Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks

NETL Resource Sustainability Meeting – April 2nd, 2024

Presenter: Nolan Theaker

Overview

- Project Team
- Technology Background
- Project Objectives and Scope
- Pilot Tour and Products
- Remaining Work
- Disclaimers
- Questions

Team Members

Project Team Members

- UND College of Engineering and Mines Research Institute
- Microbeam Technologies Inc.
- Barr Engineering Co.
- Rare Earth Salts LLC
- MLJ Consulting LLC
- North Dakota Geological Survey

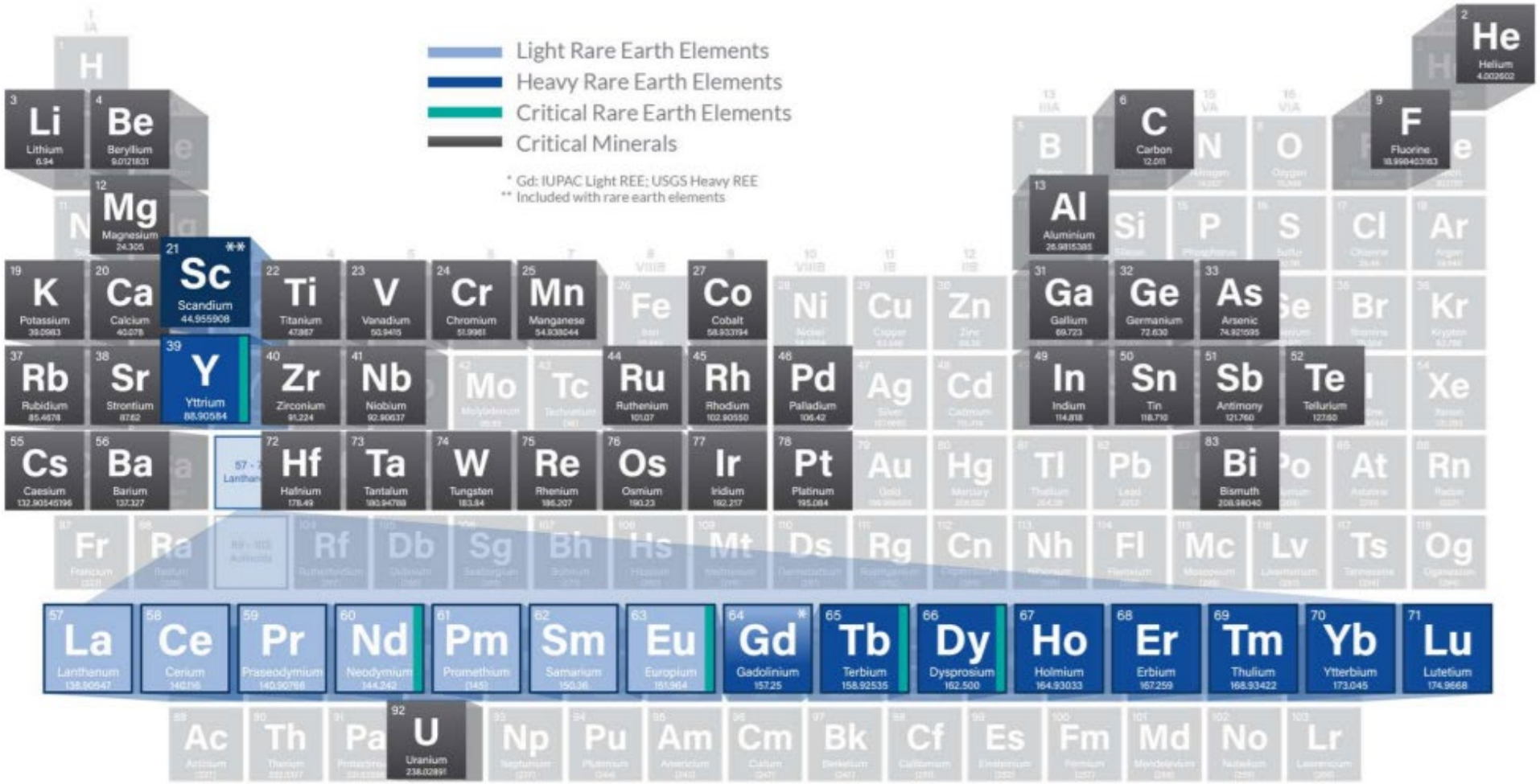
Project Sponsor Representatives/Executive Advisory Team

- U.S. Department of Energy NETL
- Lignite Research Program
- North American Coal
- Great River Energy
- Minnkota Power Cooperative
- BNI Energy

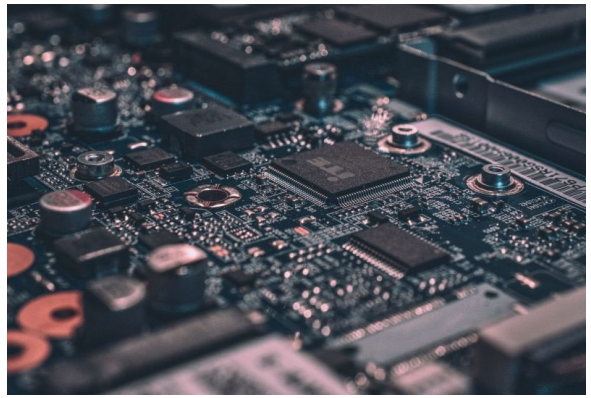
Technology Background

Background – Rare Earth Elements

- REE not rare
  - Well dispersed
- Minable deposits rare

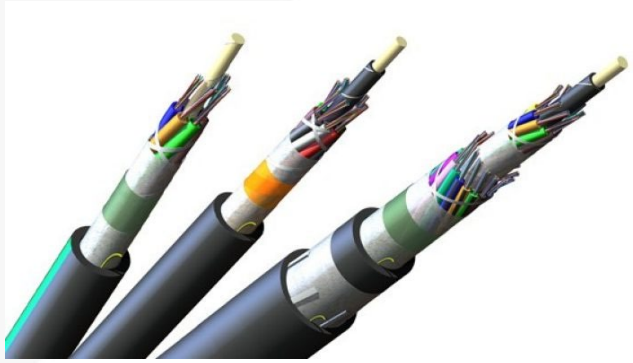


Critical Minerals – Ge and Ga



- Lignite contains more than just REE
  - Major resource of Ge and Ga
    - Semiconductor metals

- Active lignite mines contain up to 100% of the entire Ge/Ga needed for the US
  - Many have elevated concentrations



REE in Lignite

- REEs found typically bound in the organic form, somewhat in minerals
  - Higher in value than standard LREE-concentrated mineral forms, lower than the weathered clays
- As per NDGS findings, weathering from paleosols a likely concentration mechanism

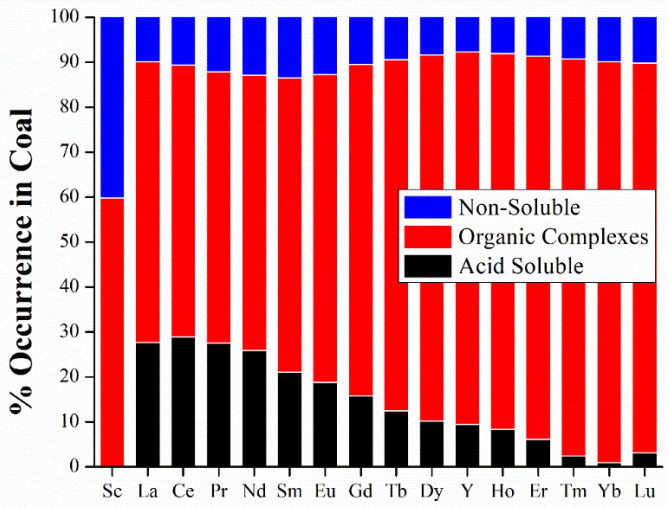


Image credit: CEMRI Data

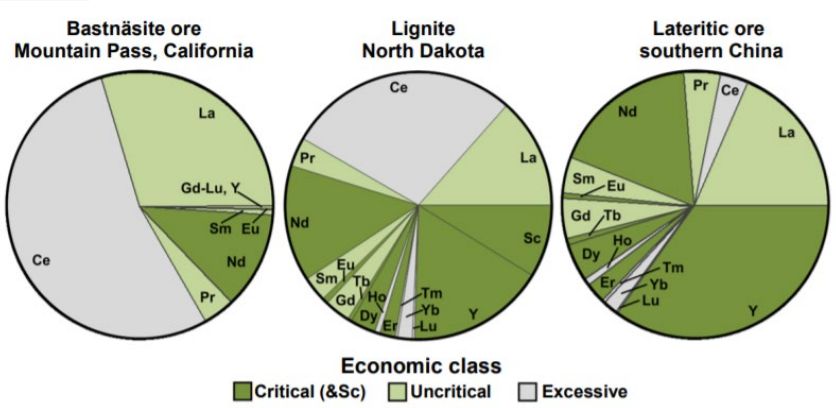


Image credit: ND Geologic Survey

Background – Lignite Binding Sites

- Produces semi-selective ionic binding sites (humic acids)
  - Process akin to commercial extractants

			High volatile bituminous			Bituminous		
	Lignite	Subbitu-minous	C	B	A	Medium volalite	Low volatile	Anthracite
% C (min. matter free)	***65-72***	72-76	76-78	78-80	80-87	89	90	93
% H	***4.5***	5-4	5.5	5.5	5.5	4.5	3.5	2.5
% O	***30***	18	13	10	10-4	4-3	3	2
% O as COOH	***13-10***	***5-2***	***0***	***0***	***0***	***0***	***0***	***0***
% O as OH	***15-10***	12-10	9	?	7-3	2-1	1-0	0
Aromatic C atoms % of total C	***50***	65	?	?	75	80-85	85-90	90-95
Avg. no. benzene rings/layer	***1-2***	?			2-3		5?	>25?
Volatile matter (%)	***40-50***	35-50	35-45	?	31-40	31-20	20-10	<10
Reflectance (%) of vitrinite	***0.2-0.3***	0.3-0.4	0.5	0.6	0.6-1.0	1.4	1.8	4

Background – Organic Extractants

- For cationic exchange mechanism – virtually all extractants are acid/base-based
- Some elements more strongly bind as compared to others
  - Selectivity from binding strength
- Can select which elements to extract at specific times

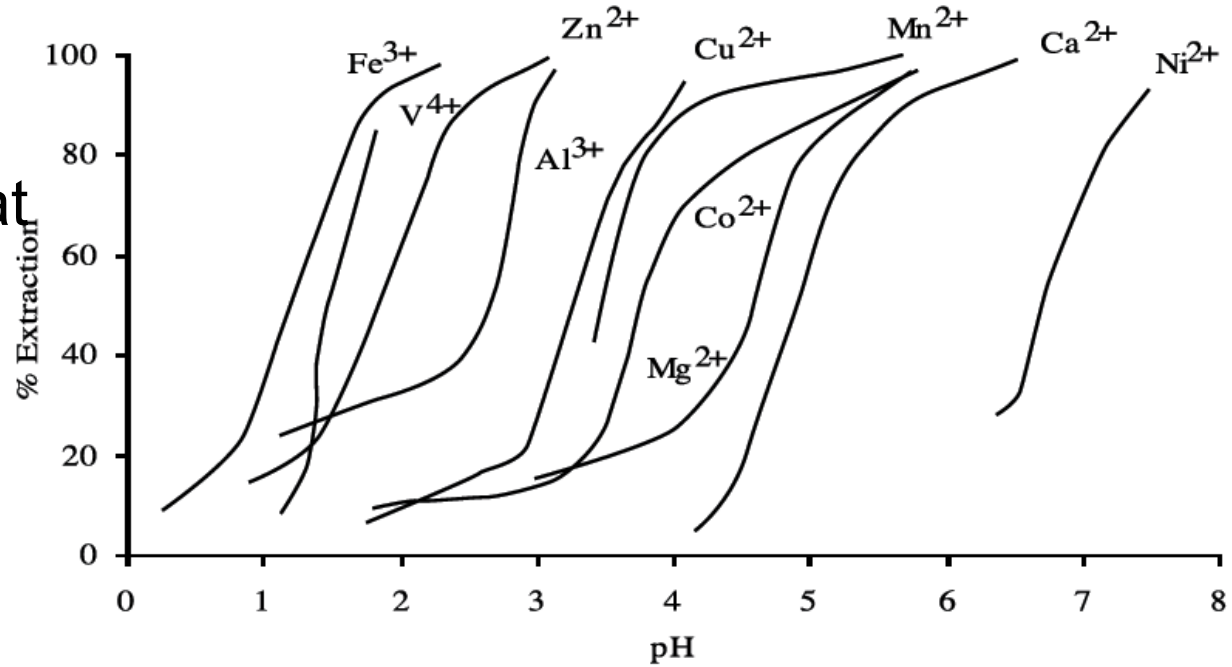
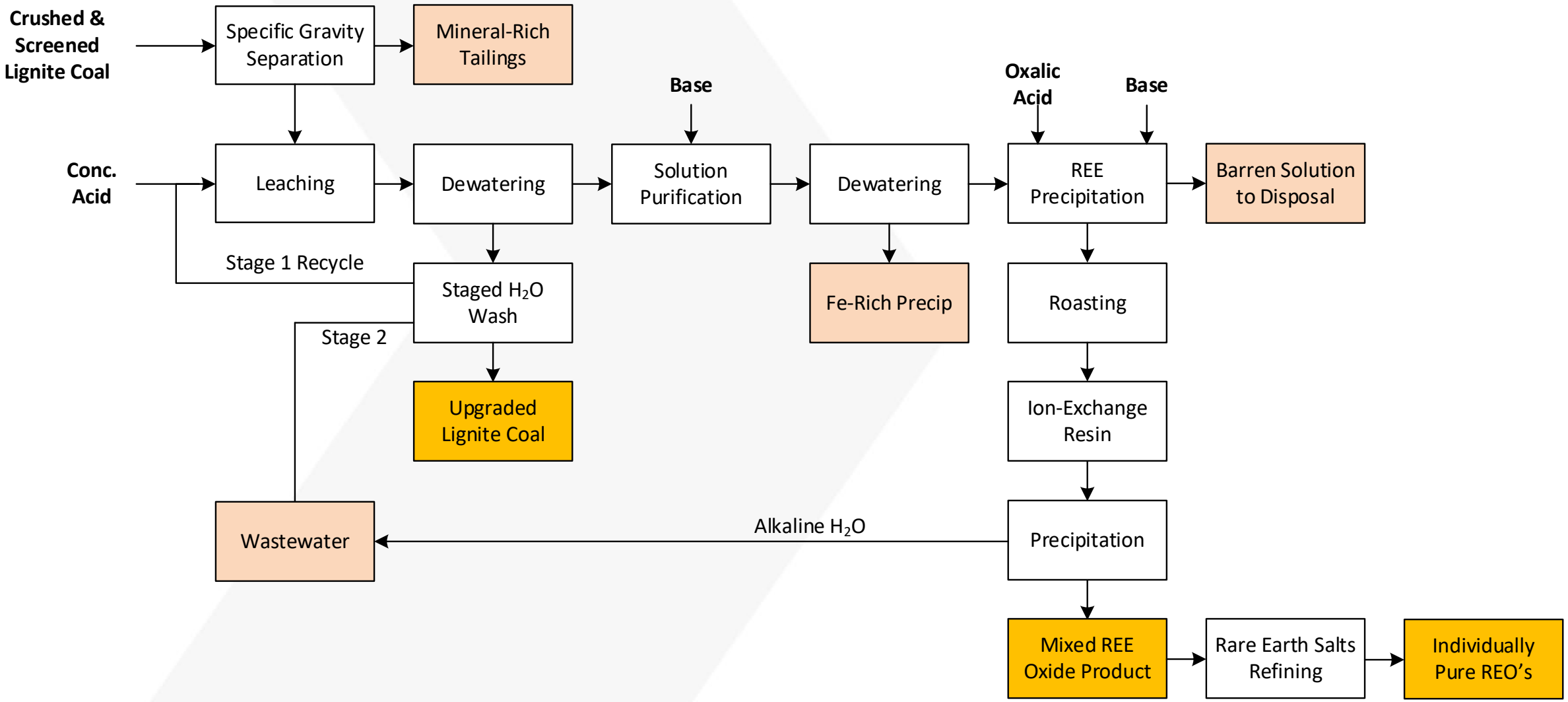


Image credit: Cyanex 272 Datasheet

Flow Diagram of UND's Mixed Rare Earth Concentrate (MREC) Process



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Upgraded Lignite Market Options

- Upgrading process – stripping out organic-bound ions
  - Overall coal ash does not significantly change, BUT
  - Organic-based ash drastically reduced
- Fuel Effects
  - Na essentially eliminated (>90% is organic bound)
- Carbon product feedstocks
  - Organic framework is highly purified, and highly functionalized
    - Functionalization allows for strengthened bonding, purity allows for high-purity applications (graphite)

Project Scope and Plans

Overall Project Goals

- As outlined by DOE – NETL in FOA 2003:
  - Development of pilot scale near 5-25% of commercial capacity of >2% REO concentrates utilizing coal-based resources of >300 ppm concentration TREE
  - Economic and environmentally-friendly extraction of REEs from coal

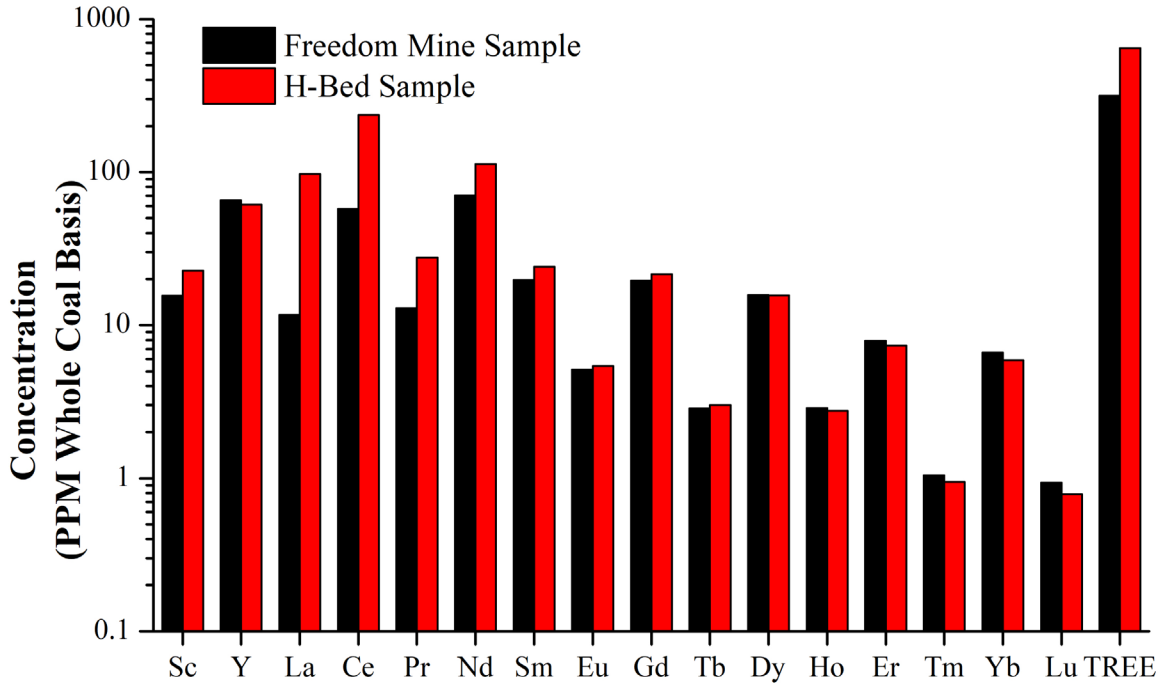
- Goal is to validate the REE extraction from LRC technology at a relevant scale for commercial deployment

Project Goal – Scale of Operation

- Pilot designed for 500 kg/hr nameplate of feedstock
  - All process areas capable of reaching or exceeding nameplate throughput as of now (highest reached across plant at 620 kg/hr throughput)
  - Goal to reach commercially-relevant throughputs, as well as be able to test materials rapidly and produce meaningful quantities of concentrate
- Scale based off of earlier TEAs for a 5-ton/hr lignite throughput tied to activated carbon usage
  - Belief is that this may still be feasible for other CBP options

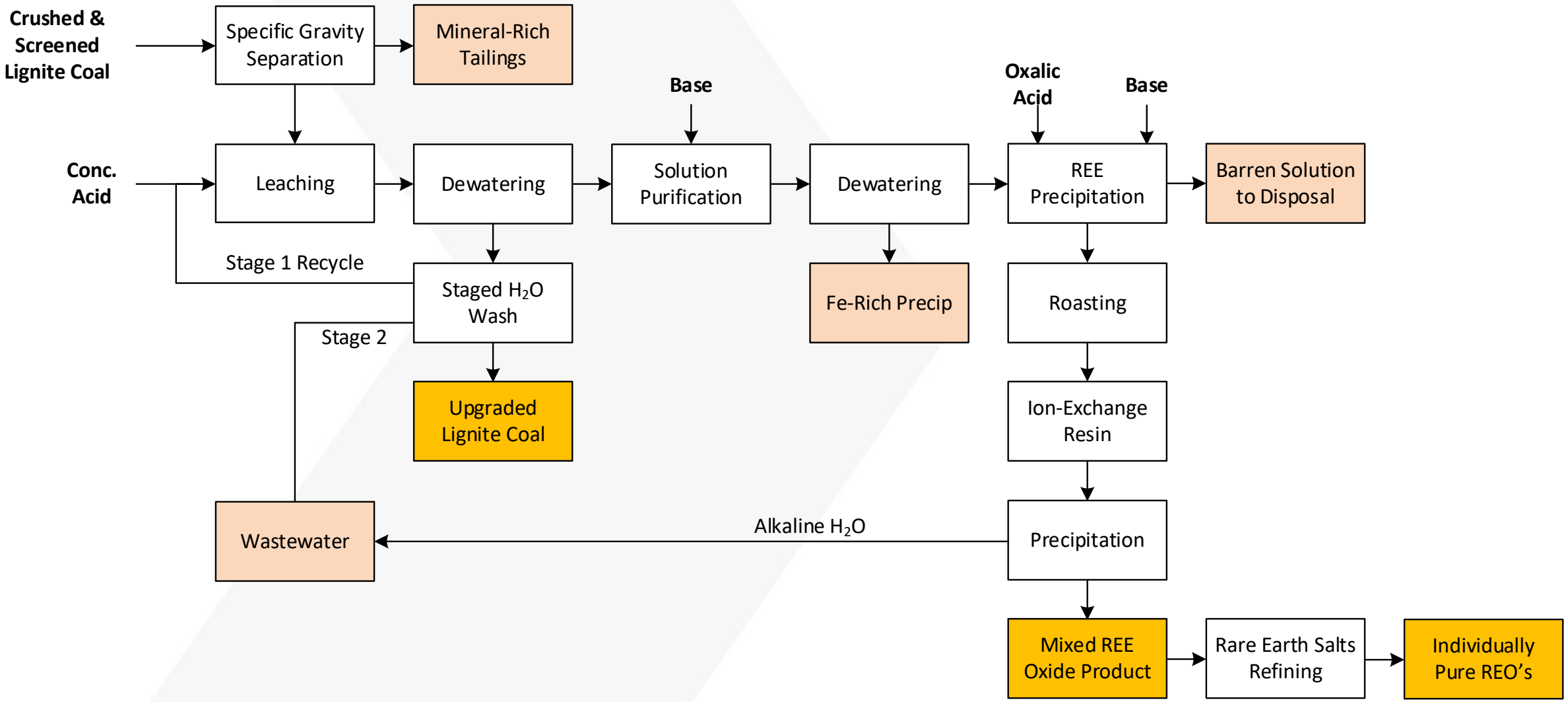
Project Goal – Feedstock Processing

- ~250 tons of feedstock (50 tons high-REE material, 200 tons of moderate, but high-value REE coal waste material gathered for processing)
  - Blending operation to keep more stable REE concentration during operation and constantly exceed 300 ppm goal



Pilot Tour and Products

Flow Diagram of UND's Mixed Rare Earth Concentrate (MREC) Process



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Coal Handling

Coal-Processing Section

Liquid Processing

Chemical Feeding

Challenges Faced

- COVID – equipment, price, people
- Lignite is extremely wet, handling is challenging
  - Paradoxically, adding water to slurry lignite makes problems worse, not better
- Building PID logic for sensor systems and designs never yet tested is quite challenging
  - Identifying right control variable (needs to be controllable and rapidly responsive)
- Some sub-processes need to be semi-batch at least for operability's sake

Processing to Date

- ~30 tons of coal leached and processed to date
  - Blending of the two coals to date
    - Approximately 10 tons of high-REE materials, 20 tons of Freedom Mine lignite mine wastes
- ~200 hours of all unit operations while chemicals are present under our belt
  - Average is quite below 500 kg/hr, but we can reach and maintain this throughput
- Now operating split shifts with trained crews – able to run 16 hours a day

Products to Date

- Delicate balance of ensuring full precipitation of REEs and CMs, but not permitting significant diluents to co-precipitate

Test #	REE Concentration (Cation)	Quantity Recovered (g – as collected)
1	10%	3,800
2	45%	300
3	62%	800
4	69%	900

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Remaining Work

Remaining Pilot Testing

- Continued pilot testing to reach 100 tons of processed feedstock
  - By end of week this is expected at 40 tons
  - Gives us longer-term analysis of process stability, operability, challenges

- Testing planned to include 24/3 testing by end of project
  - If combined plant operations, looking at ~20 tons processed into ~3-5 equivalent kg of REE concentrates in a single week
  - Trained operations staff now up to ~15, capable of handling this once more comfortable with system

Separations Processing

- Separations of pilot concentrates underway at Rare Earth Salts
  - Goals of identifying front-end TM and deleterious separations
  - Goal of separating Sc, primary magnet REEs by end of project

- Uses RES' patented electrochemical REE separation process
  - Aqueous-based
  - No organic solvents required

Economic and Workforce Evaluation

- Developing a TEA on the process
  - NOT same scale as DE-FE0032295 – see tomorrow's presentation on this
    - Goal of a smaller, modular plant at high-concentration and low-throughput resources

- Workforce needs
  - Construction and operations – what is required
  - Training methods and options available
  - Ongoing work in the state (Buelah development)

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Q&A

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