Powder River Basin CORE-CM: Advancing Strategies for Carbon Ore, Rare Earth Element, and Critical Mineral Resource Development in the Nation's Largest Coal Producing Basin

DE-FE0032048

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Acknowledgement and Disclaimer

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Energy Capital Economic Development

Phil Christopherson, Curtis Burdette, Jim Ford, Mike Shober

Los Alamos National Laboratory Est. 1943

Brent Goehring, Dan O'Malley, Bulbul Ahmmed, Peter Lawrence, Hakim Boukhalfa

State of Wyoming Geological Survey

Erin Campbell, Ranie Lynds, Kelsey Kehoe, Patty Webber

And many more stakeholders and involved partners

Project Overview

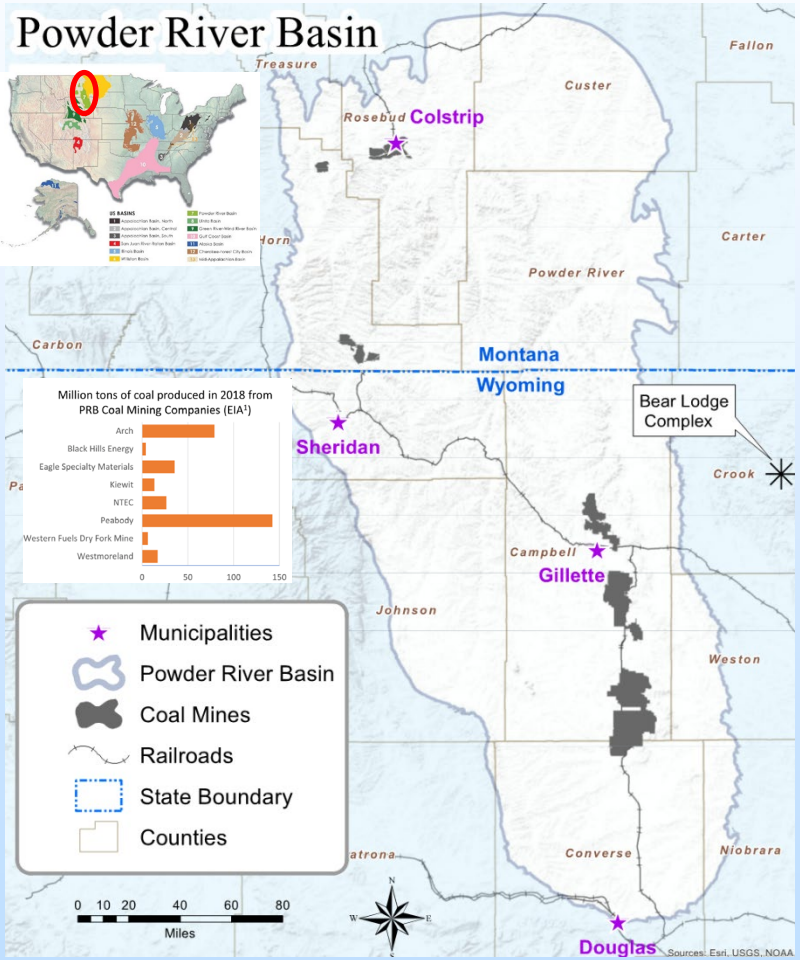
- Funding
  - DOE: $2,084,435
  - Cost Share: $521,282
- Overall Project Performance Dates
  - September 1, 2021 – August 31, 2024
- Project Participants
  - Project Lead: University of Wyoming (UW) School of Energy Resources
  - Project Partners: UW Department of Geology and Geophysics; Montana Bureau of Mines and Geology; Los Alamos National Laboratory; Campbell County, Wyoming; Energy Capital Economic Development; UW Center for Business and Economic Analysis, Battelle Memorial Institute; UW Department of Chemical Engineering; BSI Energy Ventures; Gillette College
  - Advisory Partners: Wyoming State Geological Survey; Southeastern Montana Development Corporation; Industry Partners; Wyoming Energy Authority

Overall Project Objective

To establish and initiate a strategic plan that addresses all aspects of carbon ore, rare earth element, and critical mineral resource development in the Powder River Basin (PRB) to **promote economic growth and workforce development**. The strategic plan will **bring together a committed team of stakeholders** from across the PRB of Wyoming and Montana.

Powder River Basin Background

- More than 40% of the coal produced in the US comes from the Powder River Basin[1,2]
- Original coal resource estimated at 1.16 trillion short tons[1,2], with the majority of the resource in the Paleocene Tongue River Member of the Fort Union Formation
- Surface mine extraction from thick coal seams (>50ft) results in low-cost production
- Wyoming coal is shipped to power plants in 28 states[1]
- In addition to coal mines, the PRB is home to the Bear Lodge conventional rare earth element deposit and numerous other energy industries
- **Robust energy infrastructure**, a highly trained mining and **energy technology workforce**, engaged stakeholders, abundant legacy data



[1]www.eia.gov; [2]Luppens et al., 2015

Technical Approach and Project Scope

- Project steps and work plan

Task 1: Project management	Task 2: Resource assessment	Task 3: Waste stream assessment	Task 4: Infrastructure, industries, and business assessment	Task 5: Technology assessment	Task 6: Technology innovation center assessment	Task 7: Outreach and education	Task 8: Data integration

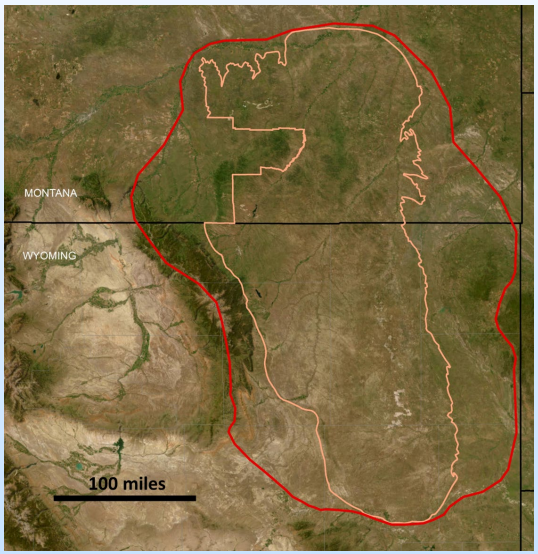
All tasks are being completed concurrently

- Project schedule – Key milestones
  - Kick-off meeting held October 27, 2021
  - Annual Forum held August 31 and September 1, 2022 in Gillette, WY
  - Updated list of stakeholders submitted October 2022
  - Preliminary workforce development content submitted December 2022
  - Annual Forum to be held April 23-24, 2024 in Billings, MT

Progress and Current Status
Resource Assessment

Powder River Basin Resources

- **Coal and associated sediments**
- **Coal ash**
- **Conventional hardrock deposits**
  - **Bear Lodge**
  - **Halleck Creek**
- **Placer and paleoplacer deposits**
- Uranium roll-front deposits
- Sedimentary phosphates
- Bentonite
- Clinker
- Oil and gas produced water
- Hardrock mine tailings
- Other waste streams
- Pegmatites

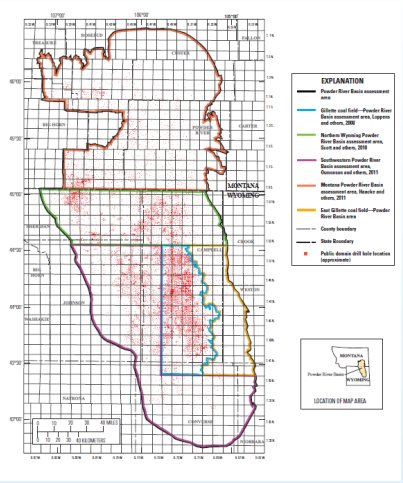


CORE-CM study area in red

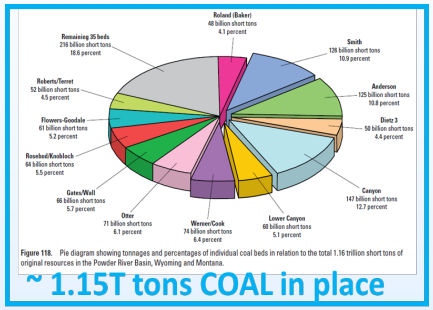
Contacts: Tyler Brown (tbrown46@uwyo.edu)
Erin Phillips (ephilli8@uwyo.edu)

Progress and Current Status

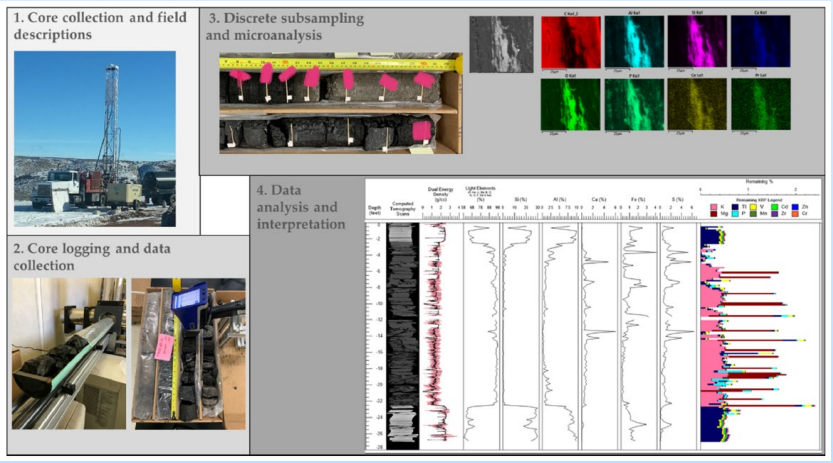
Resource Assessment – Coal and Associated Sediments



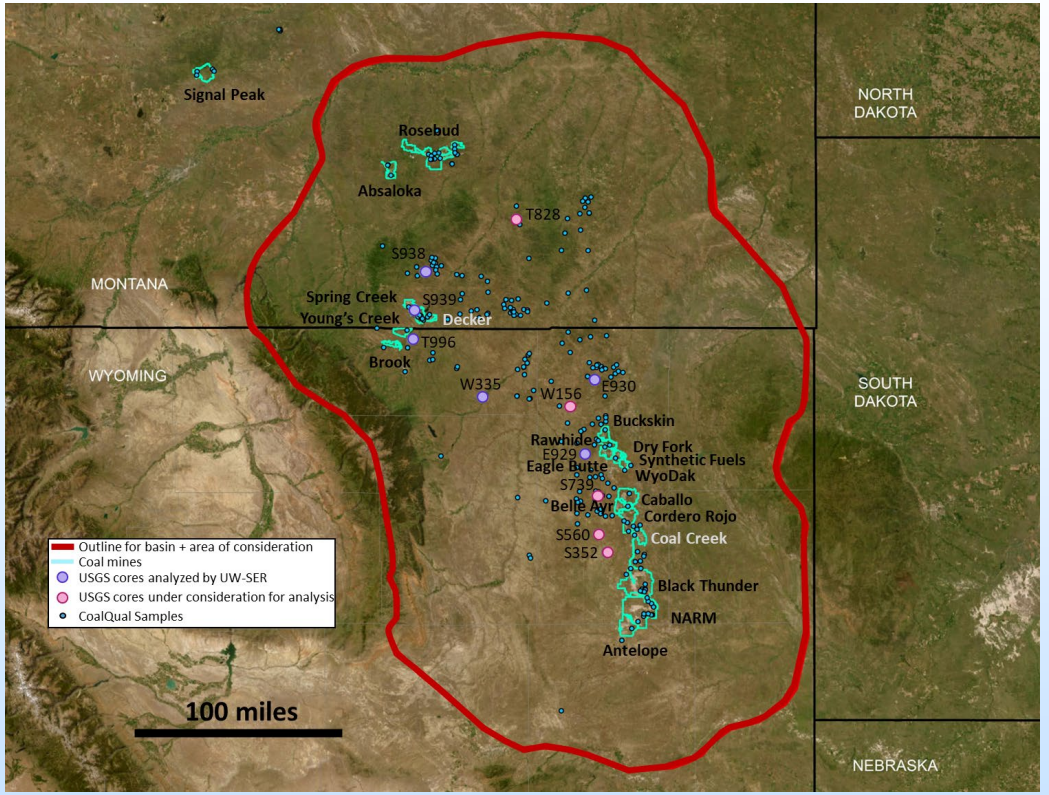
Haacke and Scott, 2013[3]



Luppens et al., 2015[2]



Montross et al., 2022[4]



Primary Data Sources for Critical Minerals Analysis

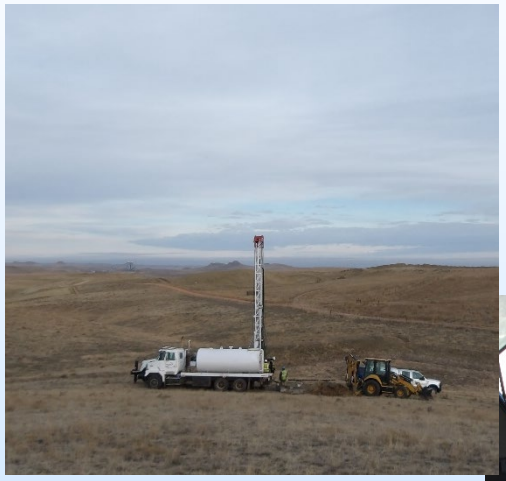
- New & pending CORE-CM coal analyses
- Industry donated coal core
- USGS coal core
- Surface sampling of coal and associated sediments
- Legacy USGS Coal Qual

1400+ data points & growing

Progress and Current Status
Resource Assessment – Recent Core Collection

Tyler Brown (UW SER) and Mark Arambel (NTEC) with Douglas Exploration drilling rig

- In February 2024 three cores were collected in collaboration with NTEC and Douglas Exploration
- 207 feet of core was collected and is in process

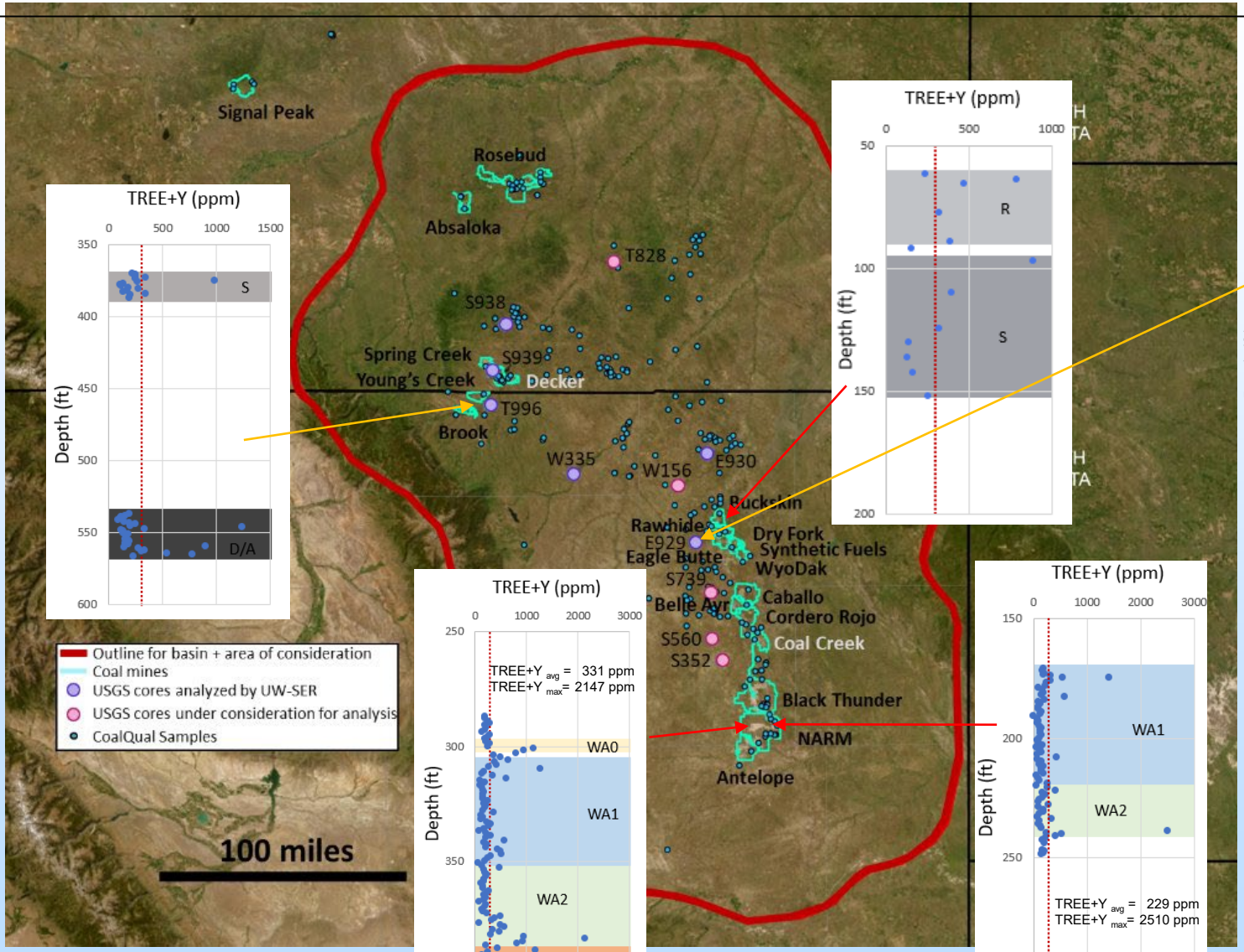


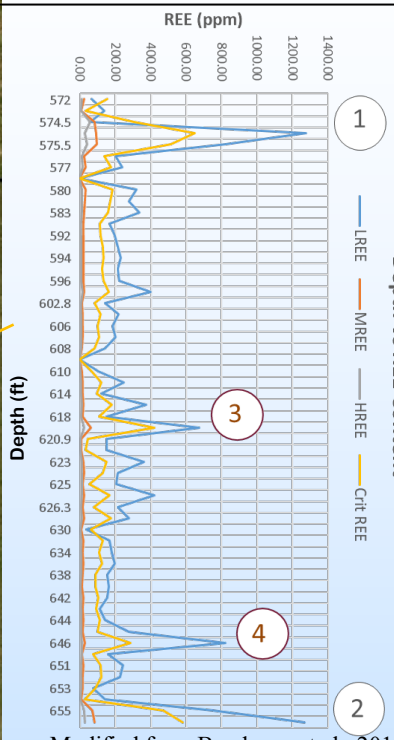
Erin Phillips (UW SER), Dave Green (Dry Fork Mine) and Bob Gregory (UW SER)

- In March 2024 two cores were collected at Dry Fork Mine with the support of Dry Fork Mine, Western Fuels, Mohl Drilling, and Pronghorn Geologic Services
- 190 feet of core was collected and is in process

Progress and Current Status

Resource Assessment – TREE+Y in Coal Cores





Modified from Bagdonas et al., 2019[5]

USGS Core E929

1 = Bounding enrichment at roof

2 = Bounding enrichment at floor

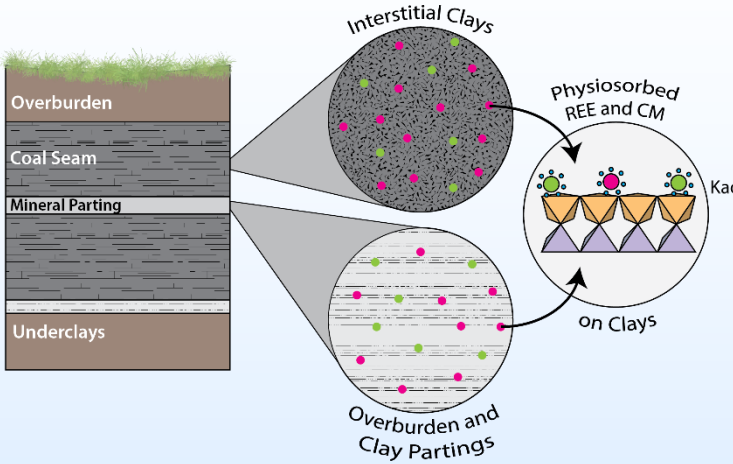
3 & 4 = Internal enrichments

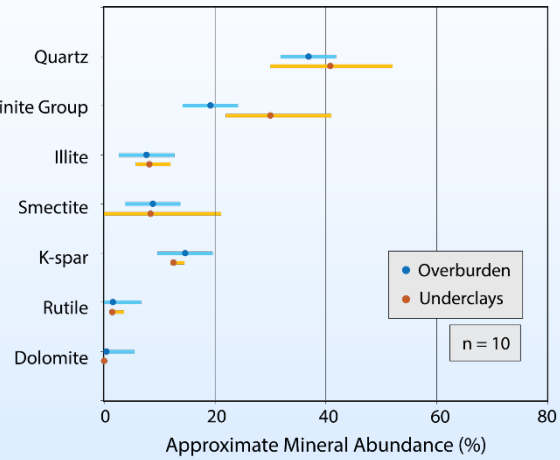
NARM and Rawhide samples collected in collaboration with Peabody Energy

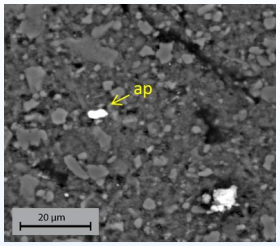
Note: all concentrations are on a dry ash basis.

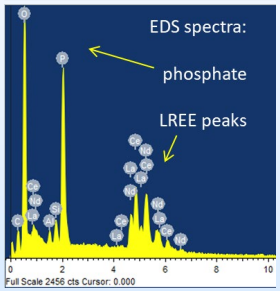
Progress and Current Status

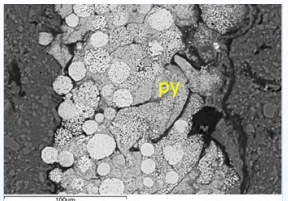
Resource Assessment – Coal-hosted clay characterization

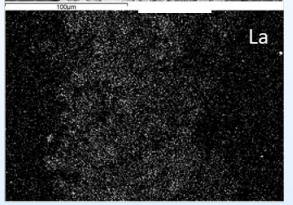


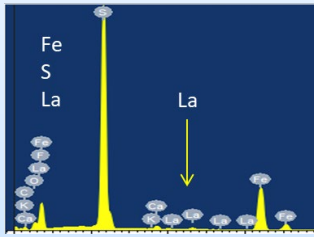


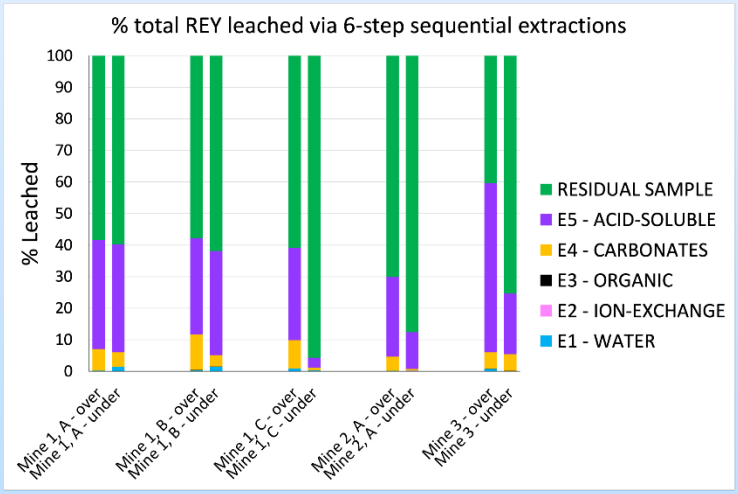












- Majority of TREE+Sc+Y in acid soluble and residual fractions
- Potential mineral hosts include:
  - Silicates
  - REE-Apatite (LREE-PO_4)
  - Pyrite (FeS_2)
- **Not an ion-adsorption type deposit**

See Stuart et al., 2023[6]

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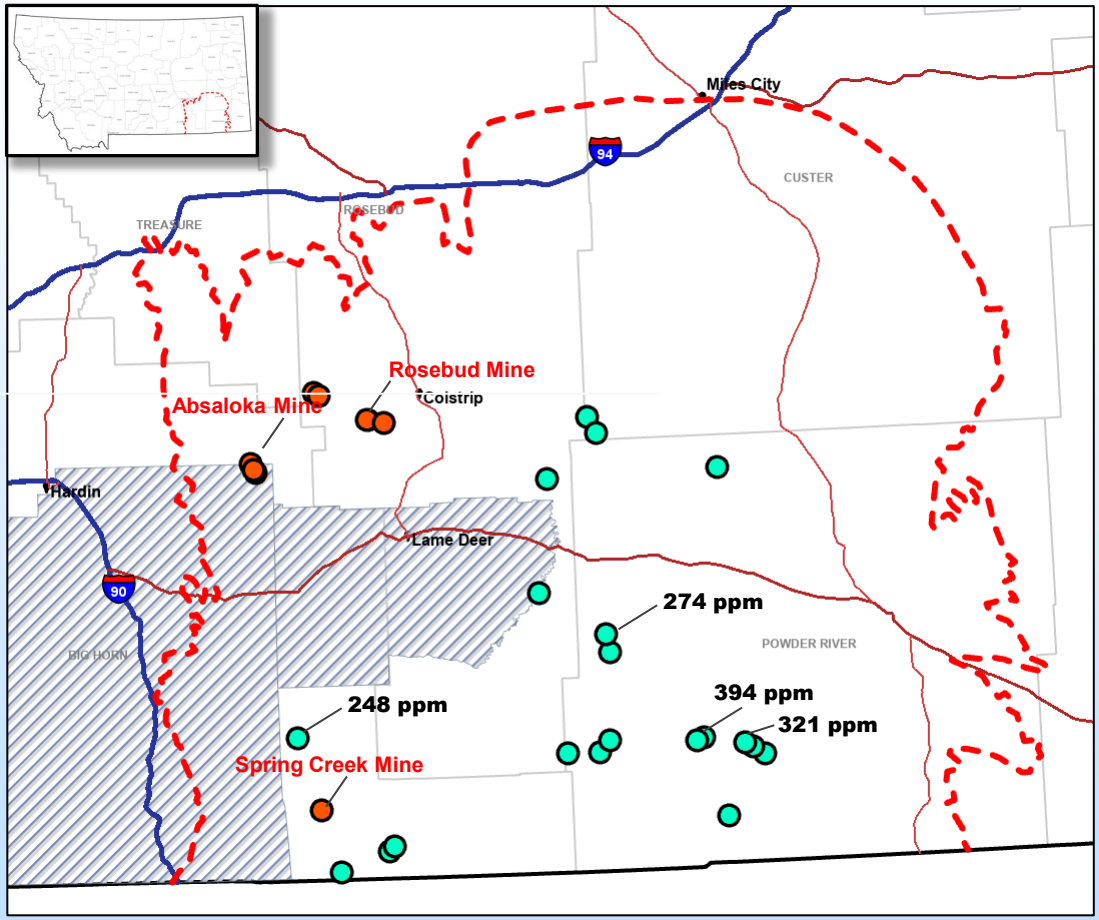
Progress and Current Status

Resource Assessment – Montana PRB Coal



PRB Boundary

Crow and Northern Cheyenne Reservations

Coal outcrop sample location

Coal sample from mine

2023 Reconnaissance Sampling

Outcrop samples (n=55)
- REY average: 101 ppm
- REY range: 7-394 ppm

Mine samples (n=20)
- REY average: 70 ppm
- REY range: 7-152 ppm

*Concentrations reported on whole coal basis

Data source: Davison, R., 2024, Preliminary Data Release of Whole-Rock Assays of Coal-Related Deposits in Central and Eastern Montana: Montana Bureau of Mines and Geology Analytical Dataset 8.[7]

Funding: United States of America's Army Research Laboratory (Department of Defense)

Contact: Ryan Davison
rdavison@mtech.edu

MBMG
Montana Bureau of Mines and Geology

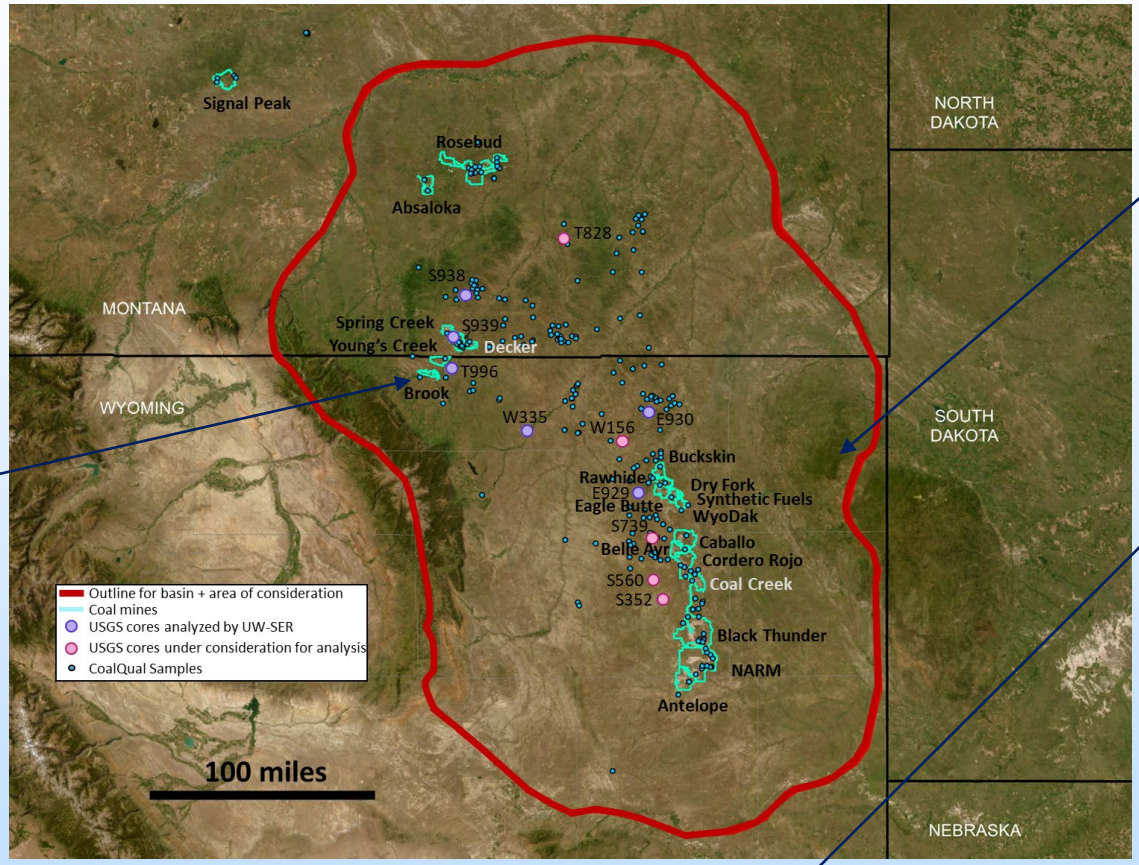
Progress and Current Status

Resource Assessment – Other TREE+Y Feedstocks

Bottom/Fly Ash: Average REY of 317ppm for 117 coal ash samples collected from 4 coal-fired power stations in the PRB [Bagdonas et al., 2022[8]; see also Huang et al, 2020[9]]

Brook Coal Mine: ~1.4M tons TREO (Average 490 ppm for Ash Basis) [Weir International Technical Report, 2024[10]]

TREE+Y in Paleoplacers & Heavy Mineral Sands: Up to 1% PRB and 6.5% in Wyoming [Sutherland and Cola, 2016[11]]



Bear Lodge Carbonatite: 314,000 tonnes TREO (2.14% cutoff) [RER Resource Update, 2024[12]]

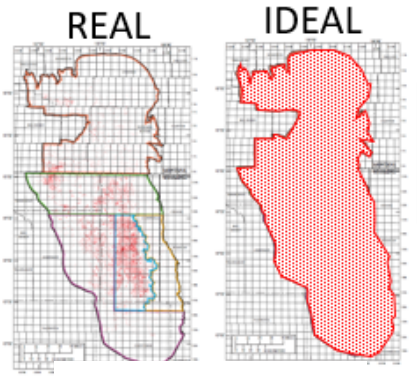
Halleck Creek Granite: ~7.5M tonnes TREO (1000ppm cutoff) [ARE Technical Report, 2024[13]]

CONVENTIONAL & UNCONVENTIONAL
TREE+Y Feedstocks

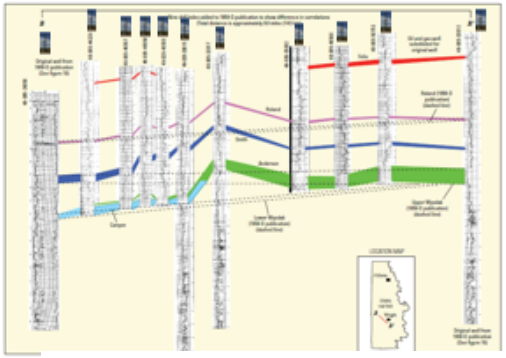
6000+ datapoints & growing

Progress and Current Status

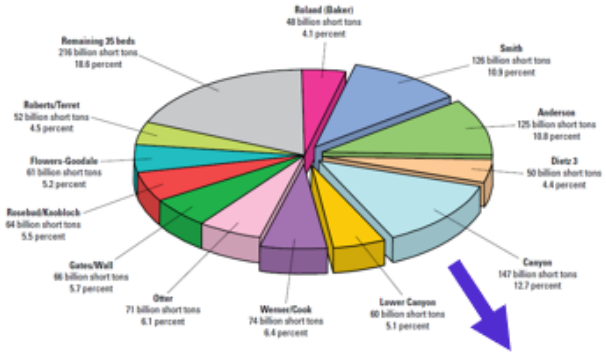
Resource Assessment – Workflow

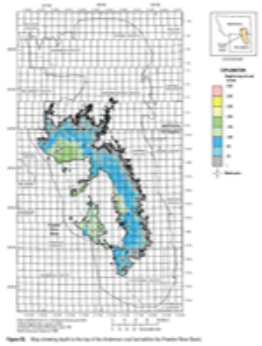


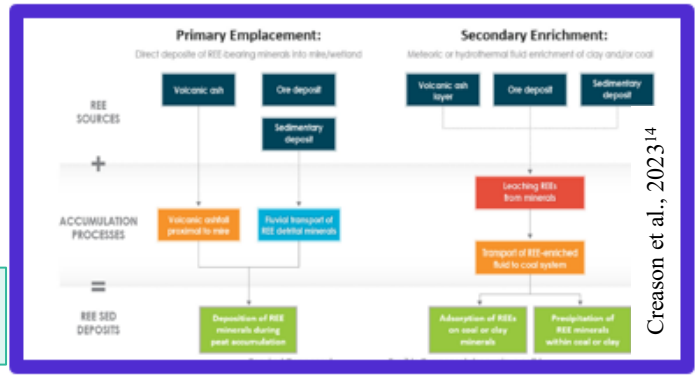
Haacke and Scott, 2013[3]



Modified from Luppens et al., 2015[2]







Creason et al., 2023[14]

Conceptual Model

↓

ID material/element of interest

↓

ID formations/members/seams with material/element of interest

↓

Correlate units using core/log x-sections

↓

Generate structure-contour & isopach maps

↓

ID Trends

↓

Fill Data Gaps

↓

Test Hypotheses for Geological Processes

↓

Predictive Model

Contact: Tyler Brown
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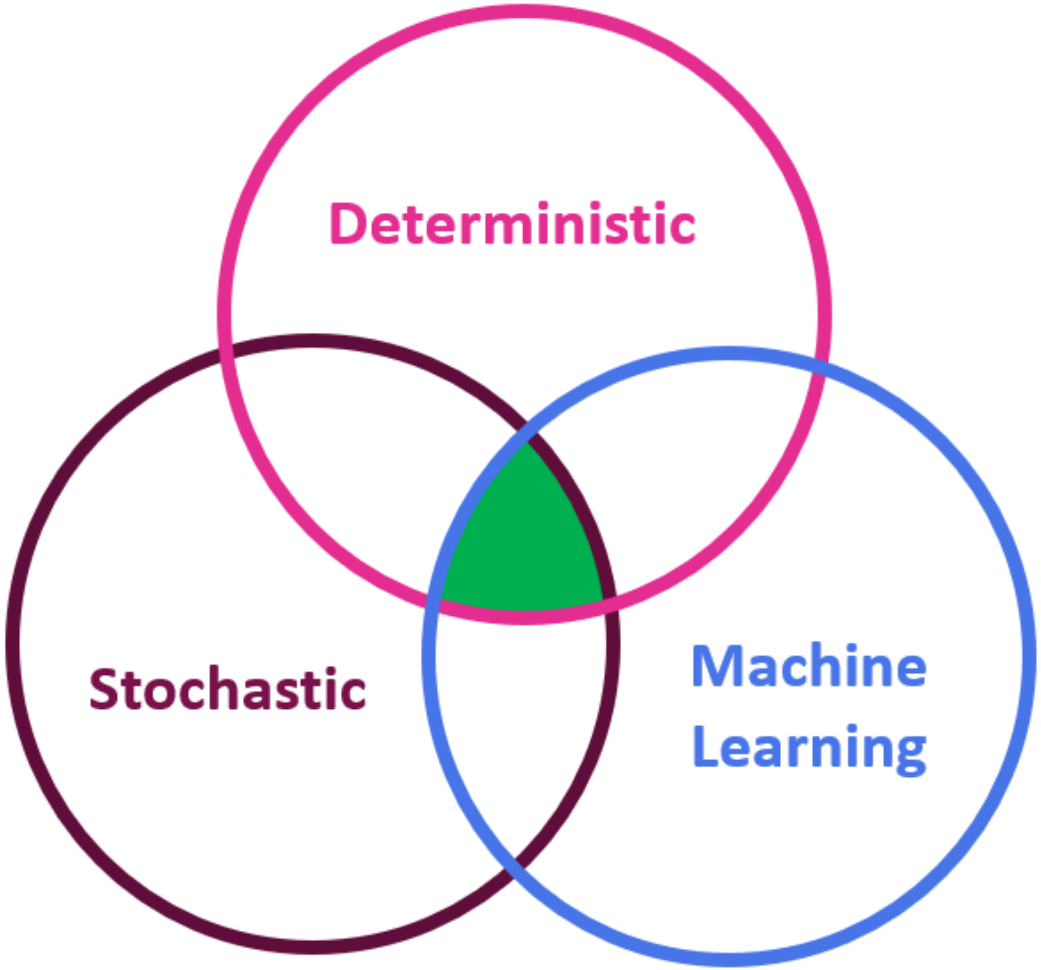
Progress and Current Status

Resource Assessment – Components of a predictive model



Conceptual Model

ID material/element of interest

ID formations/members/seams with material/element of interest

Correlate units using core/log x-sections

Generate structure-contour & isopach maps

ID Trends

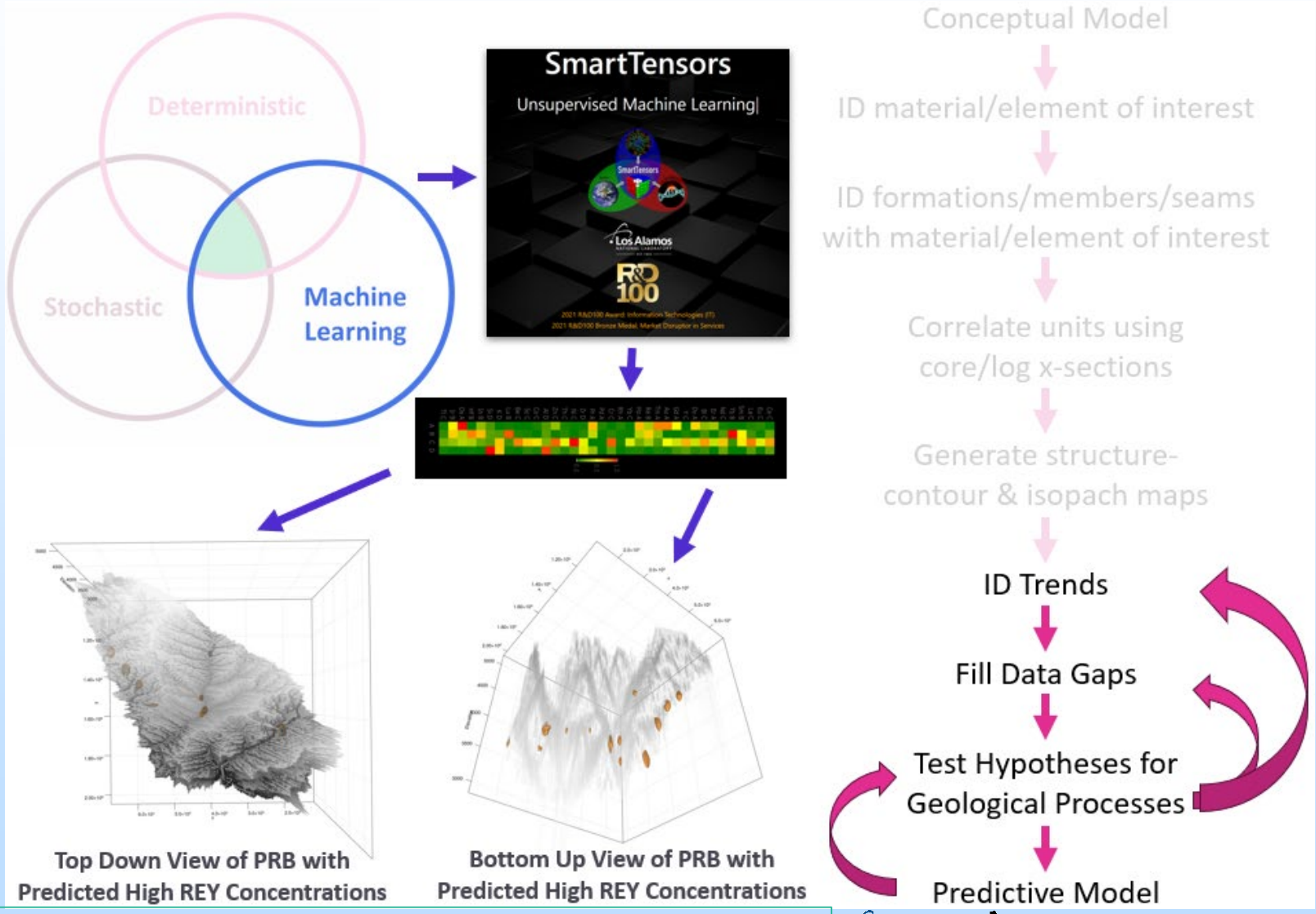
Fill Data Gaps

Test Hypotheses for Geological Processes

Predictive Model

Progress and Current Status

Resource Assessment – Utility of Machine Learning



Contact: Brent Goehring (bgoehring@lanl.gov); Tyler Brown (tbrown46@uwyo.edu)

Los Alamos NATIONAL LABORATORY

UNIVERSITY OF WYOMING

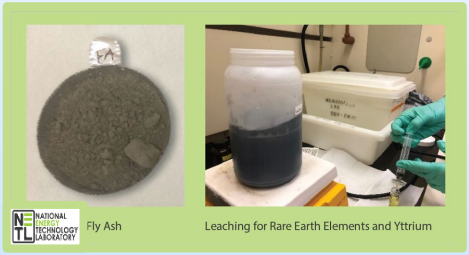
Progress and Current Status
Waste Stream Assessment

Energy-centered economy in the PRB
- Coal mining (40% of US coal)
- Coal power plants
- Oil and gas production
- Coalbed methane production
- Bentonite mining
- Uranium mining (modern in-situ extraction and legacy mining)
- Gas separation and processing
- Petroleum refining
- Wind energy

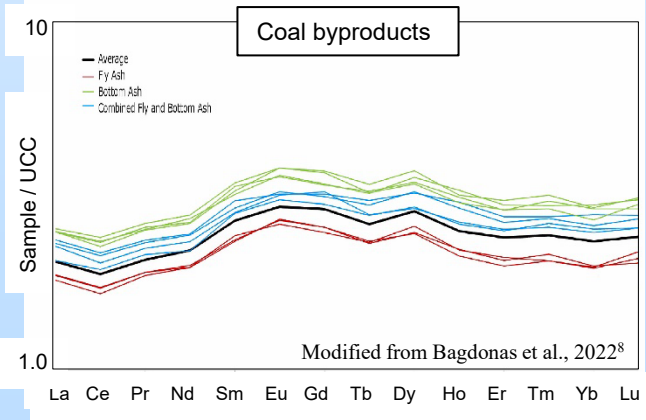
Extraction from existing waste streams (e.g., coal ash, tailings piles)

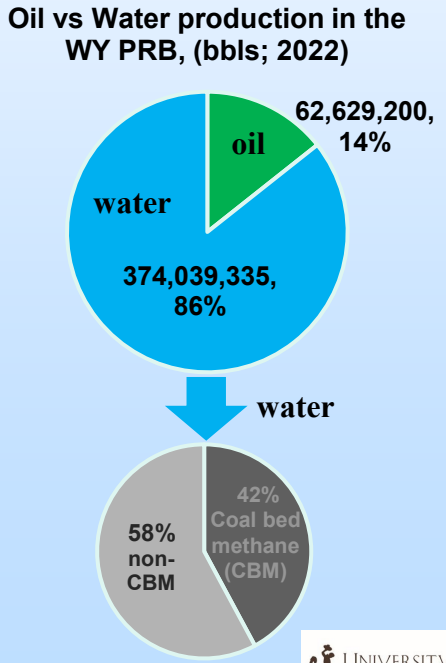
Re-purposing waste from processing (e.g., spent acids, solvents)

Utilizing existing waste (e.g., oil and gas produced water)

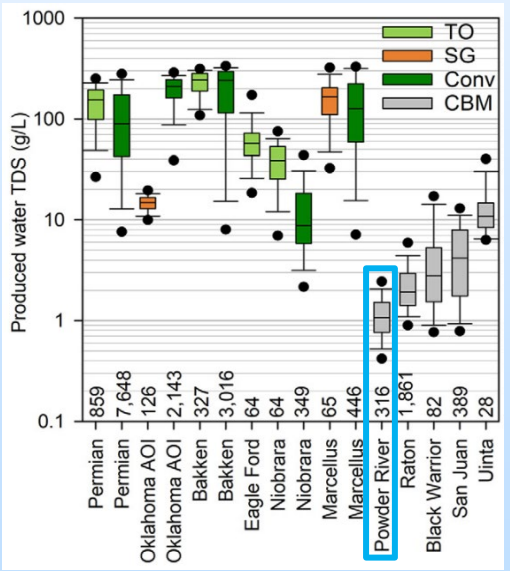


Stuckman et al., 2019[15]; Lopano et al., 2024[16]; TCF 20-21358





Source: WOGCC



Scanlon et al., 2020[17]

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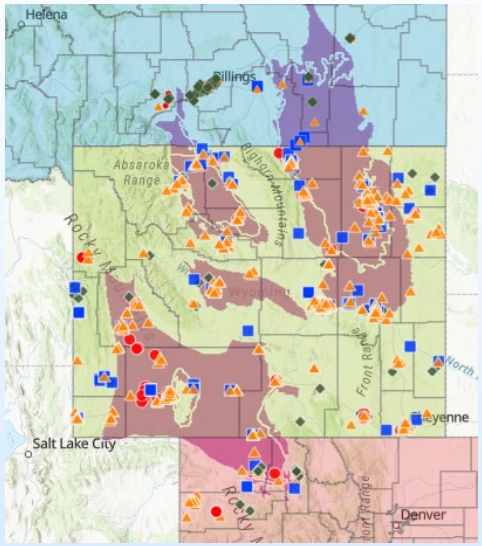
Contact: Lily Jackson
Lily.Jackson@uwyo.edu

Progress and Current Status
Infrastructure, Industries, and Business

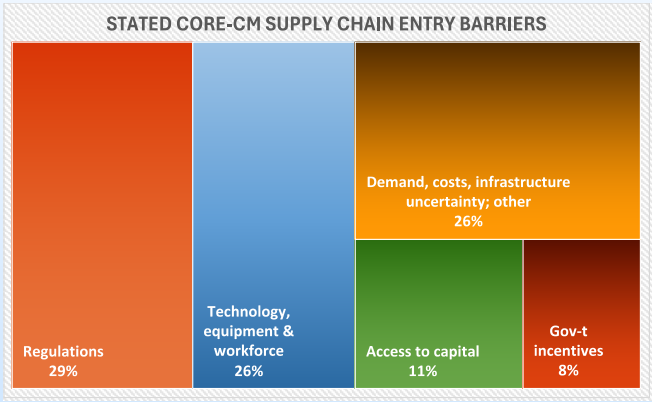


Inventory of CORE-CM Supply Chain Relevant Businesses

Exploratory Business Survey Responses (n=11)

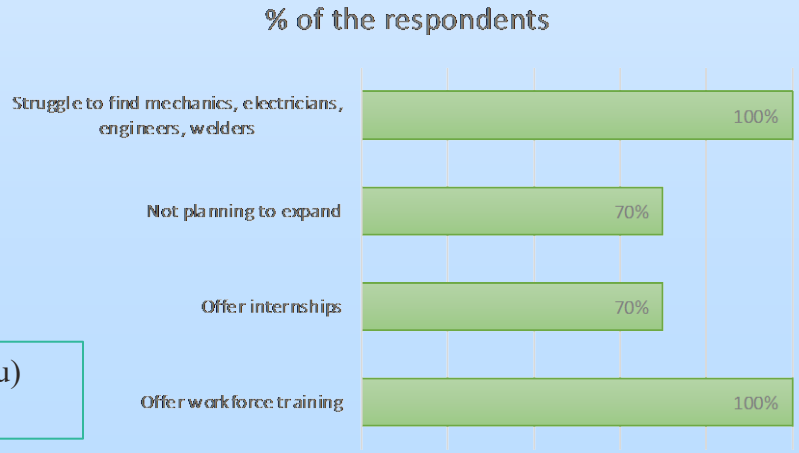
Benefits
- additional revenue
- trade independence

Risks & Uncertainty
- regulations
- market demand
- technology and production process



Next step: Preliminary Economic Impact Study
Sum of Direct, Indirect, and Induced Effects

Measured Through:
Employment Labor Income Value Added Output



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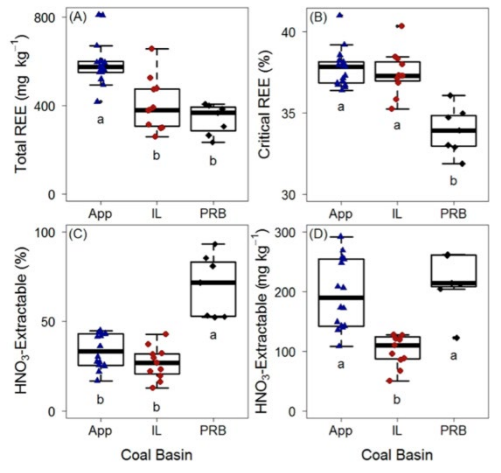
Progress and Current Status
Technology Assessment

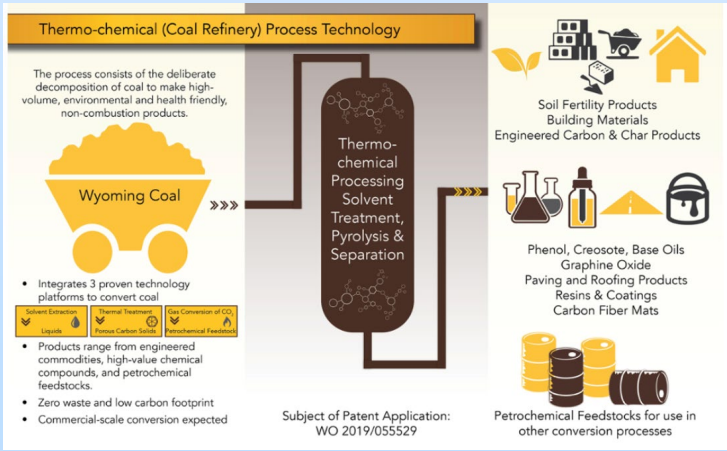
Technology Assessment, Development, and Field Testing

- Innovative and sustainable mining techniques for coal and other Powder River Basin materials
- Processes to separate and purify basin-specific rare earth elements and critical minerals
- Technologies to incorporate coal-derived carbon, rare earth elements, and critical minerals into value-added intermediate and end-use products

- Selective mining techniques
- Efficient and cost-effective data collection
  - Hyperspectral remote sensing
  - pXRF
- Focus on data collection that ultimately enables AI/ML model development



Taggart et al., 2016[18]
See also Stuckman et al., 2019[15]



UW SER Center for Carbon Capture and Conversion

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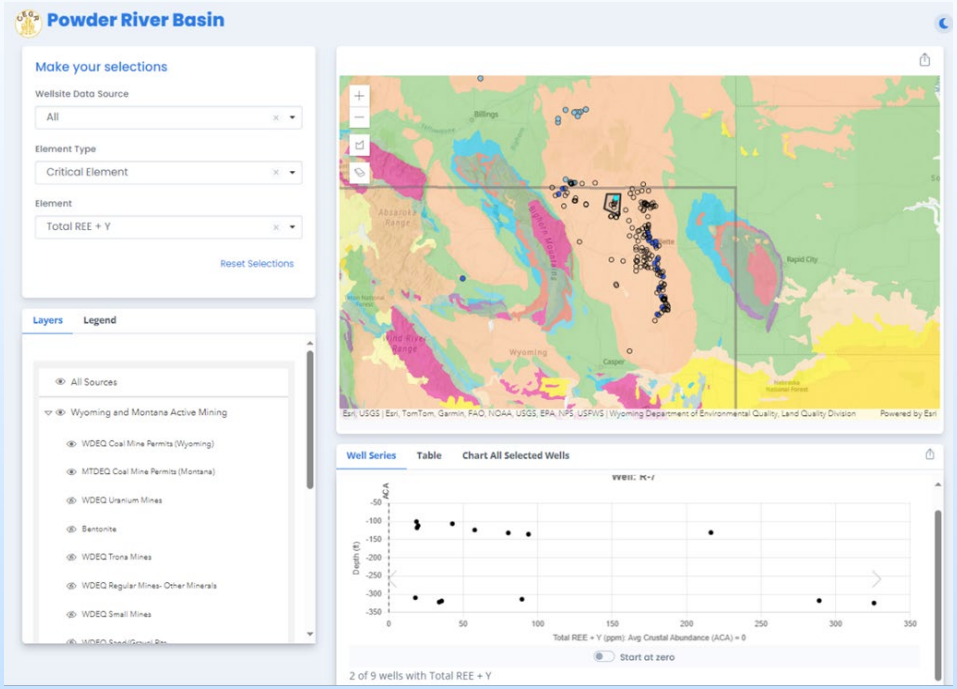
Outreach, Education, and Engagement

CORE-CM Applications for Data Viewing and Outreach



Developed in partnership with WyGISC.

Information Dissemination

Participation in conferences and workshops

- Geological Society of America Connects 2023, including **Pardee Keynote Symposium** on Critical Minerals Policy
- **DOE Tribal Clean Energy Summit**, 2022 and 2024
- International Pittsburgh Coal Conference, 2023
- Battelle Innovations in Climate Science, 2023
- National Environmental Justice Conference and Training Program, 2023
- National Academies of Science and Engineering Workshop on Mineral Resources Workforce, 2024

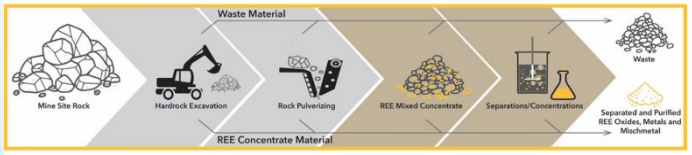
Student Engagement

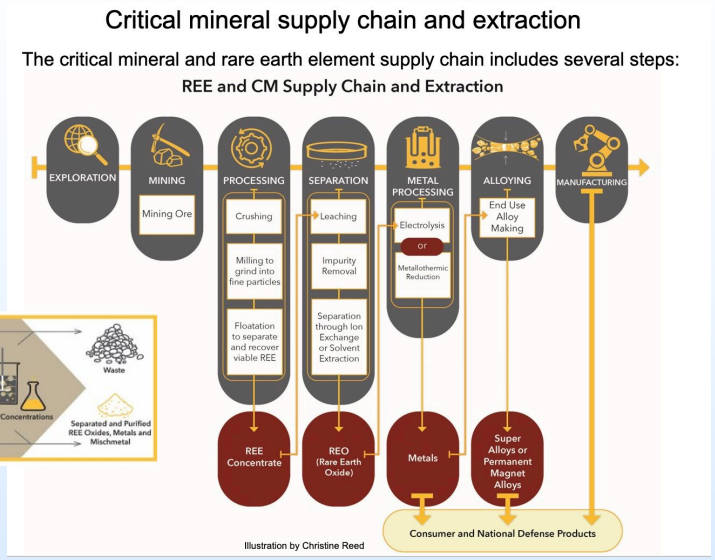
Four University of Wyoming graduate students are completing projects under the PRB CORE-CM project

Contacts: Christine Reed (christine.reed@uwyo.edu)
Kyle Summerfield (ksummerf@uwyo.edu)

Outreach, Education, and Engagement

High-Level Informational Resources





CORE-CM Second Annual Forum

Collaboration Highlights

- Joint University of Wyoming-University of Utah virtual town hall focused on critical minerals research
- Hosted a presentation on Tribal Sovereignty for University of Wyoming leadership
- Working in tandem with the Greater Green River and Wind River Basin CORE-CM project
- Hosted Dr. Charles Sims, Co-P.I. of Southern Appalachian CORE-CM, to give a presentation on the economic analysis of REE and CM globally.

Social and Environmental Justice

A place-based approach to understand the unique social, economic, and environmental aspects of a region and a community.

Building Partnerships and Community Engagement

Collaborations with Community Colleges (***Gillette College***)

Annual PRB CORE-CM Meetings (***Gillette, WY (2022)*** and ***Billings, MT (2024)***)

Outreach and Education

Social and Environmental Justice Webinar (***hosted by SER in 2022***)

Presentations at Conferences (***e.g., National Environmental Justice Conference (2023)*** and ***International Pittsburg Coal Conference (2023)***)

Tribal Engagement

Meetings with Tribal representatives to discuss CORE-CM and build relationships

Attending DOE Tribal Clean Energy Summits ***(2022 and 2024)***

Created a permitting resource guide for REE, CM, and Uranium on tribal lands which is currently under review by tribal members.

Research

Contributing to CORE-CM Environmental Justice Working Group's best practices

Policy analysis of challenges to building environmentally just CM domestic supply chains of

Summary of EJ concerns related to CORE-CM

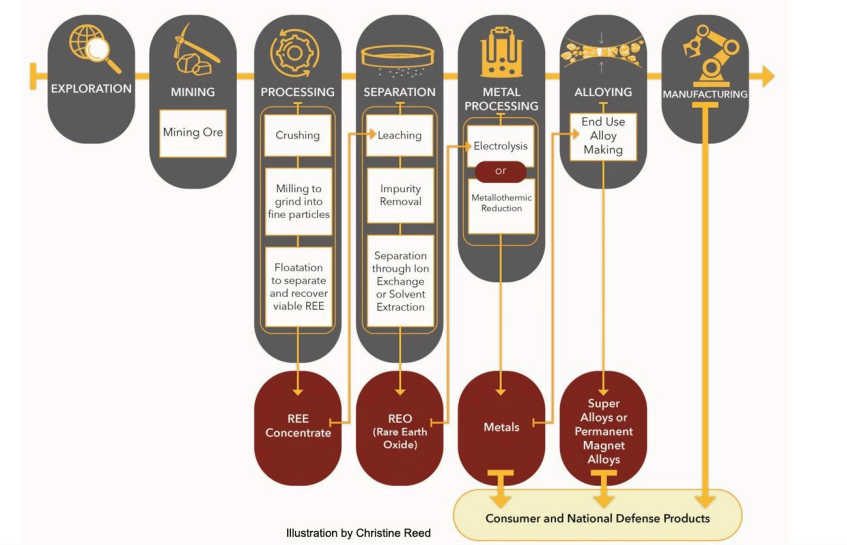
GilletteCollege

University of Wyoming | School of Energy Resources

Contact: Selena Gerace (sgerace@uwyo.edu)

Future Technology Development

- Coal Resource
- Varied CM Feedstocks
- Energy Workforce
- Energy Infrastructure



Future Technology Development and Take-away

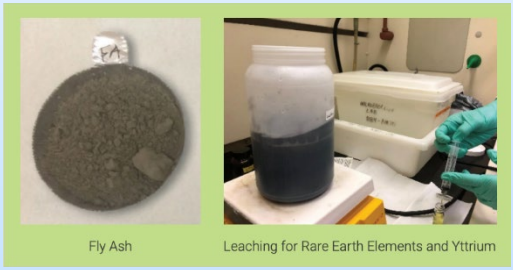
Research-to-commercialization facility operated by Energy Capital Economic Development
www.energycapitaled.com

- Coal Resource
- Varied CM Feedstocks
- Energy Workforce
- Energy Infrastructure
- Technology Development

UW SER Center for Carbon Capture and Conversion

Two forthcoming field demonstrations for high volume uses for PRB coal in Gillette Wyoming
www.uwyo.edu/ser/

NETL REE Extraction from Coal Ash

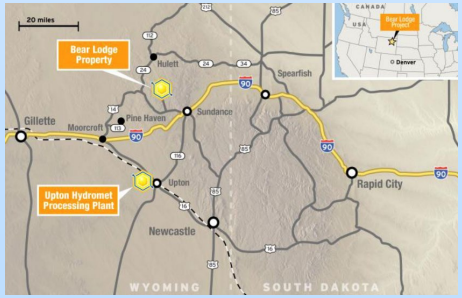


Pilot-scale testing at the WY Innovation Center in Gillette Wyoming
https://netl.doe.gov/node/10318

Coal-to-products, rare earth element, and critical mineral research and development
www.ramacoresources.com

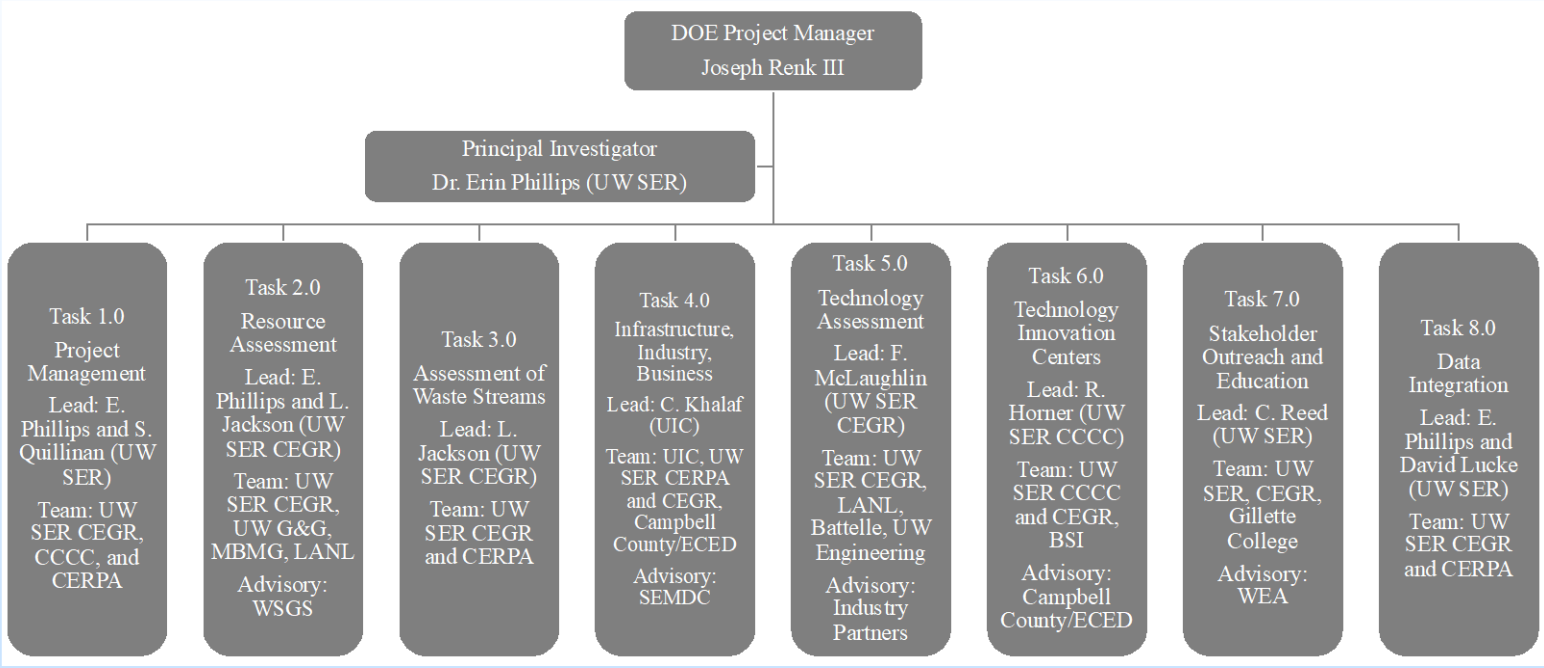
ITC WYOMING INTEGRATED TEST CENTER

Carbon capture and carbon utilization test center in Gillette Wyoming
www.wyomingitc.org/



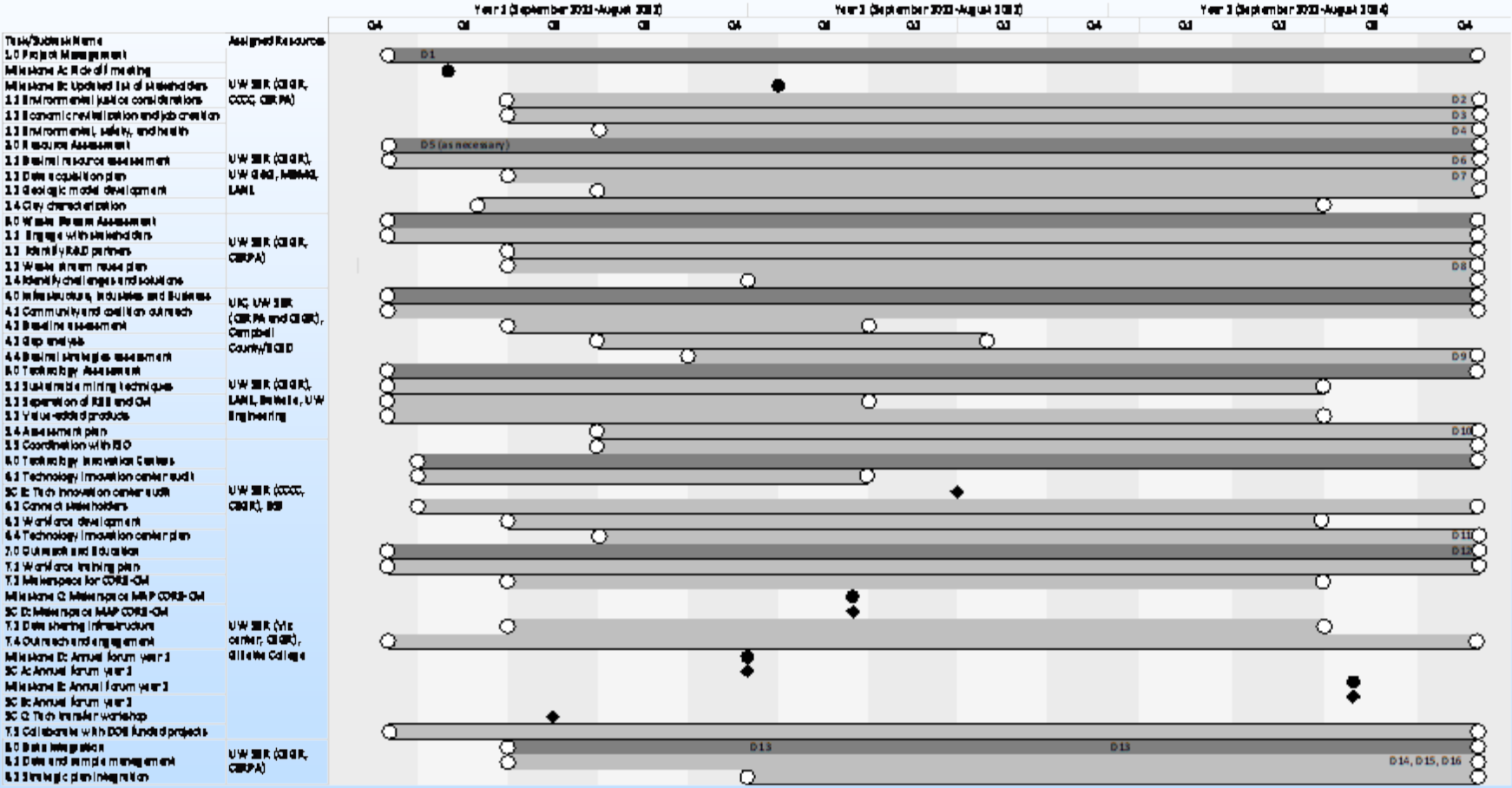
Rare Element Resources DOE-funded demonstration plant to process rare earths from Bear Lodge Deposit, Upton Wyoming
www.rareelementresources.com

Appendix: Organization Chart



UW SER = University of Wyoming School of Energy Resources; CEGR = Center for Economic Geology Research; CCCC = Center for Carbon Capture and Conversion; CERPA = Center for Energy Regulation and Policy Analysis; G&G = Department of Geology and Geophysics; MBMG = Montana Bureau of Mines and Geology; LANL = Los Alamos National Laboratory; ECED = Energy Capital Economic Development; BSI = Boston Strategies International

Appendix:
Gantt Chart



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Appendix:
Risk Management Plan

Perceived Risk	Risk Rating			Mitigation/Response Strategy
	Probability	Impact	Overall	
	(Low, Med, High)			
Financial Risks:				
Budget modifications	Low	Med	Low	The Project team has experience with projects and budgets of this type; any budget modifications will be communicated with the DOE project manager.
Cost/Schedule Risks:				
Project timeline modifications	Low	Med	Low	The Project timeline was developed based on the experience gained from previous projects. Though risk is low, the Project team will communicate with the DOE project manager if timeline modifications are required.
Technical/Scope Risks:				
Obstacles to data collection	Low	High	Low	The project team includes partners with access to databases, archived data, and archived samples and has experience processing and summarizing data.
Obstacles to geologic modeling	Low	Med	Low	The project team includes multiple partners with experience modeling geologic data.
Obstacles to delivering strategic plans	Low	High	Low	The project team includes partners who are experts in their fields and have experience with comparable projects.
Obstacles to producing outreach materials	Low	Med	Low	The task leads and collaborators for the Stakeholder Outreach and Education Task have broad experience producing outreach materials in a timely manner.
Management, Planning, and Oversight Risks:				
Project Management	Low	High	Low	Risks are negligible due to the team's collective experience in projects of this type.
Delayed approval of Foreign Nationals	Med	Med	Med	In cases where Foreign Nationals are task leads, co-task leads or other project personnel will conduct work until Foreign Nationals are approved.
ES&H Risks:				
Laboratory safety risks	Low	High	Low	All personnel working in laboratories undergo required training and all labs meet safety standards.
External Factor Risks:				
Lack of acceptance from select stakeholders	Med	Low	Low	The project currently has the support of a varied network of committed stakeholders that meet the objectives of the project.
Laboratory or other public closures	Med	Med	Med	Much of the scope of work is compiling existing data and information, so in the case of closures essential project objectives could still be met.
Lack of public acceptance	Low	High	Low	The Project team will implement best practices in its outreach strategy to stakeholders and the general public. Residents of the PRB have a long history of supporting value-added coal research.

Appendix: References

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[12]Rare Element Resources Updated Mineral Resource for the Bear Lodge Project Focused on Key Magnet Materials (news release), 2024, https://www.rareelementresources.com/
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