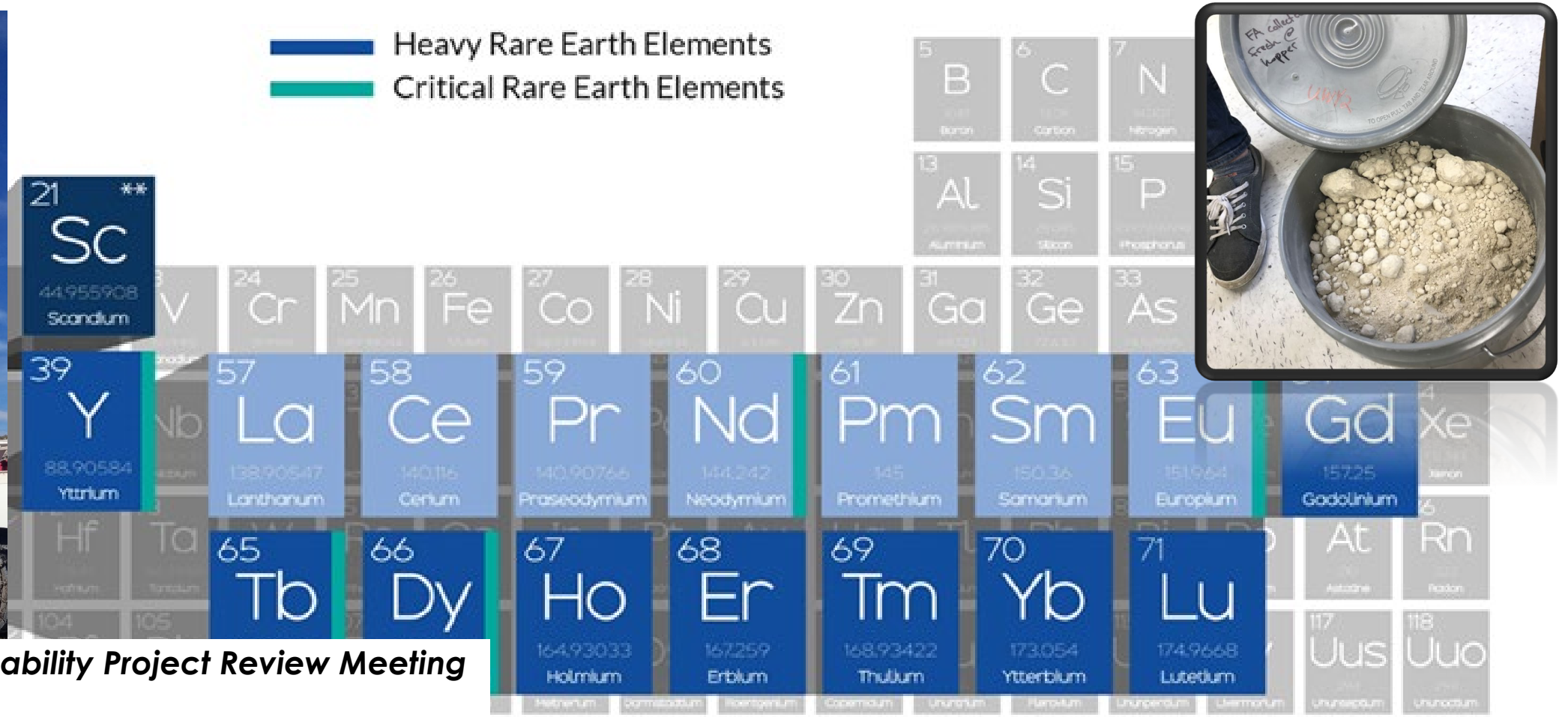
REE Extraction from Powder River Basin Coal Byproducts

TCF 2020-21358

Christina Lopano
Research Geochemist, NETL-RIC



2022 Resource Sustainability Project Review Meeting
October 26, 2022

The Opportunity: Coal Ash

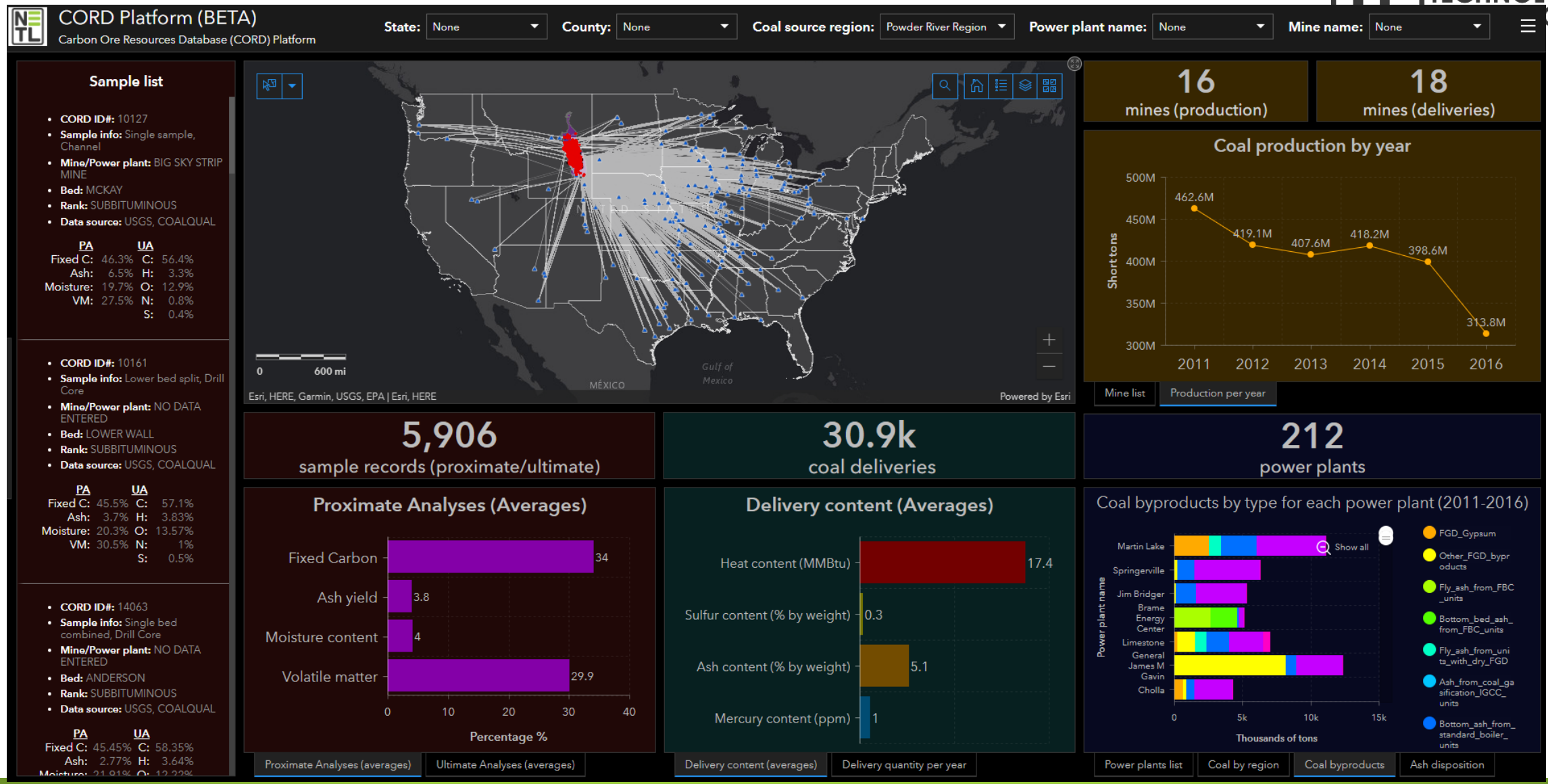
Powder River Basin

- ***Combustion Process Increases REE & CM Concentrations***

- ***Abundant waste material available across the U.S.***
  - *Landfills around the U.S. contain **1.5 billion tons of impounded ash***
  - *Geographically distributed, including by coal type*
  - *Review, closure, and/or re-impoundment in progress by statute*

- ***Opportunities exist for regional facility***
  - *100 million tons are impounded in the Upper Mountain Region (WY, MT, CO, & ND) Approximately 1.25 million tons of ash are generated annually in the region*
  - *Could support a 5 ton per day REE facility for over 20 years*

NETL Data Analytics: Understanding the Resources



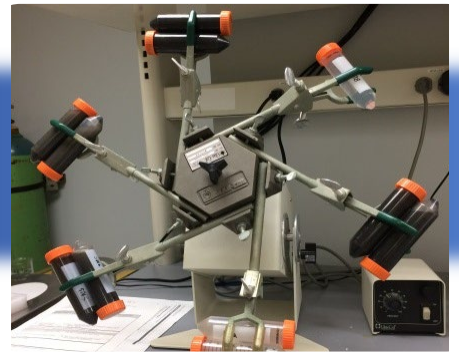
Justman et al (2022) https://doi.org/10.1016/j.dib.2021.107761

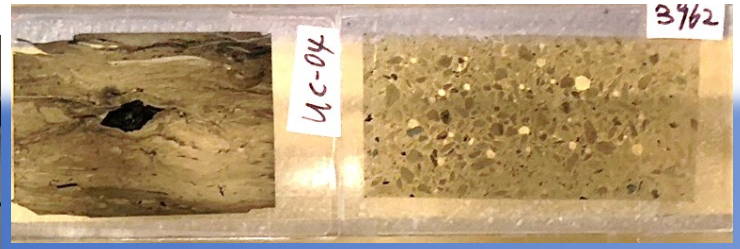
Fundamentally Understanding the Resource

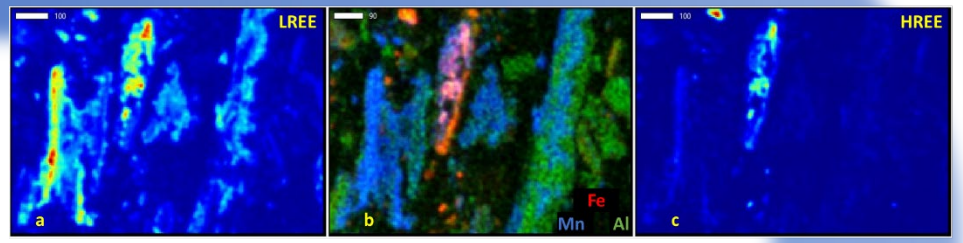
Ash & AMD Characterization to Recovery

AMD solids

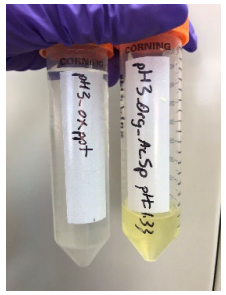
Fly ash

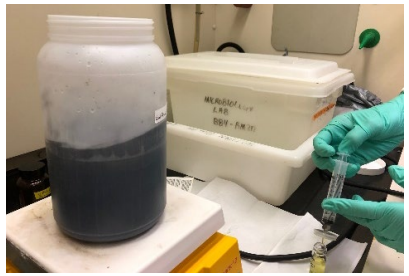




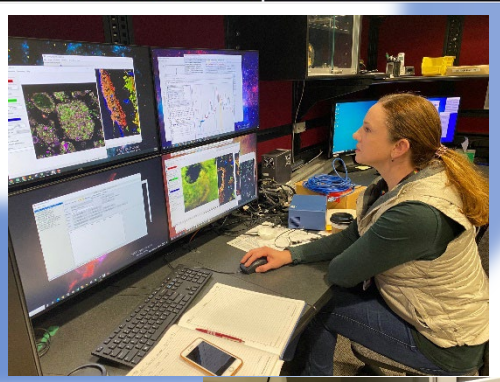


Utilize **characterization** of major REE-hosting solid fractions in different CCBs to **innovate targeted extractions** for efficient and economical REE recovery.





Stuckman, M.Y., Lopano, C.L. and Tarka, T. (2021)
U.S. Patent Pending, Serial No.: 63/053,925
https://netl.doe.gov/node/10318



Targeted Rare Earth Extraction (TREE)*

Targeting Calcium-Rich Ashes & AMD solids

TREE Advantages over REE mining:

1. Domestic/ local waste feedstocks
2. No-pretreatment
3. Up to 90% acid reduction
4. No heating/ no pressure
5. Reduced solvent use
6. Less waste management cost
7. Additional value streams such as cobalt, nickel or scandium

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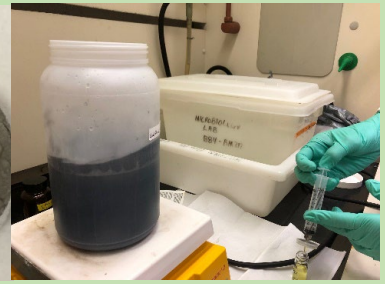
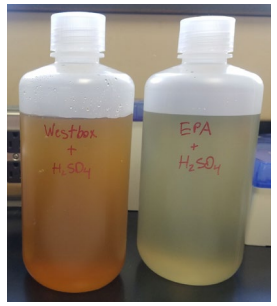
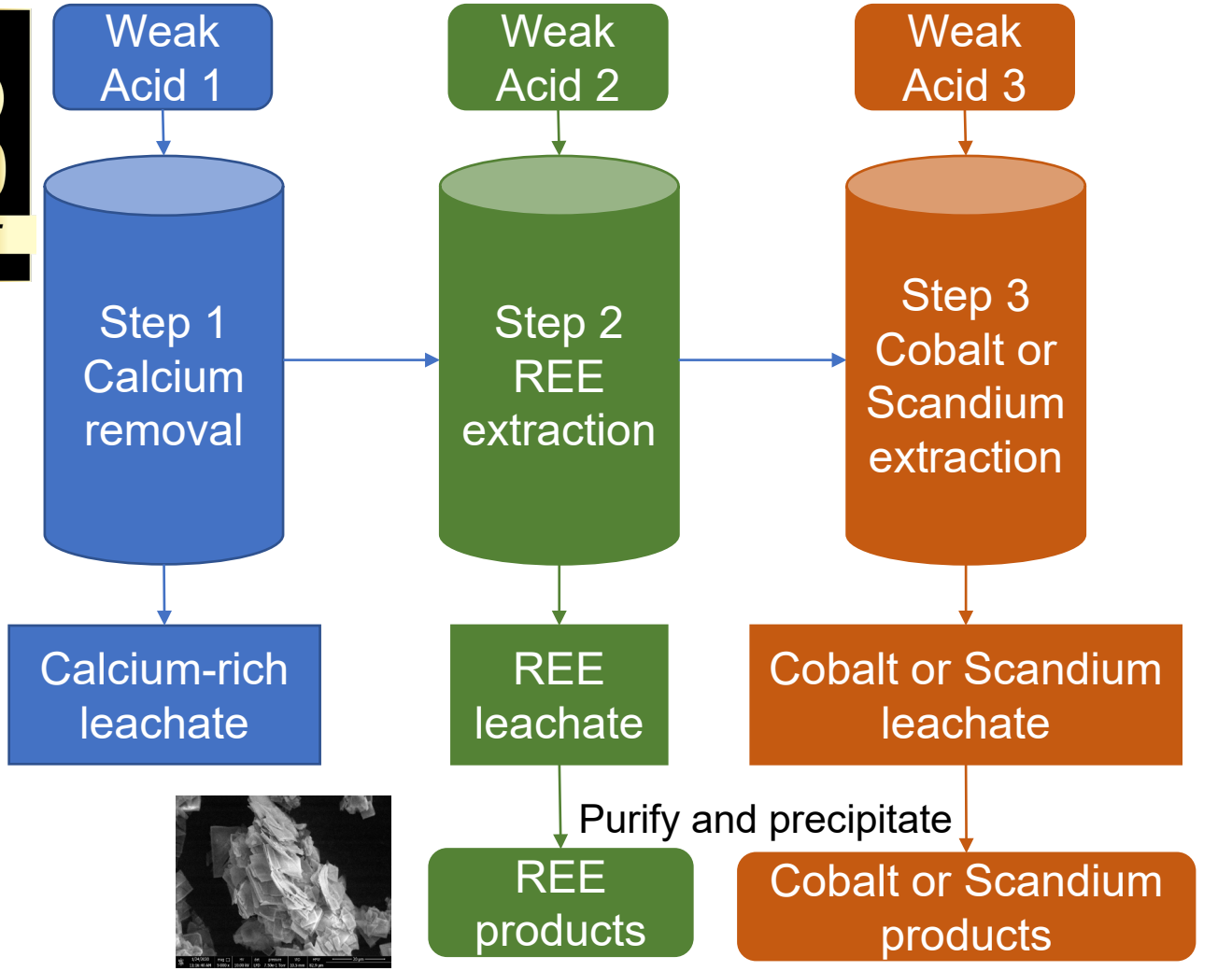


AMD solids Fly ash TREE process



REE leachate



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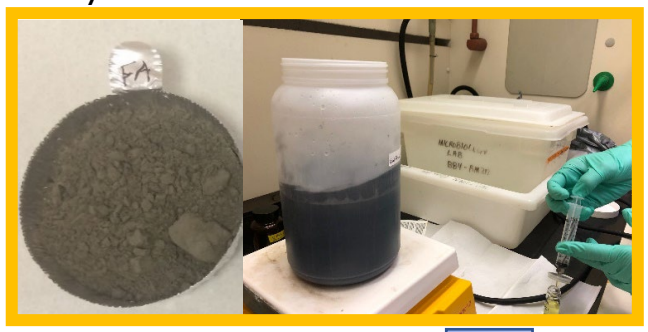
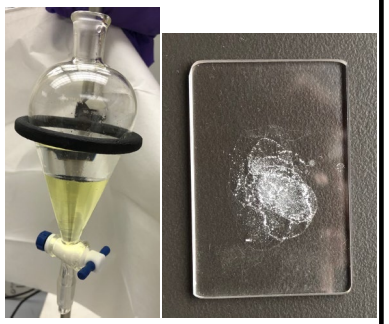
Bridging the "Valley of Death"

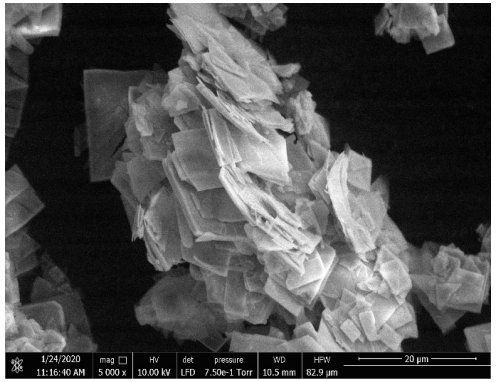
Targeting PRB Ashes for cost-saving and eco-friendly REE/CM extractions

Fly Ash Extraction





Step-leaching at ambient conditions
Targeted Rare Earth Extraction (TREE)
U.S. Patent Pending Serial No.: 63/053,925



e.g. 96wt% Pure Rare Earth Oxide (REO)

From Bench to Pilot: $1.6 million TCF Project

Wyoming partners committed to technology maturation:

- **University of Wyoming School of Energy Resources**
- **Campbell County**
- **City of Gillette**

State, Campbell County pursue rare earth opportunities

By Greg Johnson, Gillette News Record | Via Wyoming News Exchange Jul 5, 2020 Comments OPEN ACCESS

Rare Earth Elements Project Receives Federal Funding

NEWS DIRECTOR | Article Updated: June 23, 2020 | COMMENTS OFF

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U.S. DEPARTMENT OF ENERGY

Projected Started December 2020

Bridging the "Valley of Death"

US DOE Technology Commercialization Fund (TCF)

- Designed to increase the number of energy technologies developed at **DOE's national labs** that graduate to commercial development and achieve commercial success.
- Enhances DOE's technology transitions system with an enterprising and competitive approach to **lab-industry partnerships.**
- Applied program offices and national laboratories can pursue a strategic approach to commercializing technologies (requires provisional patent)
- **50% Cost share** between DOE and partners

From Bench to Pilot: $1.6 million TCF Project

NETL works with Wyoming partners committed to technology maturation:

- University of Wyoming School of Energy Resources
- Campbell County
- City of Gillette


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3 Year Project, Started December 2020

TCF-20-21358 Team

CRADA Agreement 1037 (NETL, UWy, ECED)

NETL (Pgh, Alb)

- PIs: Christina Lopano, Thomas Tarka
- RIC PM: Christy Pecyna
- Research Team: Mengling Stuckman, Ward Burgess, Alison Fritz, Jon Yang, Patricia Saint-Vincent, Circe Verba, Brian Kail

University of Wyoming – School of Energy Resources

- PM – Scott Quillinan
- Research Team: Davin Bagdonas, Erin Phillips, Charles Nye, J. Fred McLaughlin

Energy Capital Economic Development (ECED)

- PM – Jim Ford
- City of Gillette, & Campbell County, Wy

Industry Support:

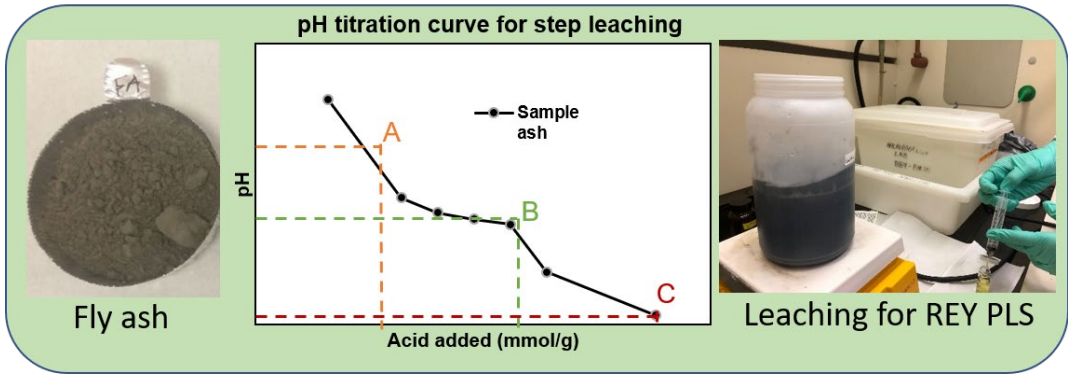
- Western Fuels, Wyoming, Inc. (Dry Fork Mine)
- Basin Electric Power Cooperative (Laramie River Station, Dry Fork Station)

Project Goals and Objectives

TCF-20-21358 Project Narrative

The project will create a small **pilot-scale production facility** that demonstrates the environmentally benign and economically viable production of REE from coal-related feedstocks. This will be achieved by working with **academic and industrial partners** to:

1. Identify the most promising feedstock(s) in the Powder River Basin (PRB) for the extraction of rare earth elements (REE) and critical metals (CM),
2. Perform extraction experiments to demonstrate the efficacy of extracting REE and CM in an economic manner, and
3. Up-scale NETL extraction technologies to a pilot scale in the PRB.



Task Breakdown

TCF-20-21358 Project Narrative

Task 1: Feedstock Screening, Testing and Optimization (~ 12 months) (UWy, NETL), PI - Lopano

- Identify promising ash materials for extraction and upscaling. Down-select to 1 to 2 candidate ashes for larger scale extraction tests and process optimization.

Task 2: Chemistry & Reaction Optimization (~ 24 months) (NETL), PI - Lopano

- NETL has developed a patent-pending step leaching process (TREE) for extraction of REE from PRB ash that reduces acid consumption by 90% over other processes for PRB ash and effectively eliminates the presence of major cations (e.g., Ca and Fe) to increase the purity of REEs in the pregnant leach solution (PLS).

Task 3: Systems Analysis and Resource Assessment (~ 36 months) (NETL) PI - Tarka

- NETL SEA will initiate a screening study to evaluate the economic performance of the sequential extraction process and subsequent product enrichment to higher purity concentrates. This work both builds the foundation for TEA work to be performed during the duration of the project and will inform research performed under Tasks 2 & 4.

Task 4: Pilot-Scale Process Operation (~ 30 months) (NETL, UWy, ECED), PI - Tarka

- Maturation of a pathway to extract and enrich REE from coal byproducts that technical risk is reduced, enabling the technology to be licensed and financed for deployment at a large scale. To achieve this, the project will culminate in the start-up and operation of a pilot-scale facility that demonstrates the performance and economic feasibility of the process. Produce 25 grams of 60% REO concentrate

Milestones & Project Goals

Year	Major Project Goals
Year 1	• Evaluate Coal Byproducts Available • Down-select to 2-3 Candidate Ashes • Optimize TREE extraction method for candidate ashes (L:S ratio, T&P, leach time, # of leaches) • Initial systems design and cost estimate • Initiate site preparations, permitting, and local outreach
Year 2	• Perform larger scale (~40 gallon) extraction tests to validate performance • Complete more rigorous process design for pilot plant • Go/No-Go on using purification techniques (NETL-RIC IP) • Optimize parameters for purification • Finalize site prep and equipment needs list
Year 3	• Finalize purification method to utilize • Procure and install equipment • Equipment shakedown • Pilot test campaign

Task 1: Evaluation of Regional Feedstock

Fly Ash, Bottom Ash, Landfilled Ash

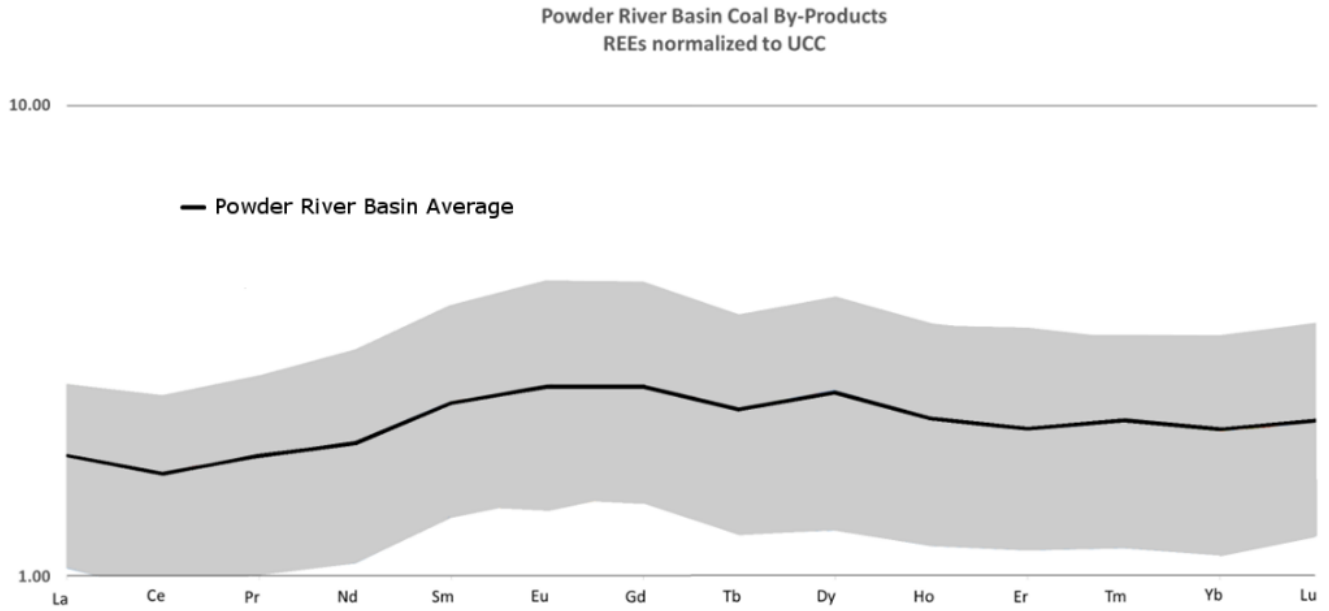
Survey of Potential Feedstocks and Resource Characterization of Powder River Basin Derived Coal Byproducts

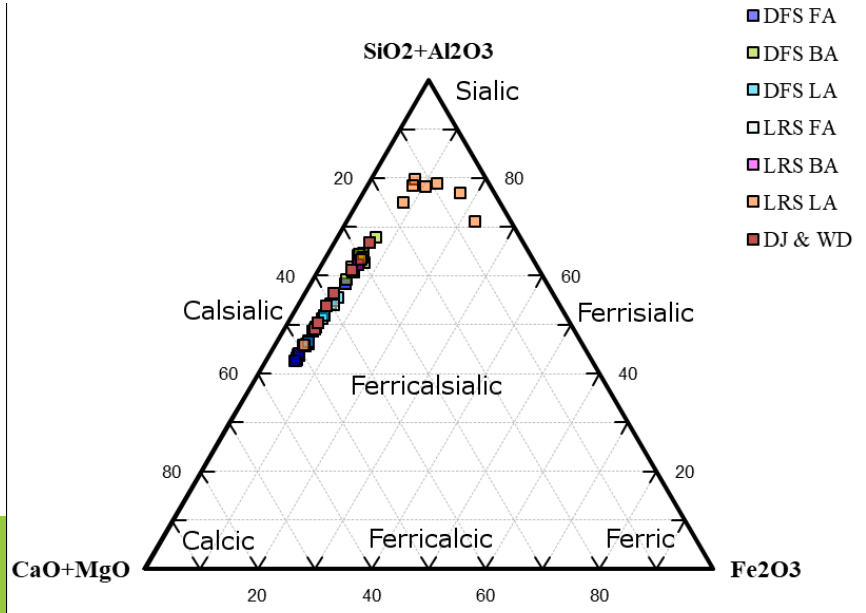
Prepared by the Center for Economic Geology Research
University of Wyoming School of Energy Resources

In Support of the National Energy Technology Laboratory
Under Agreement AGMT-1037

Contributing Authors:
Davin Bagdonas
Fred McLaughlin
Charles Nye

Acknowledgment: Parts of this technical effort were performed in support of the National Energy Technology Laboratory's ongoing research in rare earth element extraction under DOE Award TCF-20-21358.





See also Bagdonas (2022)

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Table 3.4-1

REY Averages (ppm)	FA Average	BA Average	BA Landfill	FA Landfill
Dry Fork Station Legacy Data	*329.2*	393.0	N/A	268.7*
Dry Fork Station Modern Data	255.6	307.8	N/A	262.7*
Wyodak Station Legacy Data	323.1	405.0	447.7	275.7
Wyodak Station Modern Data	297.7	297.6	No Data	300.2
Dave Johnston Station Legacy Data	303.3	No Data	No Data	325.3
Dave Johnston Station Modern Data	392.9	308.3	No Data	309.7*
Laramie River Station Legacy Data	*328.6*	No Data	298.3	263.2
Laramie River Station Modern Data	263.6	307.3	202.2	206.7

*Dry Fork and Dave Johnston Station landfills are a combined landfill of both FA and BA

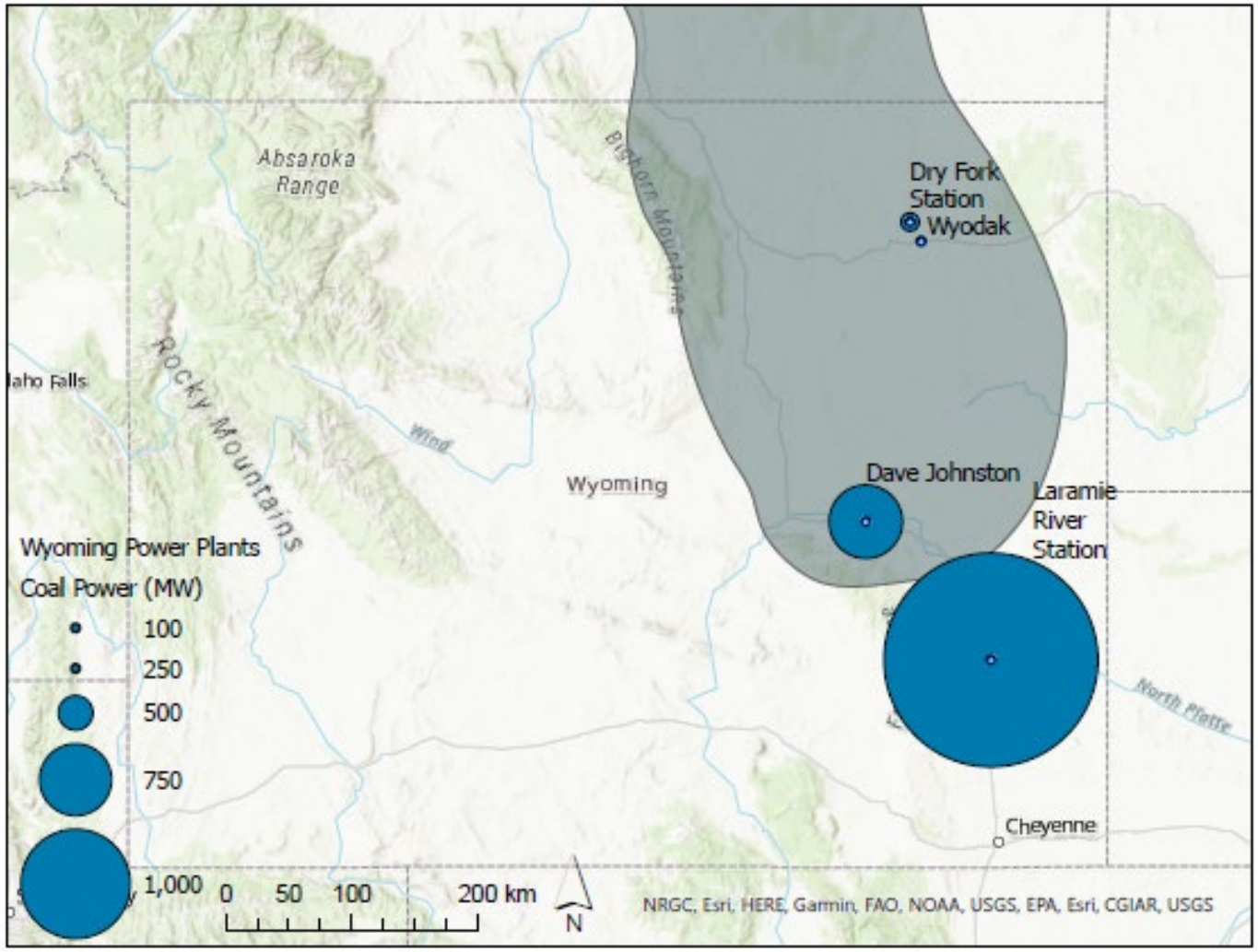
See also Bagdonas (2022)

Task 1/2 – Sampling & Lab Testing

Provided by UWy & partners

Station	Abbreviation	# Samples
Dave Johnston	DJ	4
Dry Fork	DF	3
Laramie River	LRS	4
Wyodak	WD	2

- 13 ash samples from 4 stations in Wyoming
- Full analysis (synchrotron, extraction method development) on 4+ samples

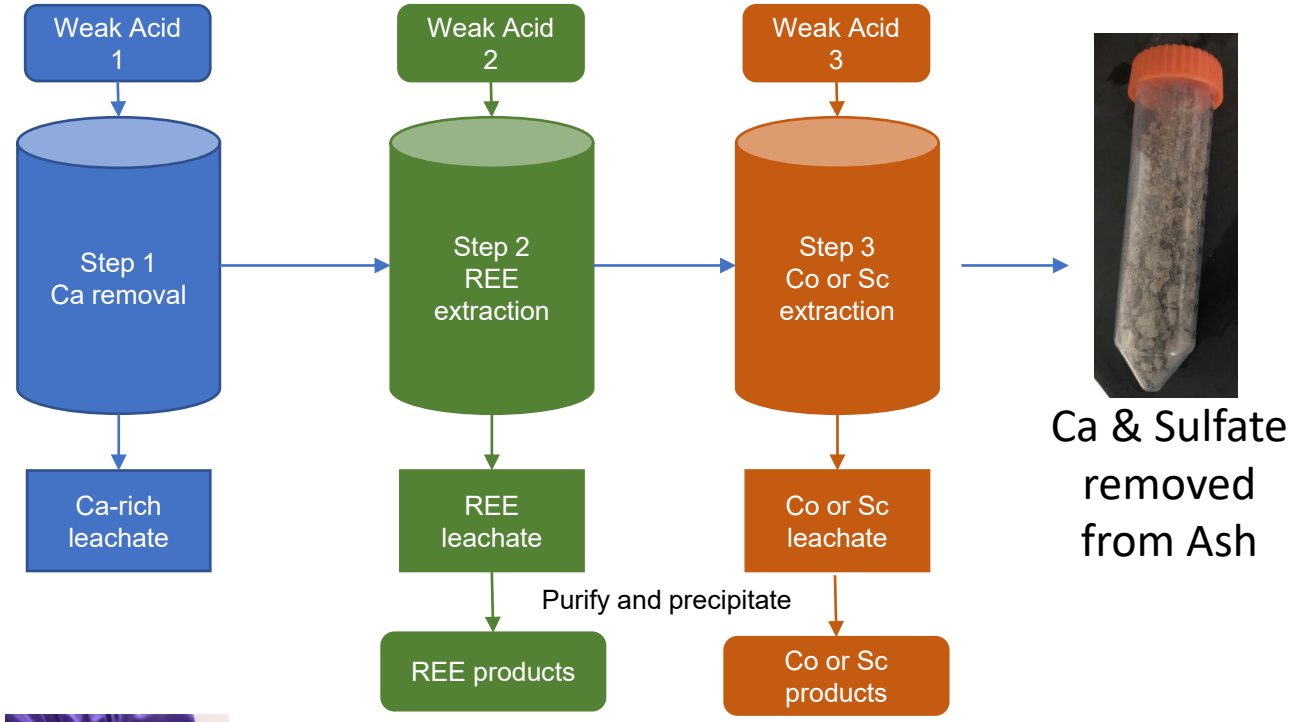


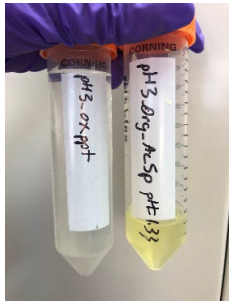
Task 2 - Targeted Rare Earth Extraction (TREE)

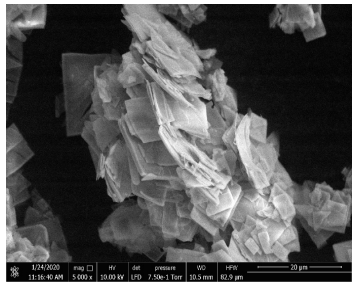
Ca-rich Powder River Basin (PRB) Ashes - Reduce Extraction Steps & Conditions

Findings to-date

- *3-step process:*
  (A) Ca, (B) then REY and (C) Sc
- *Up to **83% REY** achieved in Step 2; up to 61% Sc removal in step 3*
- *TEA Analyses aid optimization by fine-tuning reaction time, L:S, acid addition in each step.*
- Acid concentrations optimized for FA; *should* also work for LA, BA samples
- Other Co-products?: Ca-rich brine, Treated Ash







2022 R&D 100 FINALIST

*Stuckman, M.Y., Lopano, C.L. and Tarka, T. (2021) U.S. Patent Pending, Serial No.: 63/053,925
https://netl.doe.gov/node/10318

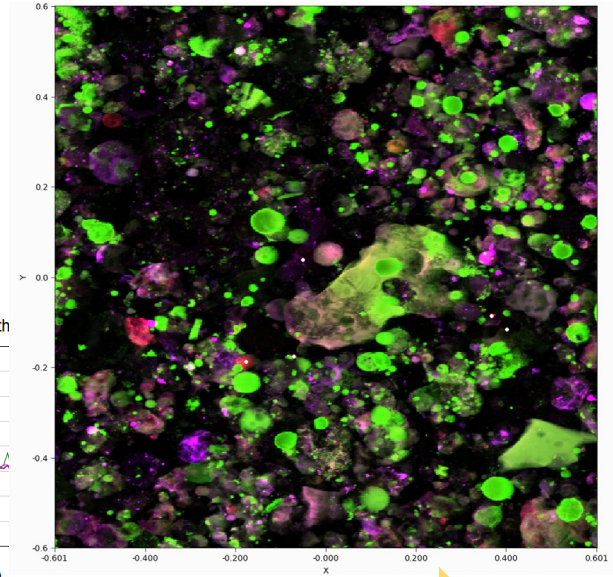
Task Timeline (Tasks 1 & 2) Dec 2020 – present

Project awarded July 2020; CRADA signed Dec 2020 (Start of project)

CRADA signed (AGMT-1037) 12/2020

Characterization & preliminary leaching (2021)

Synchrotron Characterization (2021-2022)



Samples from Wyoming: Characteristics of Wastes available

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NATIONAL ENERGY TECHNOLOGY LABORATORY

UNIVERSITY OF WYOMING | School of Energy Resources

Acknowledgment: Parts of this technical effort were performed in support of the National Energy Technology Laboratory's ongoing research in rare earth element extraction under DOE Award TCF-20-21358.

Characterization & Step leaching (2021-2022)

Upscaling 1: L level (Spring 2022)

Optimization: Step leaching (L:S, time) (2021-2022)

Upscaling 2: Barrel Leach (Summer 2022)

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Task 3: Systems Analysis & Design

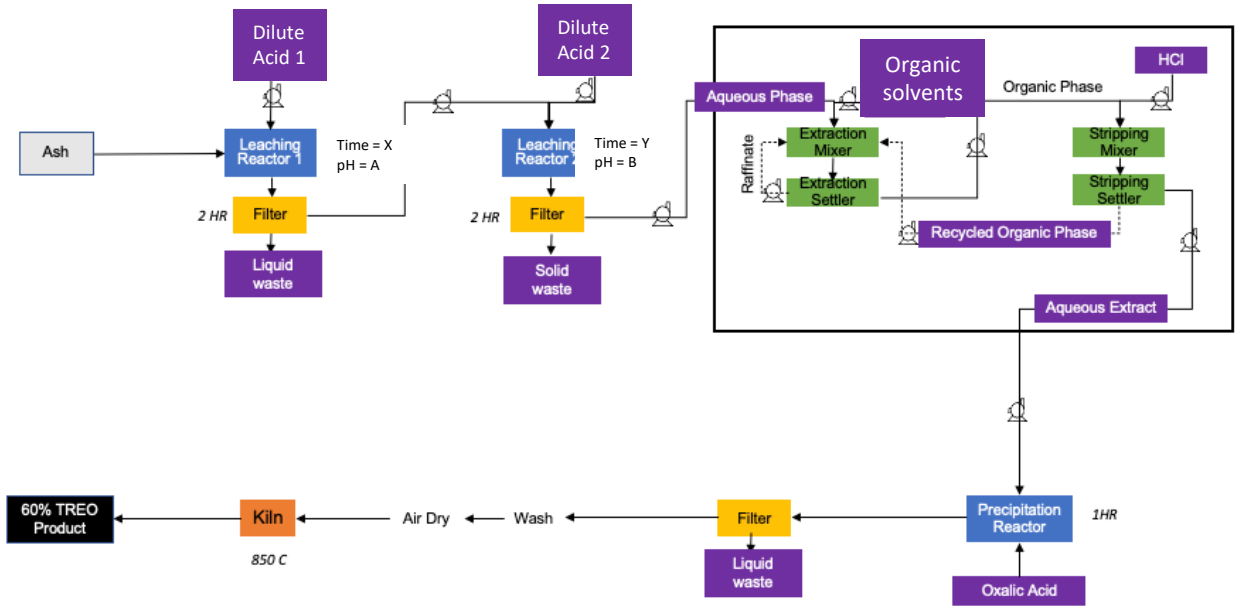
In Progress

Completed:

- Initial Systems Design, Equipment list, high-level TEA and cost estimates
- Procured big ticket items (membranes, IC Unit)
- Outlined Environmental Health and Safety Considerations

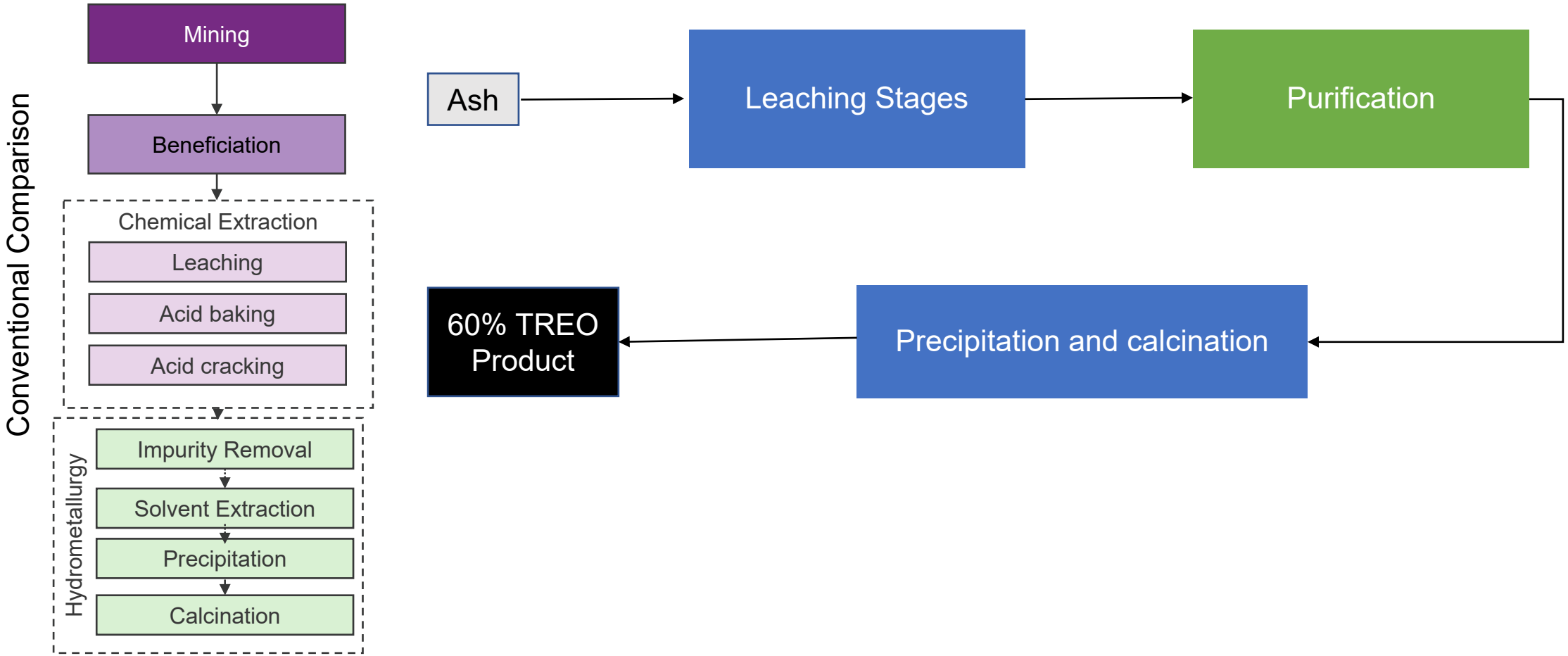
Underway:

- Facility design and EH&S Plans
- Additional equipment purchases
- Updated TEA



Task 4: Developing a process flowsheet

Developing a final product

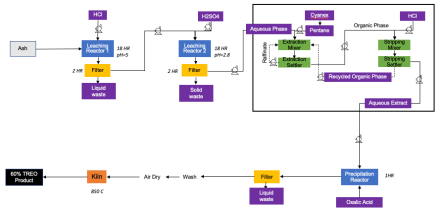


Task Timeline (Tasks 3 & 4) Dec 2020 – present

Project awarded July 2020; CRADA signed Dec 2020 (Start of project)

Task 3

- Initial systems design and high-level cost estimate (2021)
- Pilot Plant Mass and Energy Balance (Fall 2022)
- Final Systems Design and High-Level Cost Estimate (Fall 2022)
- Techno-Economic Evaluation of Process Performance and Economics (Winter 2023)



Task 4

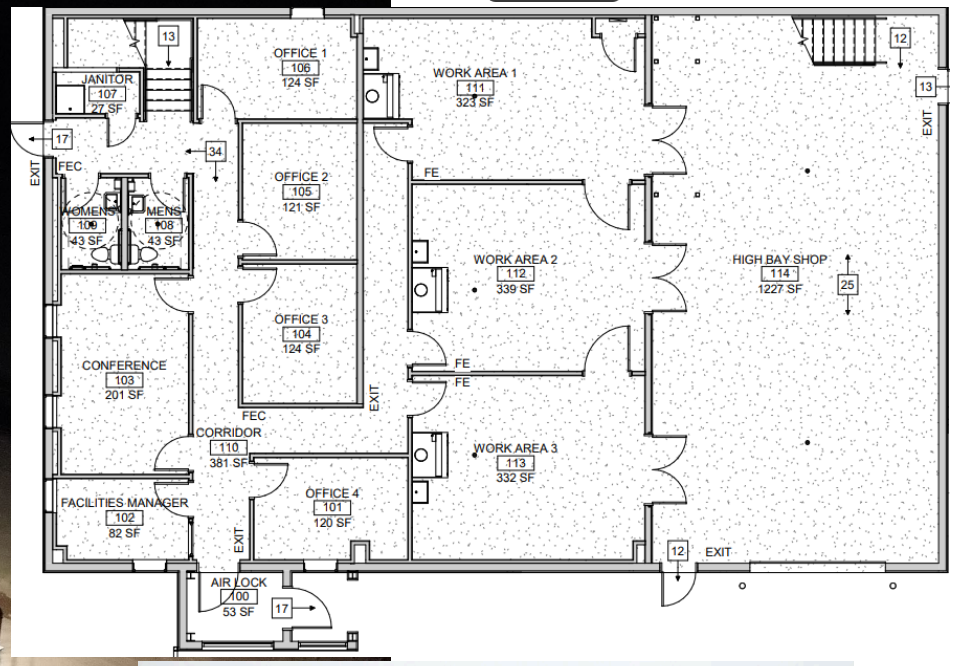
- Identify environmental health and safety needs (2021)
- Complete equipment specification and procurement (Winter 2022)
- Equipment layout and environmental health and safety plan (Spring 2023)
- Initiate pilot plant operation (Summer 2023)
- Produce 25 grams of 60% REO concentrate (Winter 2023)

Task 3 & 4: Pilot design (In Progress)

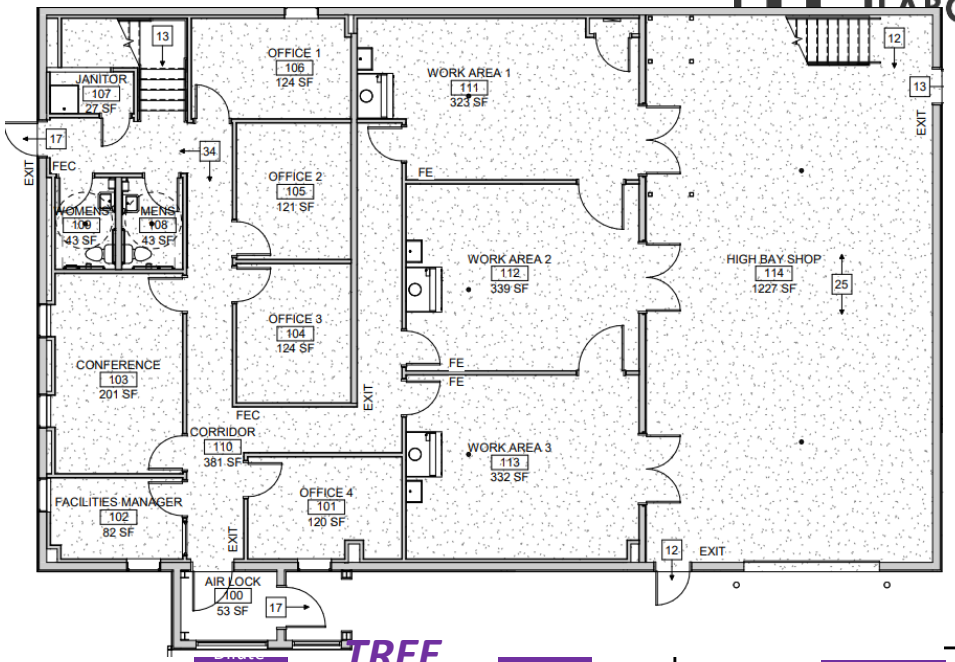
Task 4: Wyoming Innovation Center

NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL TCF Project – first tenant

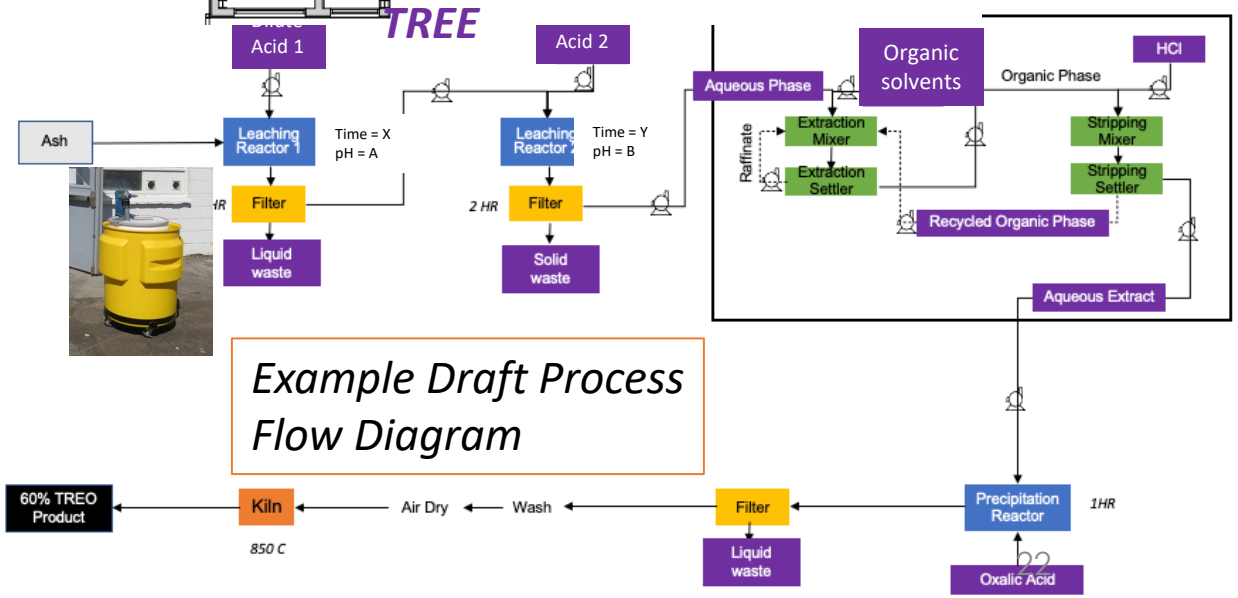


Wyoming Innovation Center



Ribbon cutting – June 14, 2022

[SER Participates in Wyoming Innovation Center Ribbon Cutting Ceremony and Meets with Key Stakeholders in Gillette (uwyo.edu)]



Summary: REE Extraction from Powder River Basin Coal Byproducts

TCF 20-21358 (PIs: Christina Lopano & Thomas Tarka, NETL-RIC)

- CRADA (AGMT-1037) between NETL-RIC, University of Wyoming, Wyoming Energy Capital Economic Development (ECED) – Signed 12/2020
- Materials obtained from Wyoming Power Plants (4 power plants, 13 types of ashes: Fly ash (FA), Bottom ash (BA), Landfill Ash (LA). Characterization and initial leaching tests completed. (2021-2022)
- Team completed a survey of available materials & logistical factors
  - Determined the best 1-2 PRB ash targets for pilot plant testing
- NETL's patent pending TREE Technology was validated for use on these materials (2021-2022). Final optimization and upscaling shake-down is ongoing

  Stuckman, M.Y., Lopano, C.L. and Tarka, T. (2021) U.S. Patent Pending, Serial No.: 63/053,925 https://netl.doe.gov/node/10318
- Developed process flowsheet & completed initial systems design and equipment list (2022)
  - Procured some big-ticket items (membranes, IC unit)
  - Health and Safety assessment is underway
- Wyoming Innovation Center construction completed and is a blank slate for our pilot – Building the pilot is Task 4 and began summer 2022

REE Recovery from PRB Coal Wastes: Pilot at WIC

TCF-20-21358

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