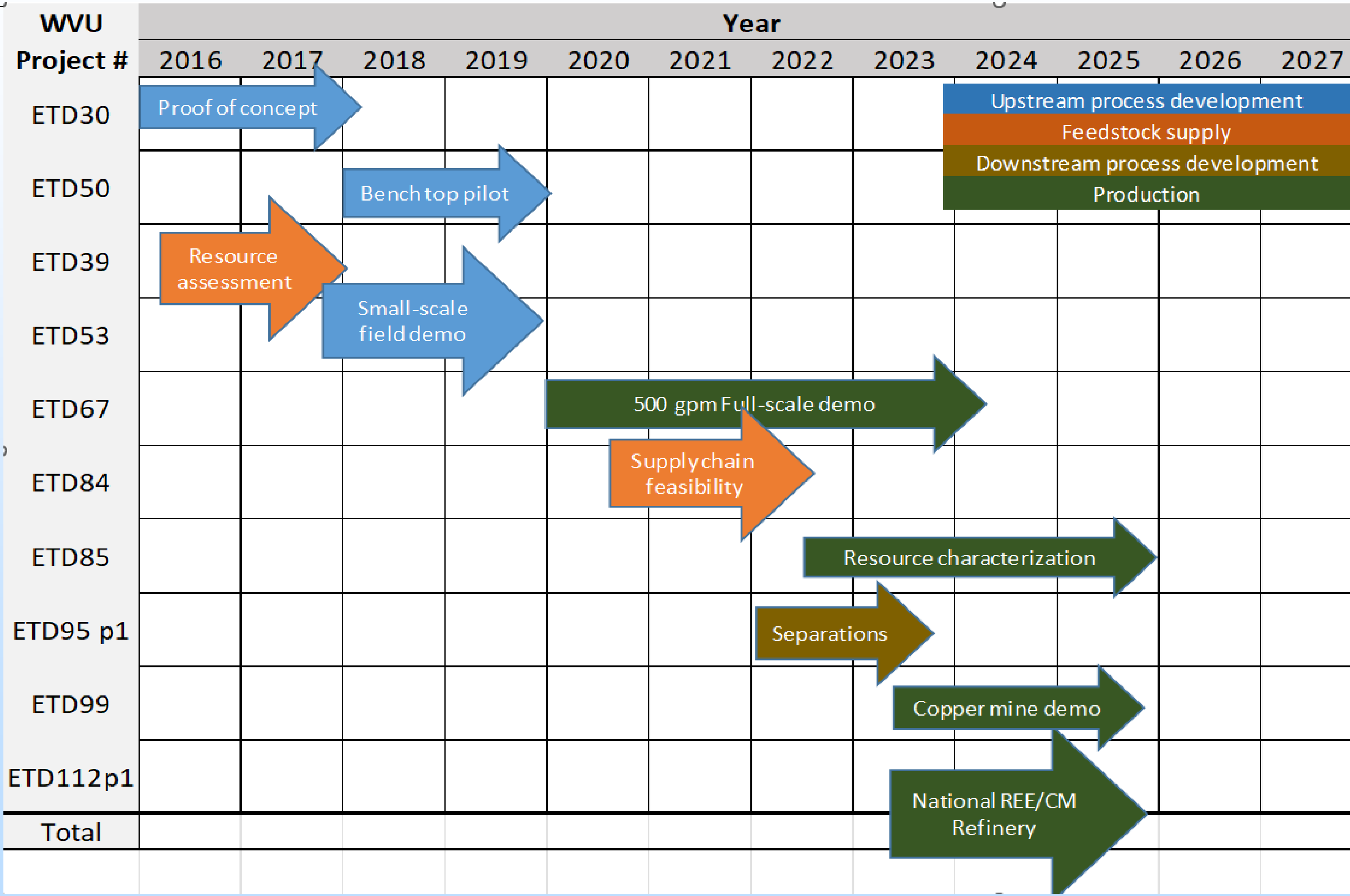


Acid Mine Drainage: AMD

1. Pyrite + O_2 + H_2O = Fe^{2+} + H_2SO_4
2. H_2SO_4 leaches REE from shale
3. REEs co-precipitate with Al, $Fe(OH)_3$
4. Monazite dissolution favors HREE
5. pH too high to mobilize U, Th



Technology Background



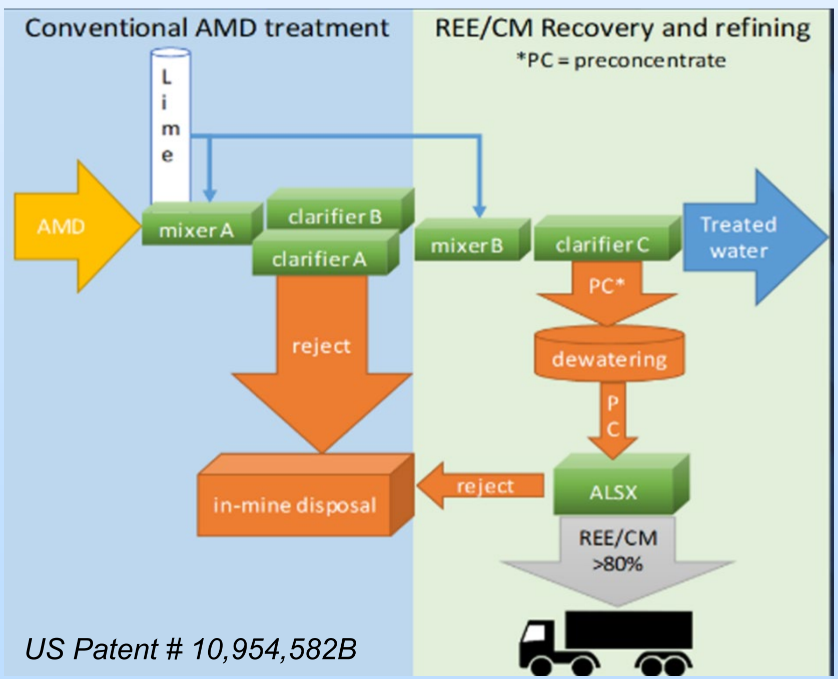
Technology Background

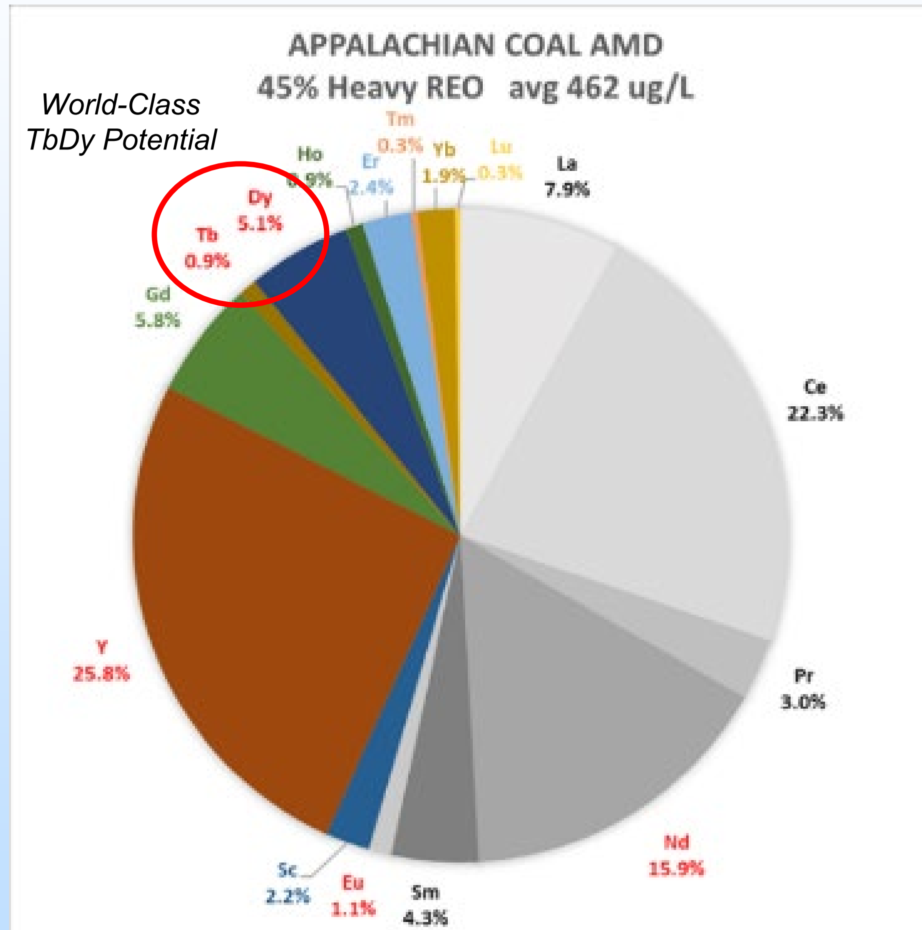
Advantages:

- Concentrates are 45% HREE
- Incentivizes AMD treatment
- Discharges CWA compliant water
- Already permitted sites
- Can go into production almost immediately
- Modest additional CapX
- Low rads, solid rejects are non-hazardous

Disadvantages

- Small, dispersed, upstream production sites





Technology Background

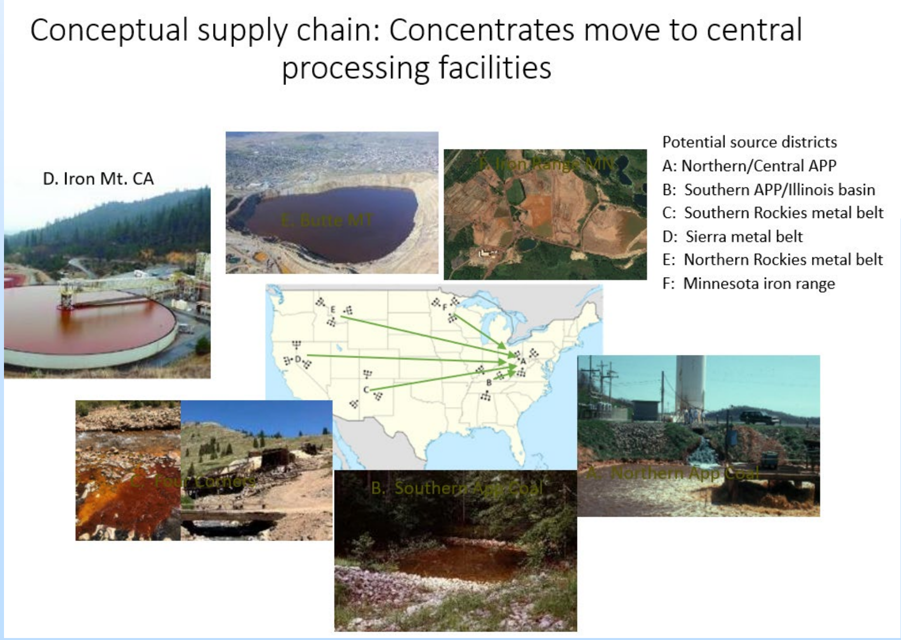
Upstream/Midstream processes

Upstream (AMDREE) site selection criteria:
- High REE load
- Access
- Site operator agreement

Downstream (refinery) site selection
- Infrastructure
- Permits/NEPA
- Workforce/Community Benefits
- Site operator agreement

Upstream:
1. Generate pre-concentrate (HPC)
2. Passively dewater to 40% solids
3. Transport HPC to an onsite or regional MREO facility

Midstream
1. Convert HPC to high-grade PLS (green), then MREO
2. Produce crude non-REE CM concentrates



Downstream processes

1. Transport MREO and CM concentrates to central refinery
2. Metathesize/leach concentrates to produce PLS
3. Staged SX to produce individually separated REO/CM products.
4. Metal reduction for select REE products

Technology Background

Upstream/Midstream processes have been proven at scale

1. HPC Clarifiers

2. Dewater Preconcentrate

3. Leach, precipitate

4. Concentrate and Recover

MREOs

Project ETD99 USDOD IBAS-Copper Mine AMD:

Converted a conventional HDS AMD plant to HPC production

100 t of HPC, 30% solids in Geotubes within a month

Horseshoe Bend AMD Plant
Montana Resources, Butte MT

Community Benefits
Site Selection

- Quality Jobs Plan
  - Strategy is in place to collaborate with regional economic development organizations, labor unions, community colleges, and others to ensure that jobs go to well-prepared local residents, to the fullest extent possible.
  - Strategy is also in place to ensure that Diversity, Equity, Inclusivity, and Accessibility goals are met in this area.
- We are prepared to make initial contact with these potential partners as soon as we are able to make location public.

Technical Approach/Project Scope

Task Name	Key Activities/Deliverables
Task 1.0 - Project Management and Planning	Project Management Plan, Technology Maturation Plan
Task 2.0 - Community Benefits Plan	Stakeholder engagement, Community Benefits Plan
Task 3.0 - National Environmental Policy Act	Environmental Volume, Environmental Assessment
Task 4.0 - Permits for Construction and Operation	Permit identification and maintenance, water discharge, air emission, solid waste, other permits.
Task 5.0 - AACE Class 3 FEED Study	Process engineering, mechanical engineering, civil/structural engineering, electrical engineering, architectural engineering, cost estimation
Task 6.0 – Optimization and Integration Testing	Verification and validation test work, data management
Task 7.0 – Partnership Management, Contract Development and Execution	Partnering agreements, material disposition, offtake agreements, EPC selection, financial plan

Technical Approach/Project Scope

(1-2 Slides)

Table 4. Screening criteria for potential refinery locations.

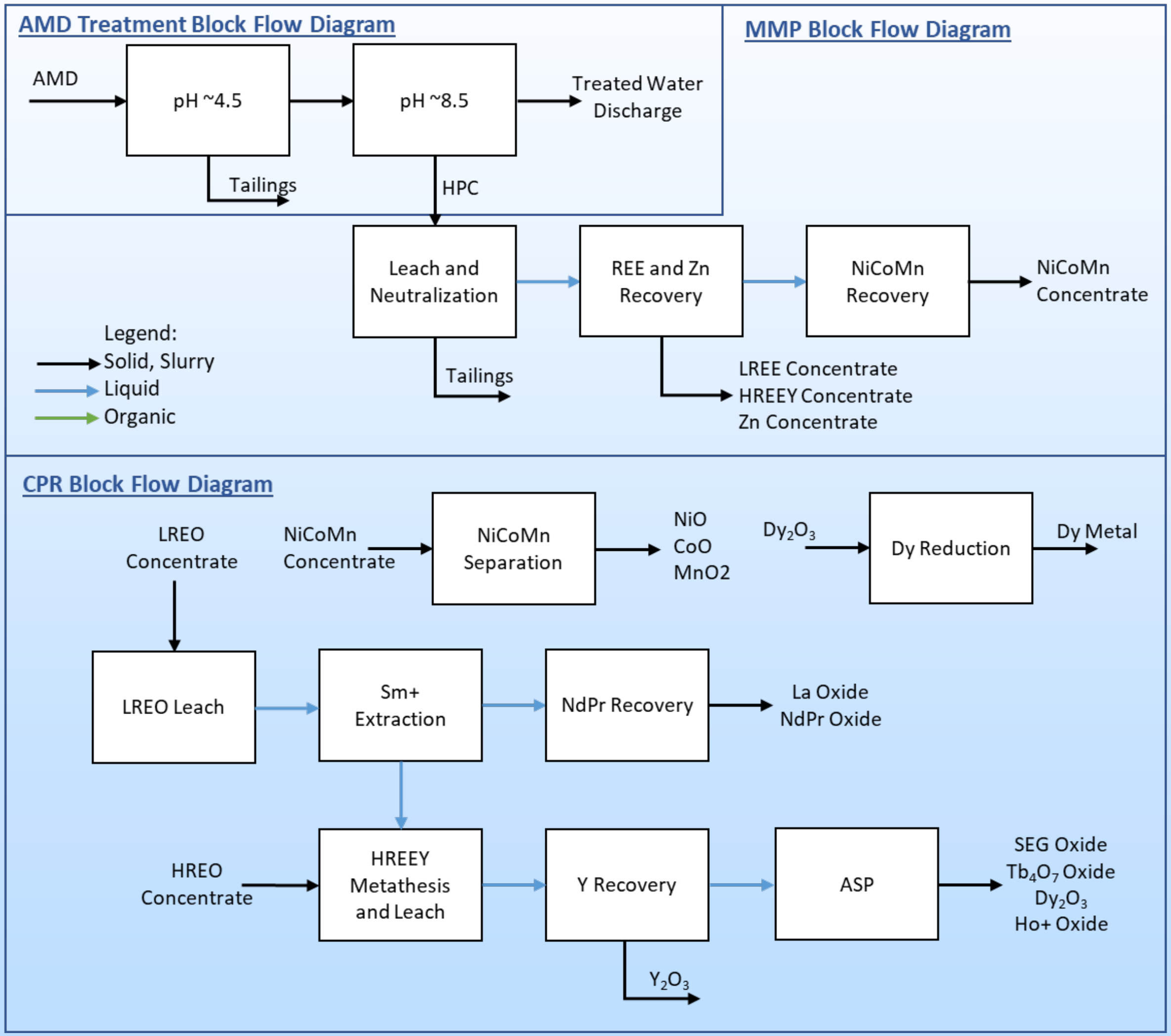
Criteria		Parameter	Quantify
	Permit Holder	Company Name Contact Information	
Site	Minimum 100 ac. flat	Y/N	
	Coal Basin	NAPP/CAPP	
	On site, high quality (low pH) AMD	pH<4	gpm
Access	Rail and truck access	Ready? ROW only?	
	Distance from Interstate Highway	Via paved highway	miles
Infrastructure	Onsite power/distribution	describe	
	Water Source (network)	potable/Industrial	gpm
	Water Source (storage)	potable/Industrial	Acre ft.
Waste Storage	High capacity impoundment (slurry)	available capacity	Acre ft.
Ownership	Use/Ownership	Sale, lease conditions	

Process Performance Goals

Process Performance Parameter	Baseline target
Design production rate, as REO product	1 t/day
Process recovery	80%
Minimal REM product purity	99.9%
Project payback pperiod	7 years
Project IRR	15%
New jobs created (direct and indirect)	100
% of design capacity after 1 year of operation	50%
% of design capacity after 2 years of operation	75%

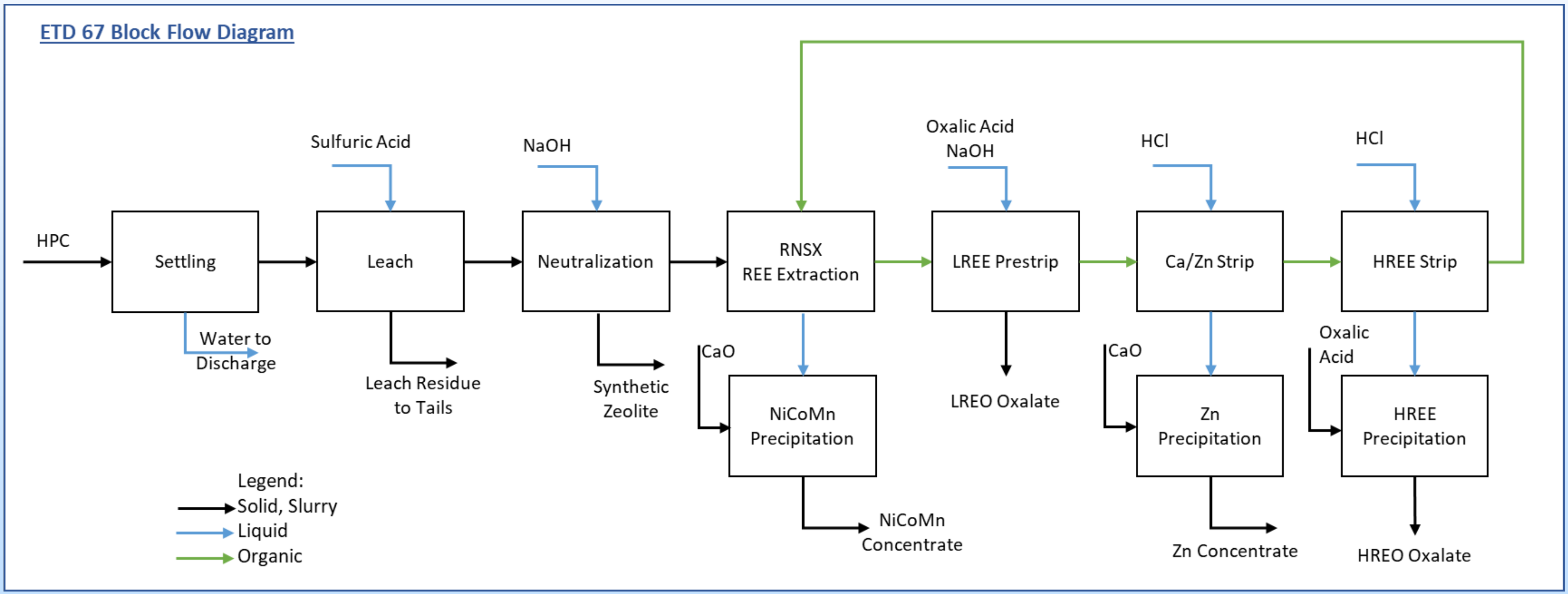
Technical Approach/Project Scope

(1-2 Slides)



Modular MREO Process

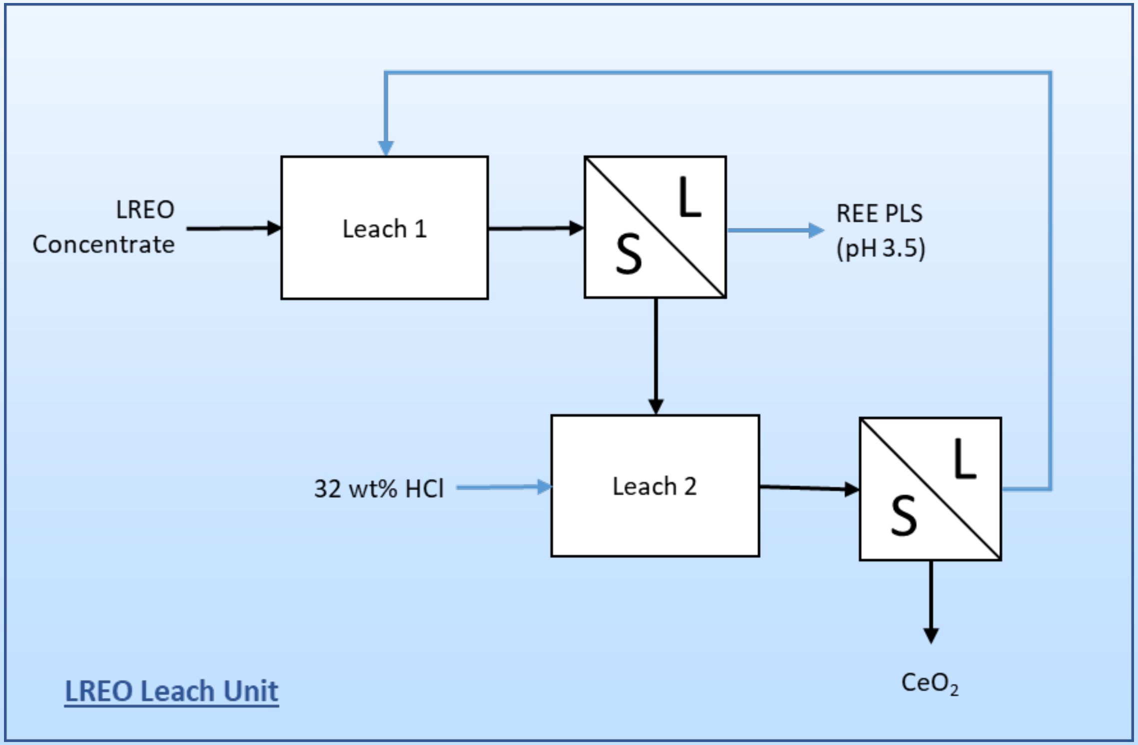
The MMP Process can be adapted to various feedstocks



Central Refinery Process

LREO Leach Process

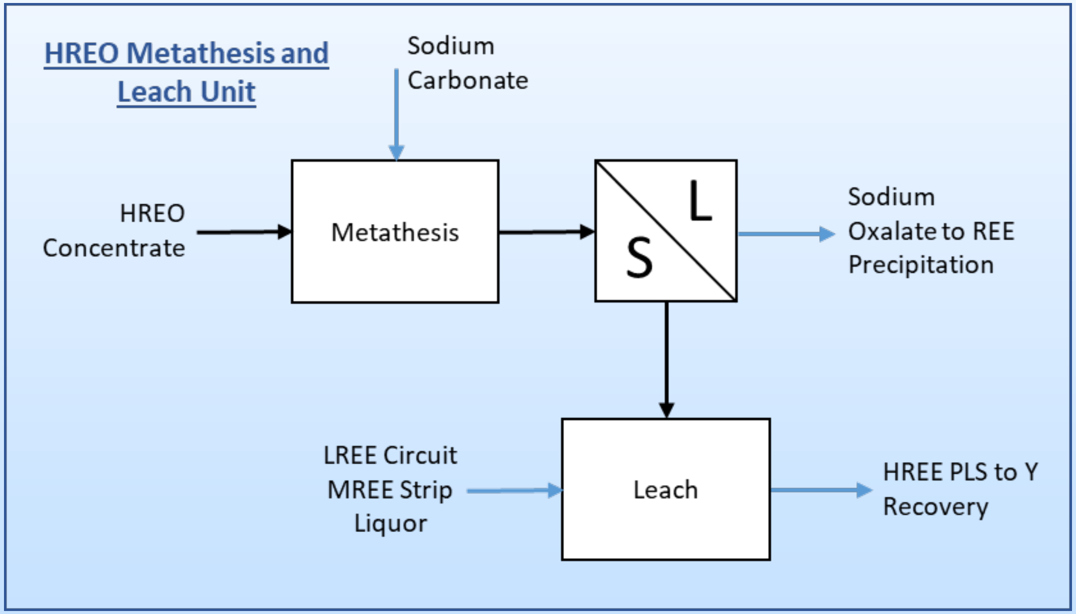
a. > 95% REE* recovery
b. < 3% Ce recovery
c. No neutralization
d. Low temperature (40 C)
e. CeO_2 can be sold as a product



Central Refinery Process

HREO Metathesis Process

a. Reduces acid/base consumption
b. Oxalates are recycled in the process
c. No neutralization

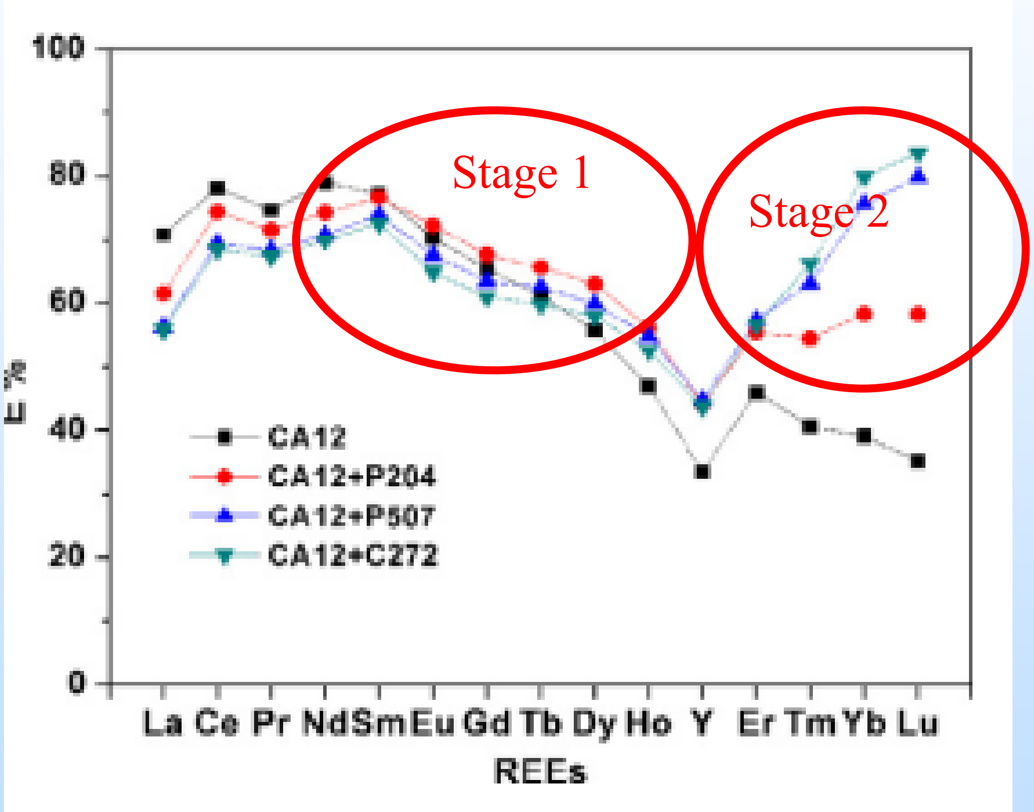


Central Refinery Process

Yttrium Recovery Process

Collaboration with Glycosurf:

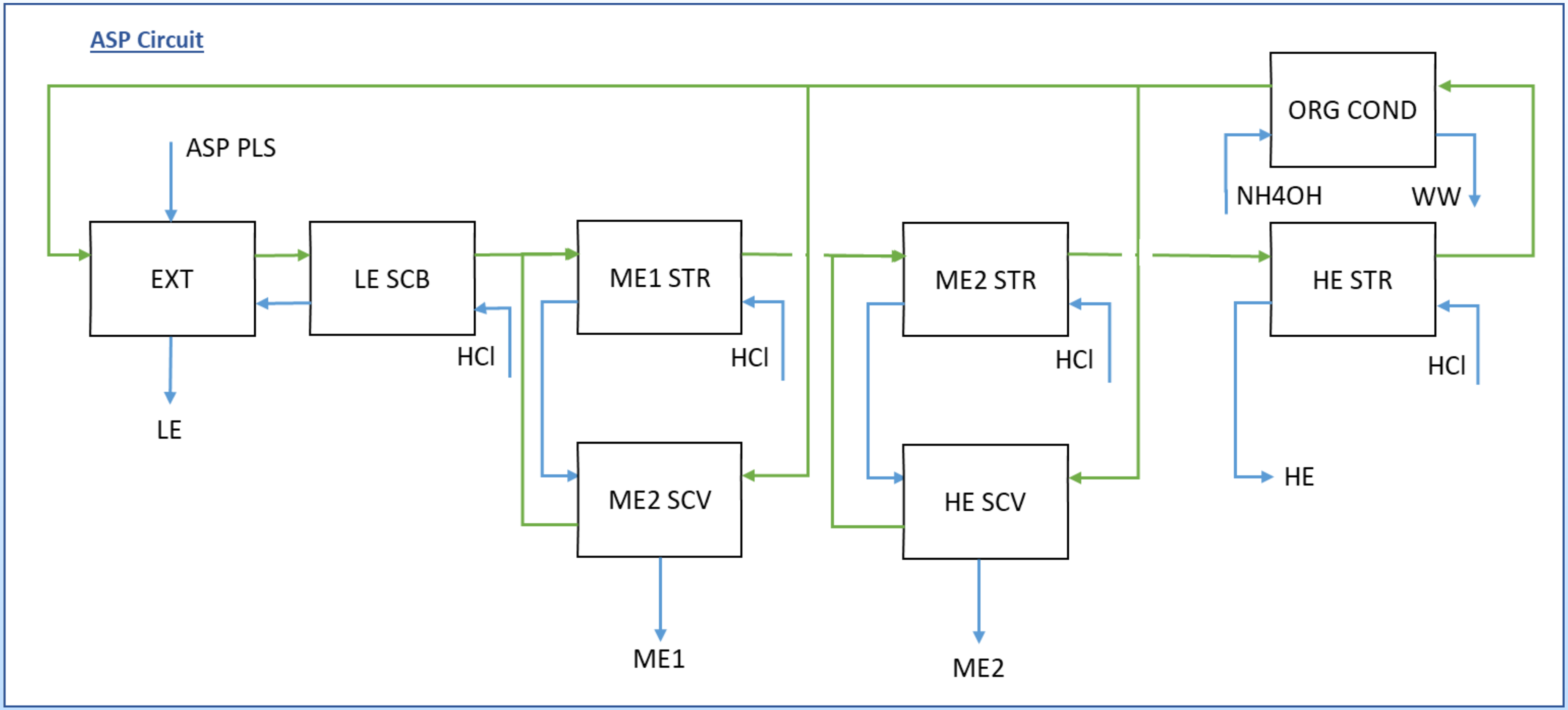
a. Develop the CA-12 extractant domestic supply
b. Glycosurf CA-12 is purer than Chinese supplied CA-12.
c. Evaluation of alternative Extractants (CA-13)



(Wang et al., 2011)

Central Refinery Process

ASP Process Block Flow Diagram

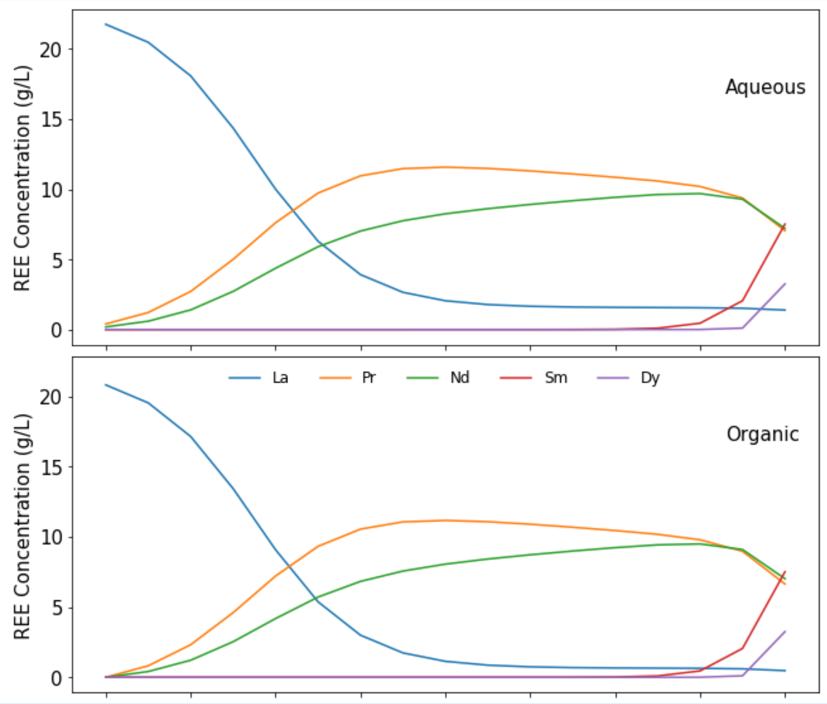


Advanced Simulation

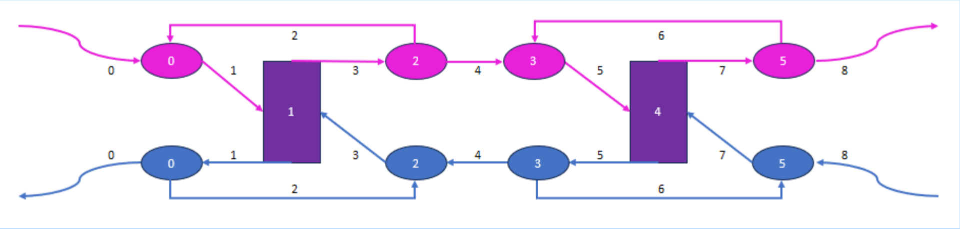
Integration of Linear Circuit Analysis (LCA) and Sequential Solving

Chemical Equilibrium-Based Modeling

$$K_{eq} = \frac{\dfrac{Q_{org} y^0_{RM}}{Q_{org}}}{\dfrac{Q_{aq} x^0 - \Delta e}{Q_{aq}}} \times \left(\frac{\dfrac{Q_{aq} x^0_{eq} + \sum n_e \Delta e}{Q_{aq}}}{\dfrac{Q_{org} y^0_{RH} - \sum n_e \Delta e}{Q_{org}}} \right)^{n_e}$$

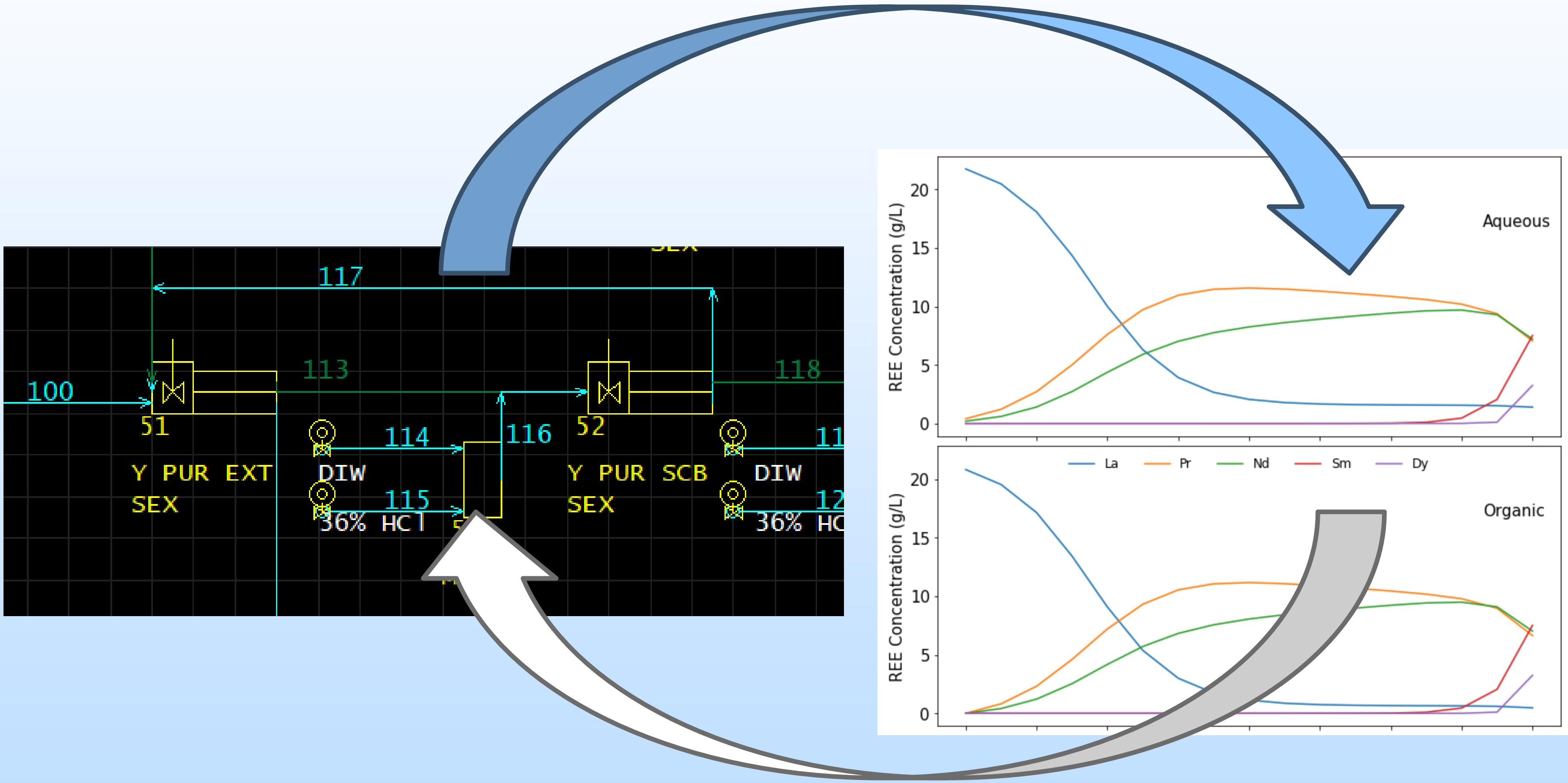


LCA-Based Nodal Analysis



Advanced Simulation

Integration with METSIM for Design and Operation



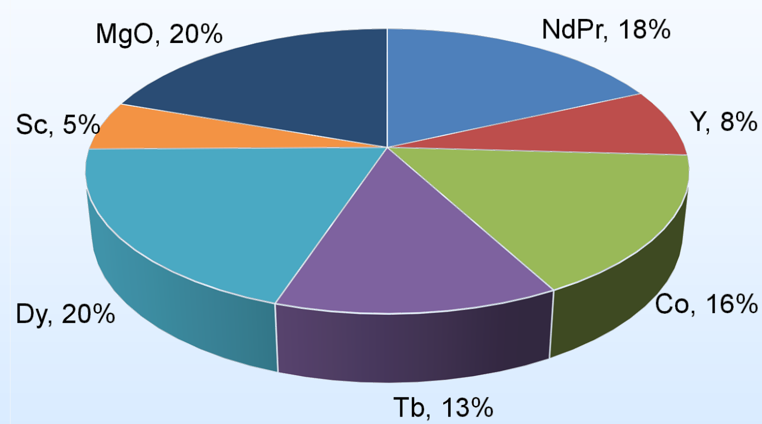
Management of Feed Composition Changes - Proactive Control System Adjustment
Digital Twin Optimization
Alternative ASP Configurations

Economic Perspective

Results from Pre-FEED/Class IV Estimate

- Techno-economic assessment was conducted to evaluate overall economic feasibility of the concept:
  - Revenue estimate
  - Capital cost estimate (Class IV, ±40%)
  - Operating cost estimate
  - Life cycle financial analysis
  - Sensitivity analysis
  - Monte Carlo simulation
- Evaluated different plant configurations and price sensitivity
- Full results published in (Larochelle et al., 2021)
- Anticipating improvements due to process modifications

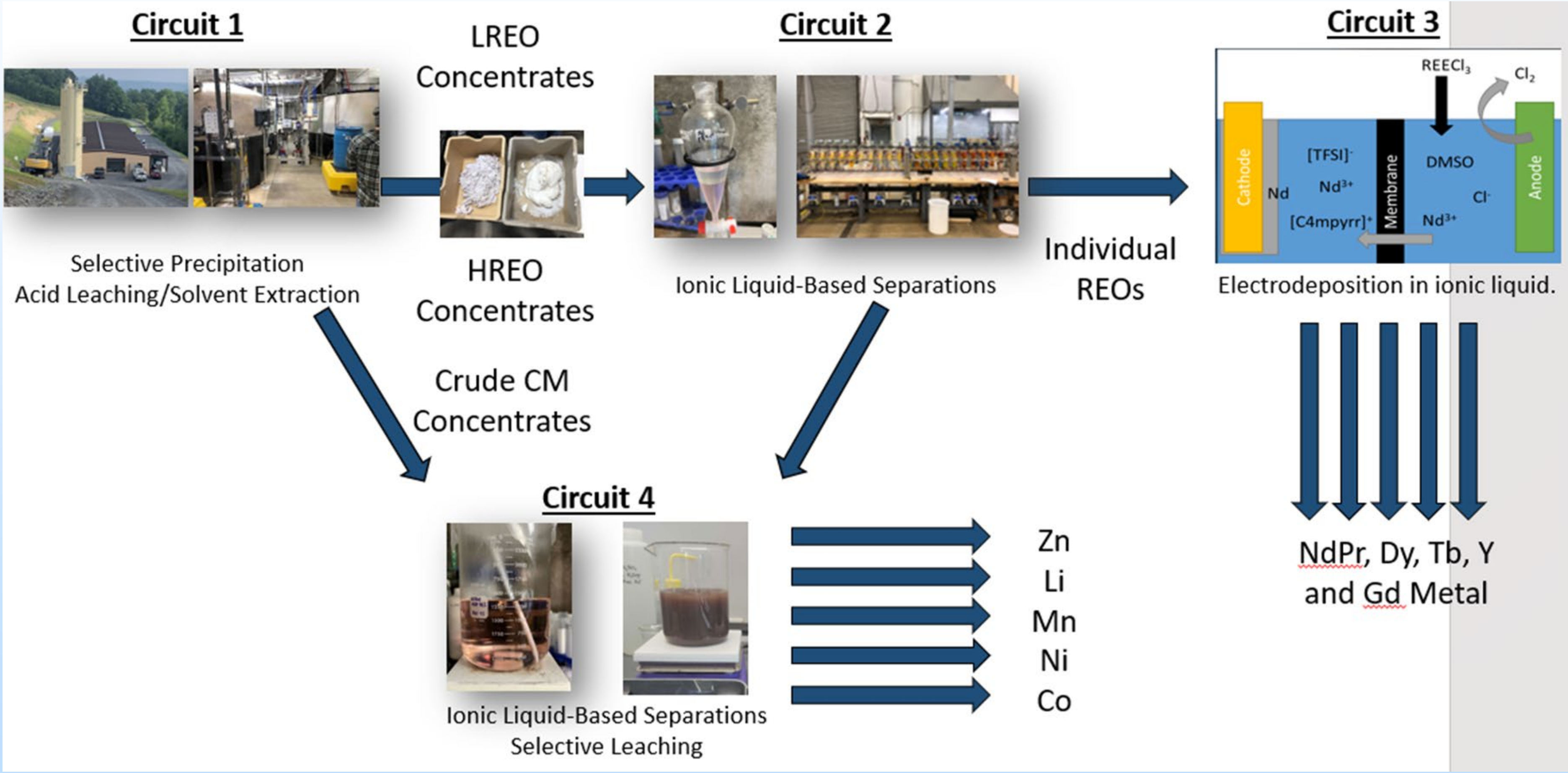
Revenue Distribution for Magnet REE Case



Parameter	All REEs/CM, except La + Ce	Magnet REE + CM
REE Production (t/y)	348	255
CM Production (t/y)	6,972	6,972
Annual Revenues ($ MM/yr)	$83.6	$67.9
Capital Cost ($MM USD)	$172.7	$158.3
Operating Cost ($ MM/yr)	$27.2	$27.2
Net Present Value$_{10\%}$ ($ mil)	$270	$154
Rate of Return	33%	25%
Discounted Payback Period	3.5 years	5.5 years

Plans for future testing/development/ commercialization

Transition to Ionic Liquids and/or Novel Extractants



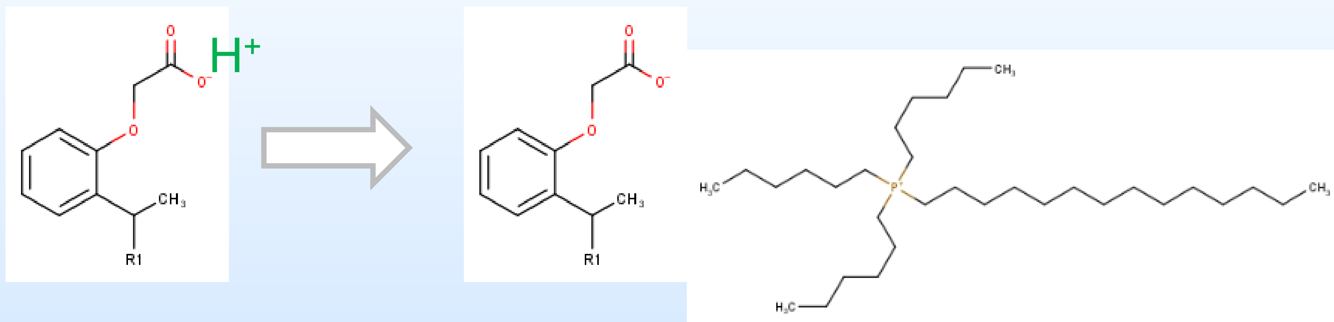
Acidic Extractants vs Ionic Liquids

SOPAA

$Ln^{3+} + 3\ H\text{-}SOPA \rightarrow Ln(SOPA)_3 + 3\ H^+$

$[P_{66614}][SOPA]$

$LnCl_3 + [P_{66614}][SOPA] \rightarrow [SOPA][LnCl_3][P_{66614}]$



Elements	SOPAA Circuit 1, 2	[c101][SOPA]
Tb / Y	**3.09, 1.86**	**1.94**
Dy / Y	2.44, 1.75	2.21
Ho / Y	**1.73, 1.41**	**1.94**
Er / Y	1.67, 1.65	1.94
Tm / Y	1.36, 2.51	2.78
Yb / Y	1.25, 5.09	4.17
Loading (M)	0.15, 0.13	0.17

Summary

1. Key Findings: The team has developed a technically and economically attractive separation technology for REE/CM

2. Scaleup: We have a fully automated operationally-scaled plant that takes in 500-1,000 gpm AMD and produces REO at a rate of 3.7 t/yr

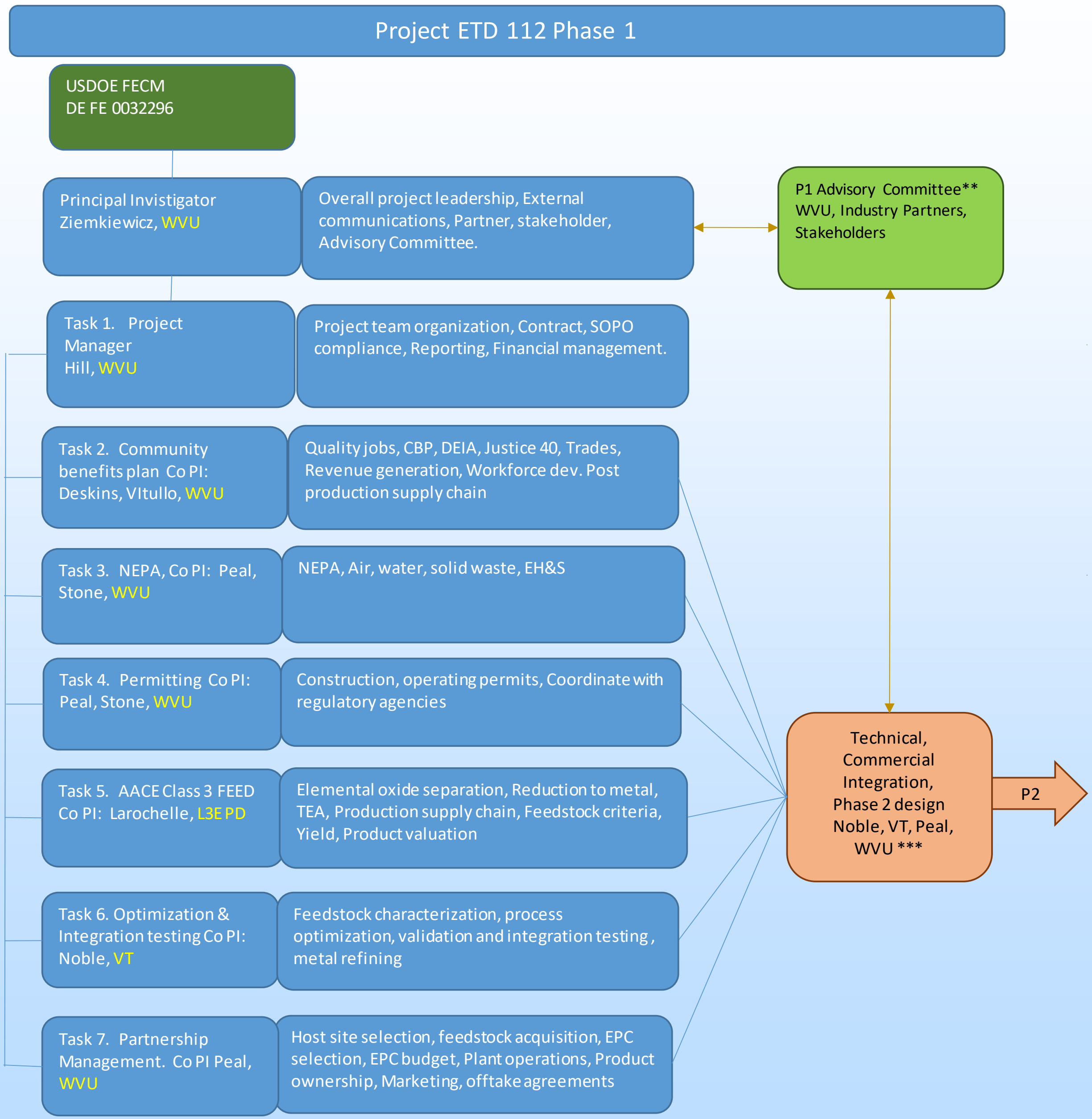
3. It has been in operation since October 2022

4. Current work: Produce a class 3 FEED for the 400 t/yr Central Refinery

Appendix

– Organization Chart
– Gantt Chart
– Conventional Solvent extraction vs. Ionic liquid extraction

Organization Chart



Gantt Chart

31-Mar-24		Project Month: X=Planned completion																				
Task/Sub Task	Completion	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Task 1.0 - Project Management and Planning																						
Subtask 1.1 – Project Management Plan	100%	X																				
Subtask 1.2 – Technology Maturation Plan	100%			X																		
Task 2.0 - Community Benefits Plan																						
Subtask 2.1. Community/Stakeholder Engagement	100%			X			X									X						
Subtask 2.2. Quality Jobs Plan																						
Subtask 2.3. Diversity, Equity, Inclusion, and Accessibility (DEIA) Plan																						
Subtask 2.4. Justice40 (J40) Initiative Plan																						
Subtask 2.5. Community,Engagement Plan																						
Task 3.0 - National Environmental Policy Act (NEPA)																						
Subtask 3.1 Environmental Volume	100%										X											
Subtask 3.2 Environmental Assessment Preparation																						
Subtask 3.3 Environmental Impact Statement Preparation	90%												X									
Task 4.0 - Permits for Construction and Operation																						
Subtask 4.1 Permit Identification and Maintenance	90%										X											
Subtask 4.2 Water Discharge Permitting																						
Subtask 4.3 Construction Stormwater Permitting																						
Subtask 4.4 Air Emissions Operating Permitting																						
Subtask 4.5 Solid Waste Permitting																						
Subtask 4.6 Other Construction and Operational Permitting	50%															X						
Task 5.0 - AACE Class 3 FEED Study																						
Subtask 5.1. Process Engineering	25%										X											
Subtask 5.2. Mechanical Engineering																						
Subtask 5.3. Civil/Structural Engineering																						
Subtask 5.4. Electrical Engineering																						
Subtask 5.5. Instrumentation Engineering																						
Subtask 5.6. Architectural Engineering																						
Subtask 5.7. Cost Estimation	0%														X							
Task 6.0 – Optimization and Integration Testing																						
Subtask 6.1. Feedstock Characterization																						
Subtask 6.2. Pre-concentration																						
Subtask 6.3. Leaching																						
Subtask 6.4. Solvent Extraction	15%									X												
Subtask 6.5. Solution Recovery/Purification																						
Subtask 6.6. Metal Refining																						
Subtask 6.7. Data Management	50%															X						
Task 7.0 – Partnership Management, Contract Development and Execution																						
Subtask 7.1. Host Site Selection	60%				X																	
Subtask 7.2. Feedstock Acquisition																						
Subtask 7.3. Material Disposition Plan	20%												X									
Subtask 7.4. Offtake Agreements	10%															X						
Subtask 7.5. EPC Selection																						
Subtask 7.6. Funding/Financial Plan																						
Subtask 7.7. IP Management																						

e Gantt chart
lifetime in years on
xis and major tasks
al axis. Use symbols
r and minor
shaded lines or the
duration of each task
of work completed to

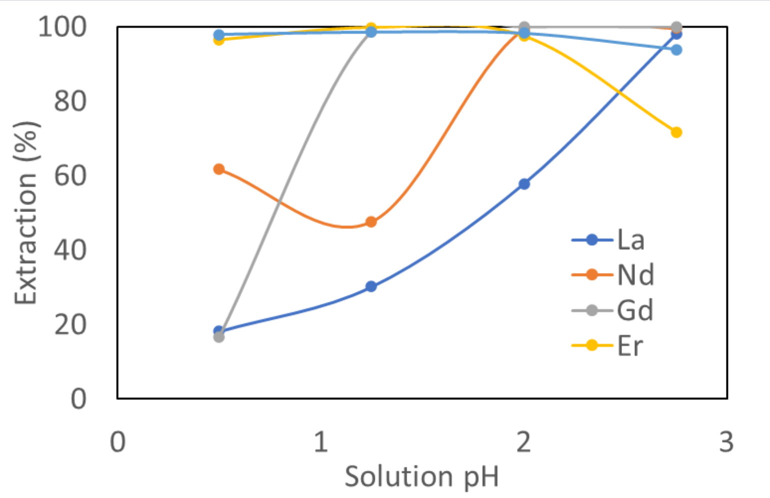
Acidic Extractants vs Ionic Liquids

Elements	C572	[c101][C801]	[C101][c572]
Eu / Sm	1.87	1.03	1.29
Gd / Eu	1.33	1.44	1.27
Tb / Gd	2.43	2.29	2.27
Dy / Tb	**1.67**	**2.01**	**1.94**
Ho / Dy	**1.29**	**1.92**	**1.70**
Ext. Conc. (M)	1 M	0.5 M	0.5 M
Loading (g/L)	18.0	16.1	20.0

SPEx: Highly Acidic Extractants

Advantages

- Easy to synthesize
- High acidity
- Many possible conformations
- High potential for transition to ionic liquid



Weaknesses

- High Acidity
- Unproven
- Optimum conformation not yet identified