

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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David Jacoby



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Glen Murrell



Phil Christopherson, Curtis Burdette, Jim Ford



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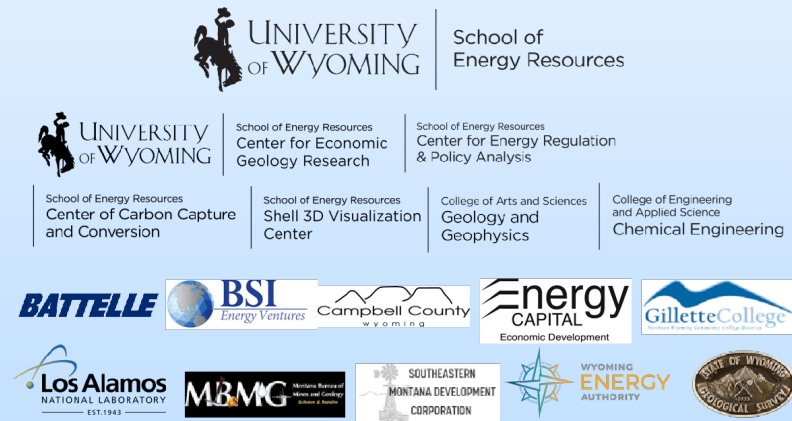


Erin Campbell, Ranie Lynds, Kelsey Kehoe

And many more stakeholders and involved partners

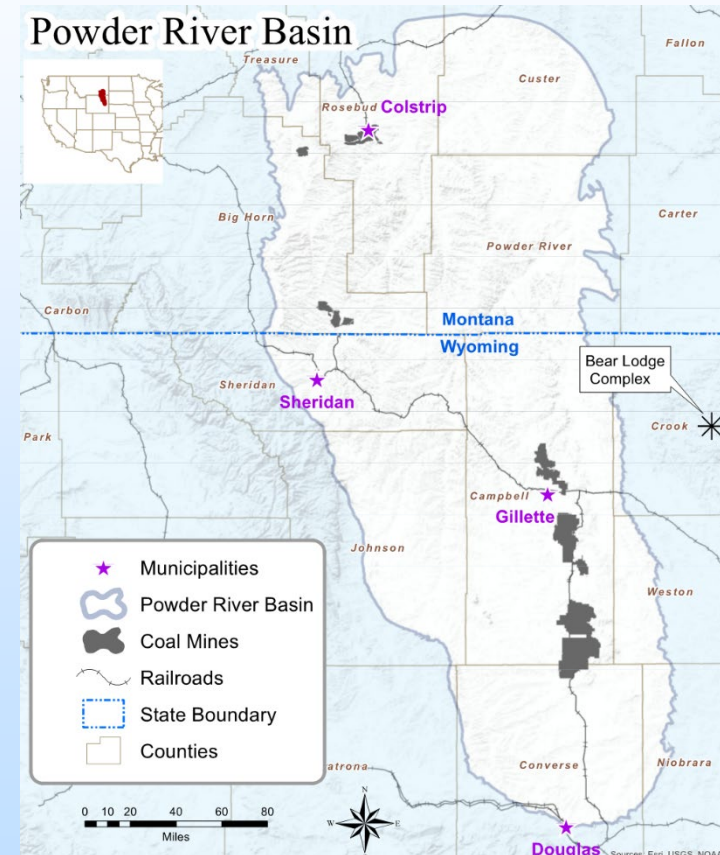
Project Overview

- Funding
 - DOE: \$1,584,435
 - Cost Share: \$396,282
- Overall Project Performance Dates
 - September 1, 2021 – August 31, 2023
- 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; 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



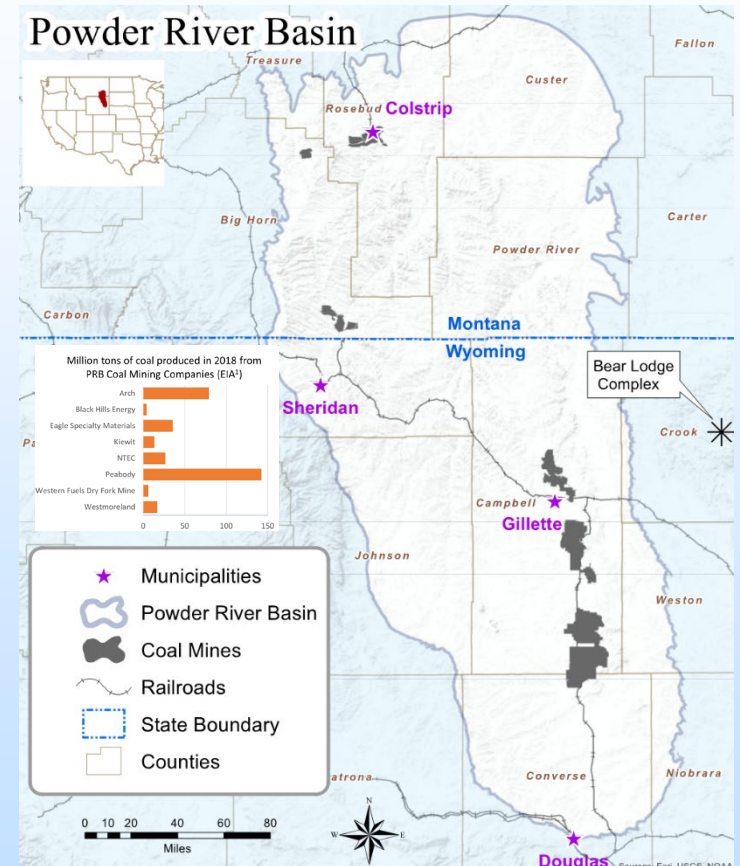
Project Overview

- Overall Project Objectives
 - Provide an economic benefit to the people who live and work in the Powder River Basin of Wyoming and Montana by stimulating new resource development centered around the nation's largest coal mines
 - Offer a low-cost pathway to the national security benefits associated with domestic rare earth element, critical mineral, and carbon ore industries
 - Bring together a committed network of stakeholders from across the CORE-CM value chain

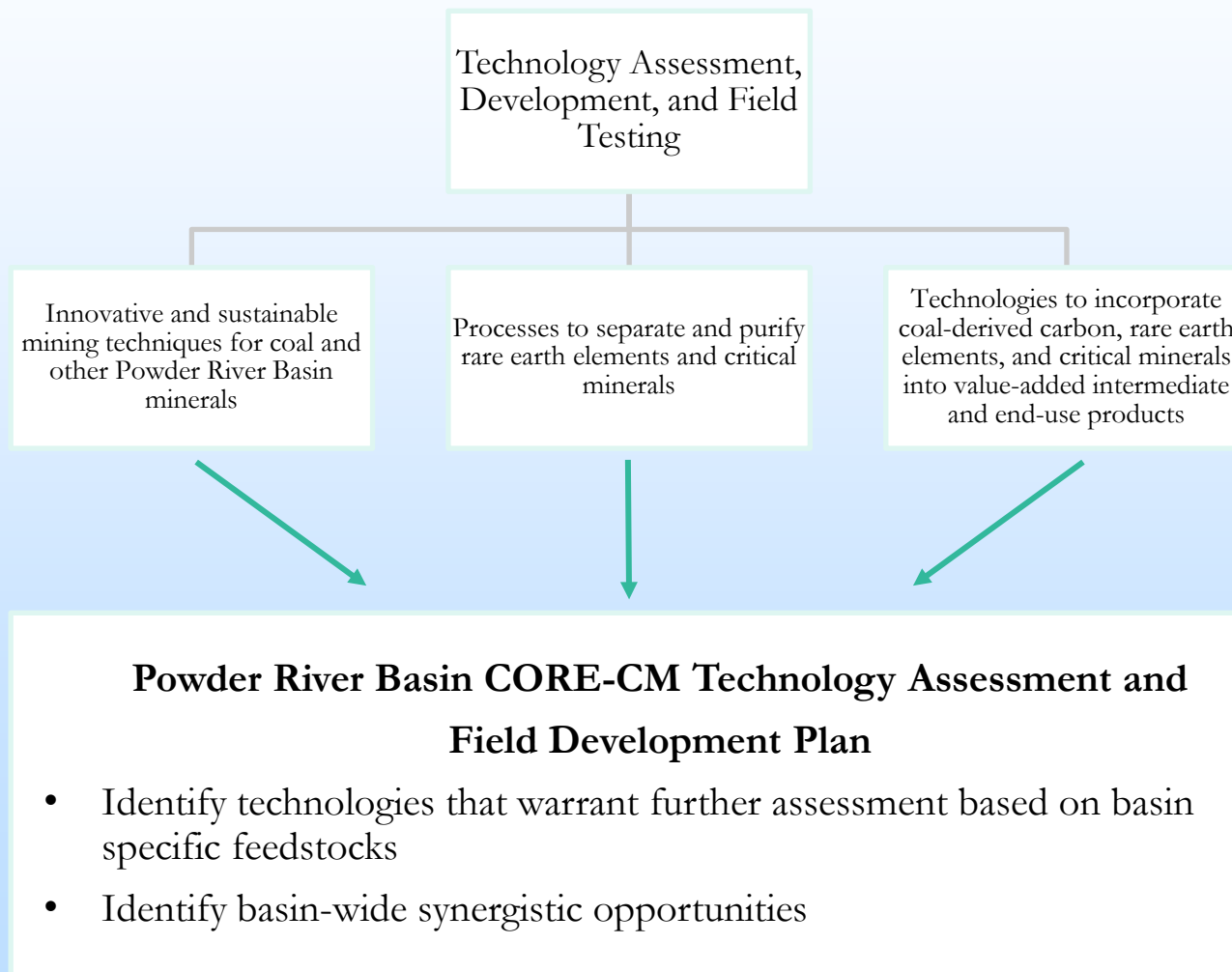


Powder River Basin Background

- 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 states¹
- 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

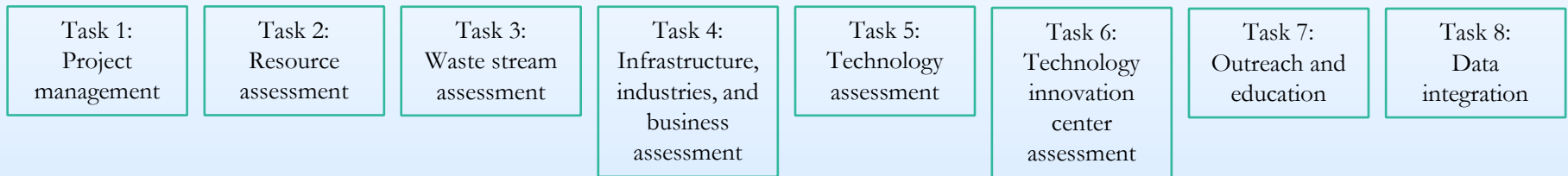


Technology Background



Technical Approach and Project Scope

- Project steps and work plan



All tasks are being completed concurrently

- Project schedule – Key milestones
 - Kick-off meeting held October 27, 2021
 - Annual Forum (year 1) held August 31 and September 1, 2022
 - Updated list of stakeholders submitted October 1, 2022
 - Launch of workforce development content – By December 15, 2022
 - Annual Forum (year 2) – By August 15, 2023


Technical Approach and Project Scope

- Project success criteria
 - Completion of two annual forums
 - Completion of workshops on technology, workforce training, and other topics
 - Launch of workforce training content
 - Review of Technology Innovation Centers
- Project risks and mitigation strategies
 - See appendix for complete risk management plan

Risk	Overall Risk Rating	Mitigation/Response Strategy
Obstacles to data collection	Low	Use of publicly available and archived samples and data; experienced project team
Obstacles to geologic modeling	Low	Use of publicly available and archived samples and data; experienced project team
Obstacles to delivering strategic plans	Low	Use of publicly available and archived samples and data; experienced project team
Lack of acceptance from select stakeholders	Low	Support of varied network of stakeholders from project inception; best practices for inclusive outreach
Lack of public acceptance	Low	Best practices for inclusive outreach; historical support for similar projects in the PRB

Progress and Current Status

Powder River Basin Resource Assessment



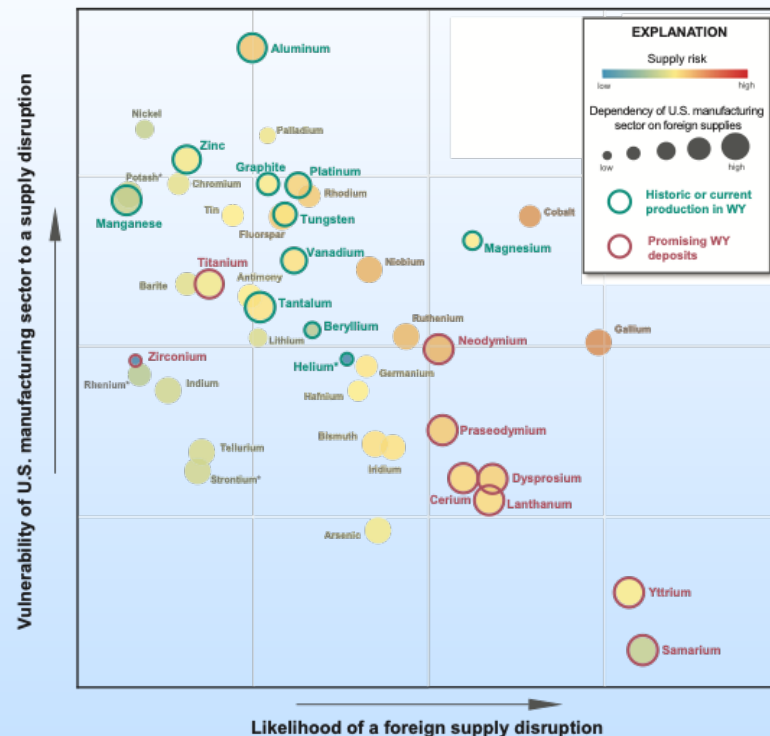
Powder River
Basin Rare
Earth Element
and Critical
Mineral
Potential
Feedstocks

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

Progress and Current Status

Powder River Basin Resource Assessment

Critical Mineral	Potential Feedstocks in PRB	Reason for inclusion
REE+Y	Coal, coal byproducts, Bear Lodge, other conventional, paleoplacers, phosphates, U roll-fronts	Promising deposits
V	Co-production with U; heavy oils, phosphates	Historic or current production
PGE	Precious metal deposits	Historic or current production
Ti	Igneous deposits, black sands, coal, coal byproducts	Promising deposits
Al	Anorthosite, coal, coal byproducts	Historic or current production
Co	Base metal deposits	High supply risk and vulnerability
Ga	Base metal deposits	High supply risk and vulnerability
Zr	Coal, coal byproducts, paleoplacers, base metal deposits, pegmatites	Promising deposits
W	Metamorphic rocks, pegmatites, base metal deposits, paleoplacers	Historic or current production



³Wyoming State Geological Survey, 2022, modified from

⁴USGS open file report 2021-1045

Progress and Current Status

Powder River Basin Resource Assessment

Sample and Data Compilation Plan

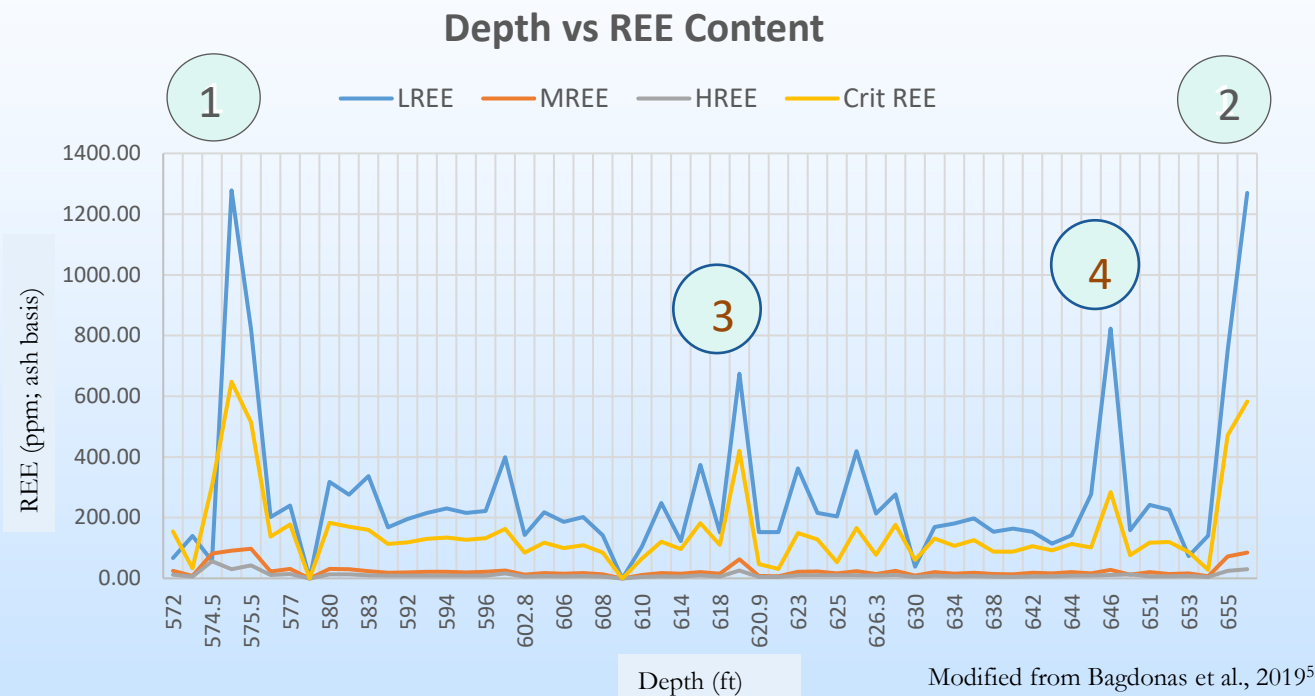
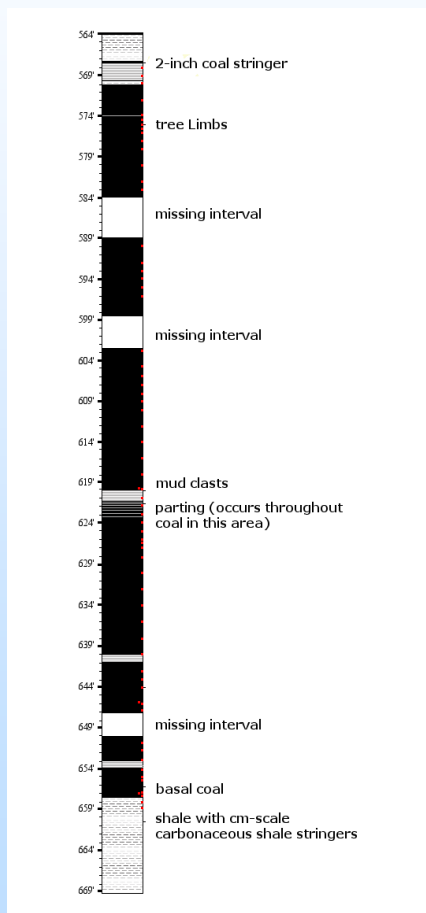
- Published and unpublished legacy data
 - USGS COALQual, NURE, others
 - State geological survey records
- State-of-the-art data previously collected by the University of Wyoming School of Energy Resources
 - USGS Core Research Center coal core (~200 geochemical analyses)
 - Industry donated core and bucket samples (~300 geochemical analyses)
 - Industry donated coal ash samples (~160 geochemical analyses)
- Geochemical analysis of samples archived at the University of Wyoming School of Energy Resources
 - Six industry donated coal cores
- Collection of new samples for geochemical analysis
 - USGS Core Research Center
 - Industry partners



Progress and Current Status

Powder River Basin Resource Assessment

Powder River Basin Coal



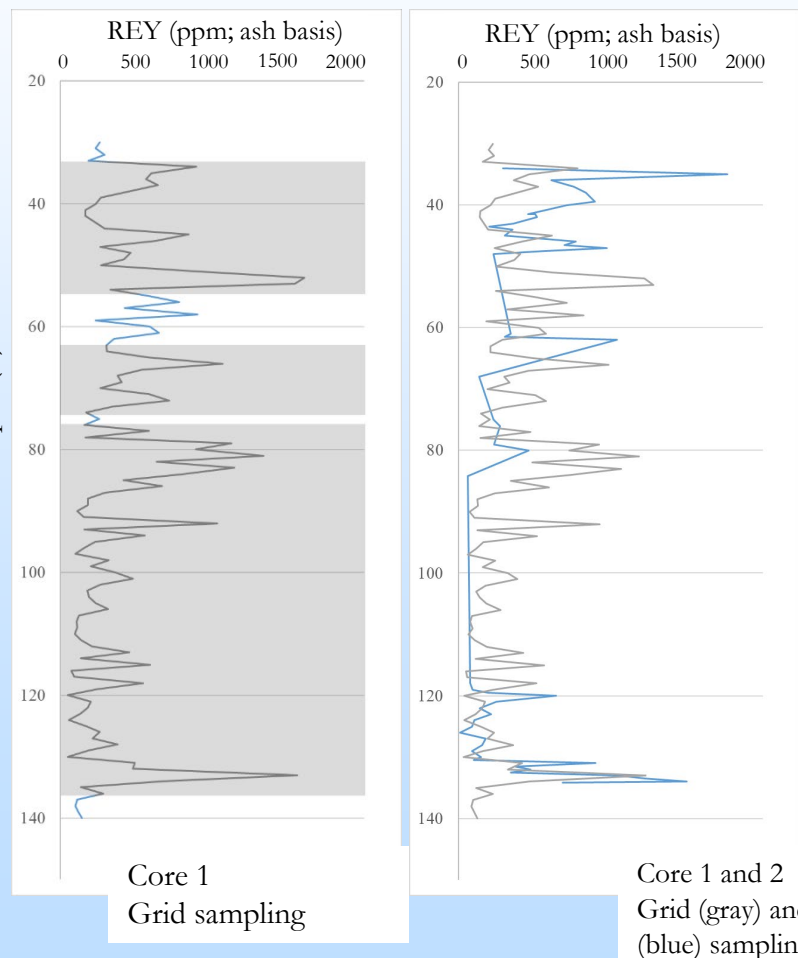
USGS Core E929

- 1 = Bouding enrichment at roof
- 2 = Bouding enrichment at floor
- 3 and 4 = Internal tonstein enrichments

Progress and Current Status

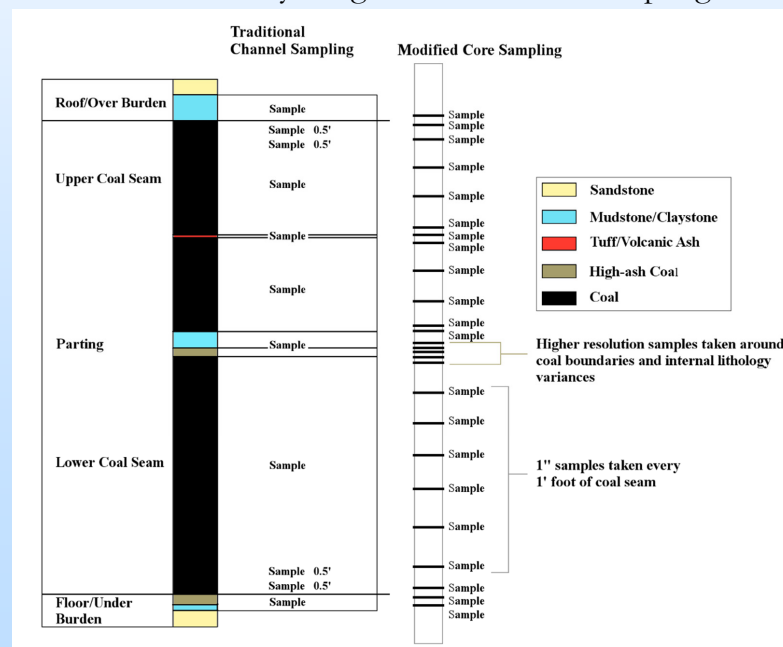
Powder River Basin Resource Assessment

Powder River Basin Coal



Prior to the start of the PRB CORE-CM project, two industry donated coal core were obtained from an interval including the entire Wyodak-Anderson coal system.

- One core was grid sampled and the other was selectively sampled for clay
- Upper, middle, and lower seams (gray shading at left)
- Demonstrates the necessity for grid and selective sampling



Sampling approach
Montross et al., 2022⁶

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Progress and Current Status

Powder River Basin Resource Assessment

Powder River Basin Coal Ash

- Calcium enriched PRB coals conducive to high recovery REE extraction^{7,8}
- PRB coal ash has middle and heavy REE enriched profiles⁹
- Average REY of 317ppm for 117 coal ash samples collected from 4 coal-fired power stations in the PRB⁹
- Critical REE (Nd, Eu, Tb, Dy, Er, Y) concentrations above 36% of total REY⁹, falling into the “promising” resource category¹⁰

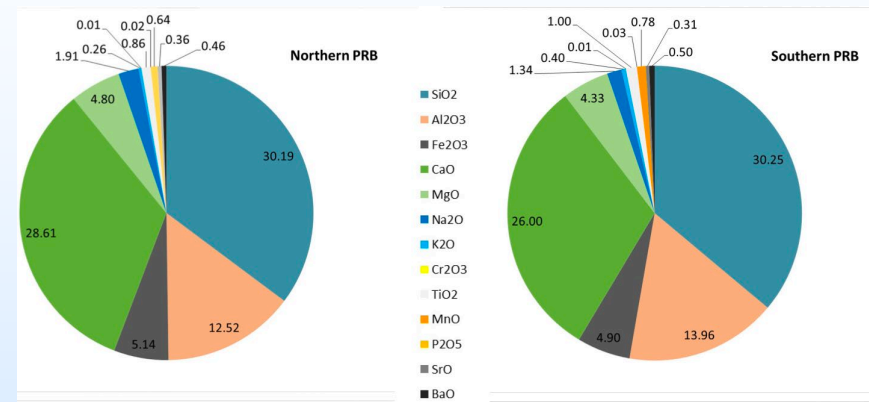
⁷Taggart et al., 2016

⁸Stuckman et al., 2019

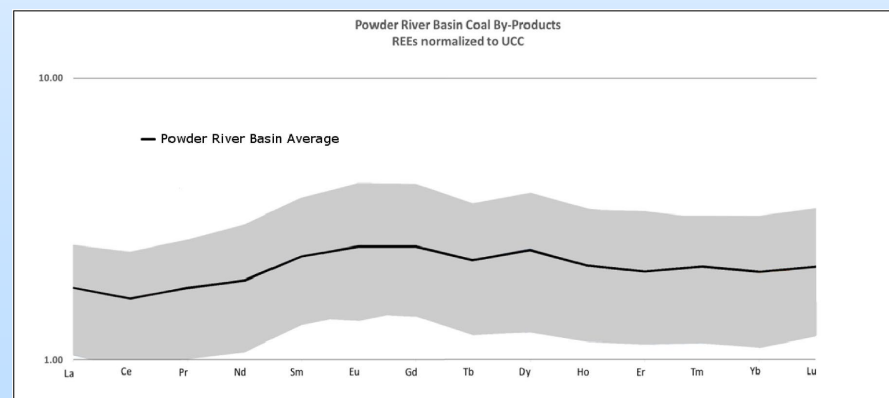
⁹Bagdonas et al., 2022

¹⁰Seredin and Dai, 2012

¹¹Bagdonas and McLaughlin, 2017



Average major element chemistry of PRB coal ash from four power plants in the PRB¹¹



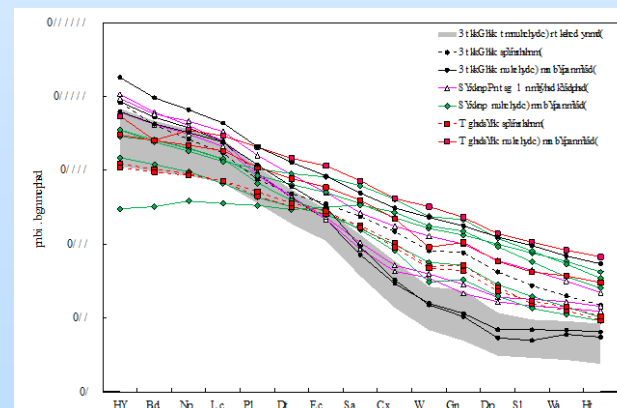
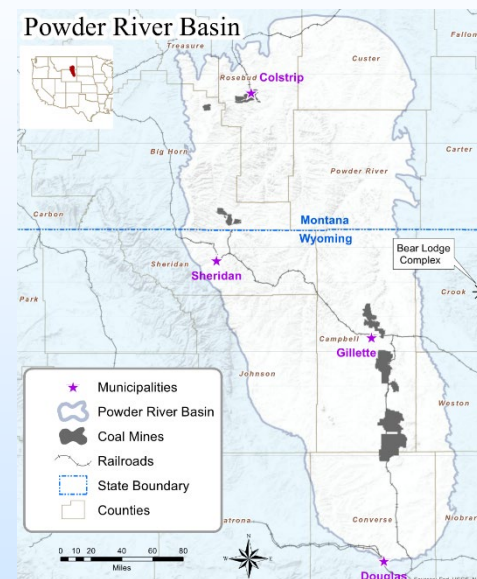
REE profile for PRB coal ash⁹

Progress and Current Status

Powder River Basin Resource Assessment

Bear Lodge Deposit

- Eocene alkaline complex including carbonatite dikes and veins
- Bear Lodge Critical Rare Earth Project development by Rare Element Resources¹²
- Measured and indicated resource of 18 million tons at 3.05% TREO (1.5% cutoff grade)¹²
- Prefeasibility study shows potential 45 year mine life¹²
- DOE-sponsored rare earth separation and processing demonstration facility at Upton Wyoming
- Synergies with other REE feedstocks in the PRB, including coal and coal byproducts, are being considered in resource assessments



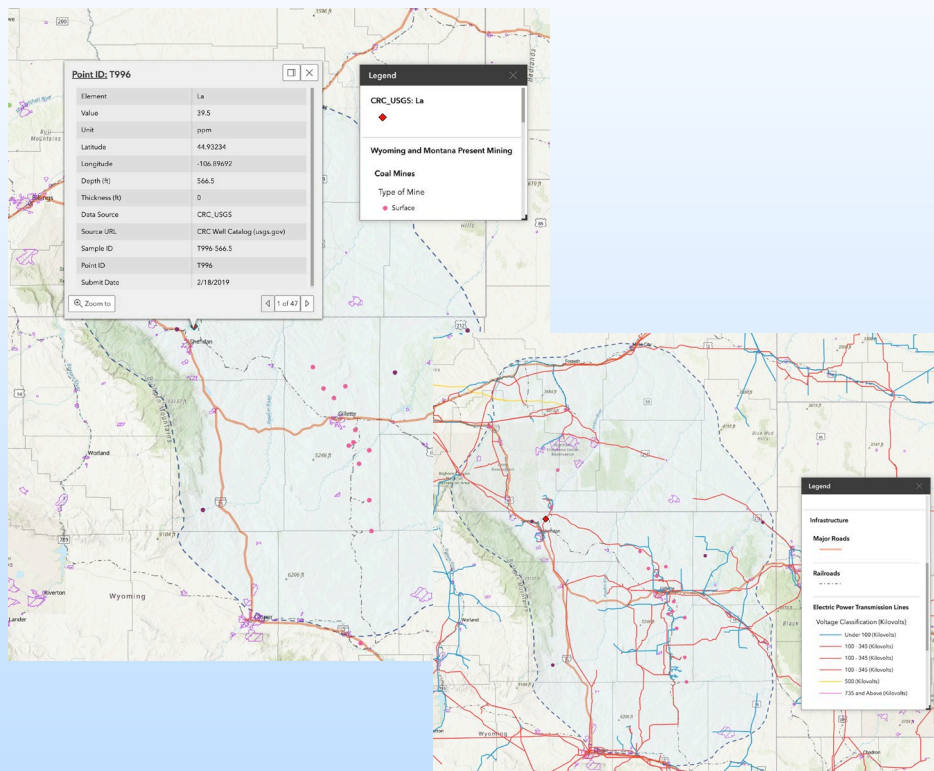
¹²rareelementresources.com

Andersen et al. (2017)¹³

Progress and Current Status

Powder River Basin Resource Assessment

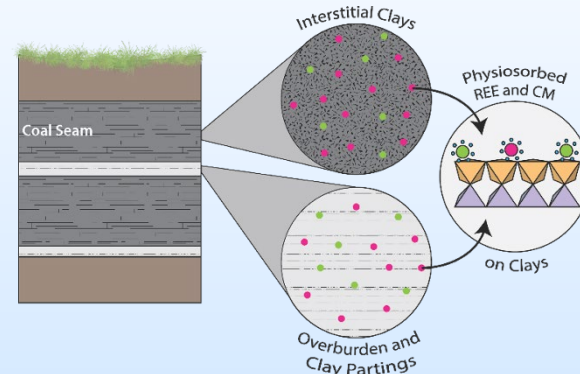
GIS Application and Data Management



A web application to display geochemical data and Powder River Basin infrastructure



Clay characterization



How do REE and CM fractionate into clay minerals within PRB coal deposits?

Isolate clay minerals

- Perform sequential extractions
- Quantify supernatant liquids
- Determine relationship between clays and trace metal occurrence

Analyze additional clay samples for increased resolution

- Repeat for coal samples

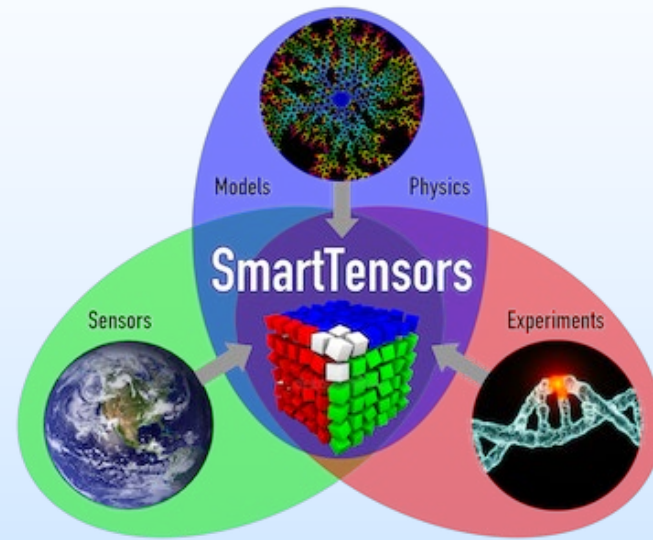
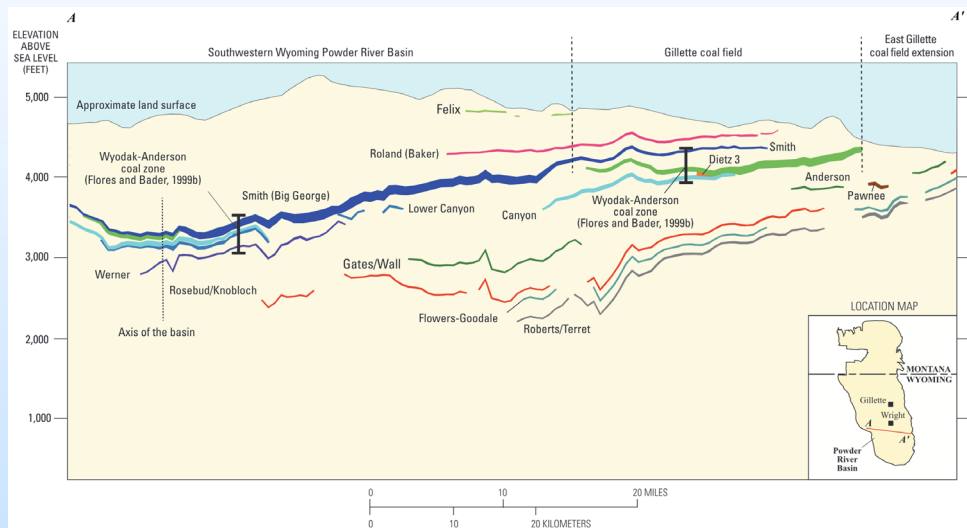
Contacts: Sophia Stuart, ssuart2@uwyo.edu;
John Kaszuba, John.Kaszuba@uwyo.edu

Progress and Current Status

Powder River Basin Resource Assessment

Initial Geologic Model Development

Powder River Basin Coal Geology and Stratigraphy



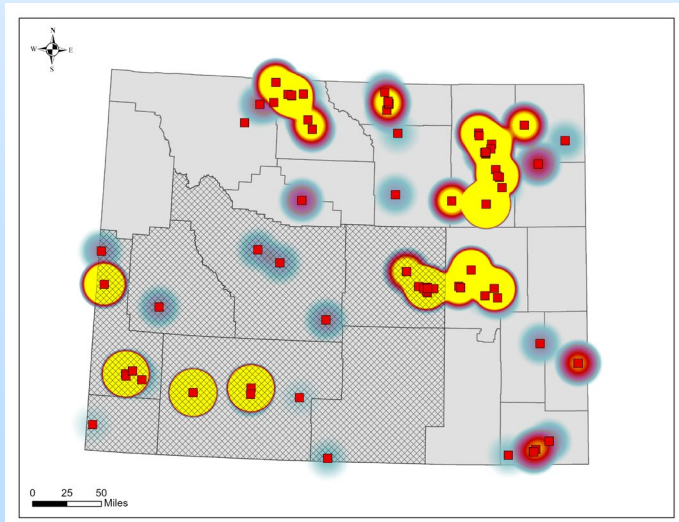
- Utilization of the R&D 100 Award winning SmartTensors framework to learn signatures underlying the data
- This will be combined with geostatistical techniques to produce a geologic model identifying rare earth and critical minerals

Progress and Current Status

Infrastructure, Industries, and Business

Approach

- Inventory and map all relevant infrastructure and industries in the Powder River Basin
- Collaboration with Campbell County Wyoming, the Montana Department of Commerce, and economic development groups to identify companies with potential to be part of CORE-CM supply chain
- Identify relevant businesses by North American Industry Classification System (NAICS)



Businesses: Mining & Processing

NAICS Code 2121 - Coal Mining

NAICS Code 2122 – Metal Ore Mining

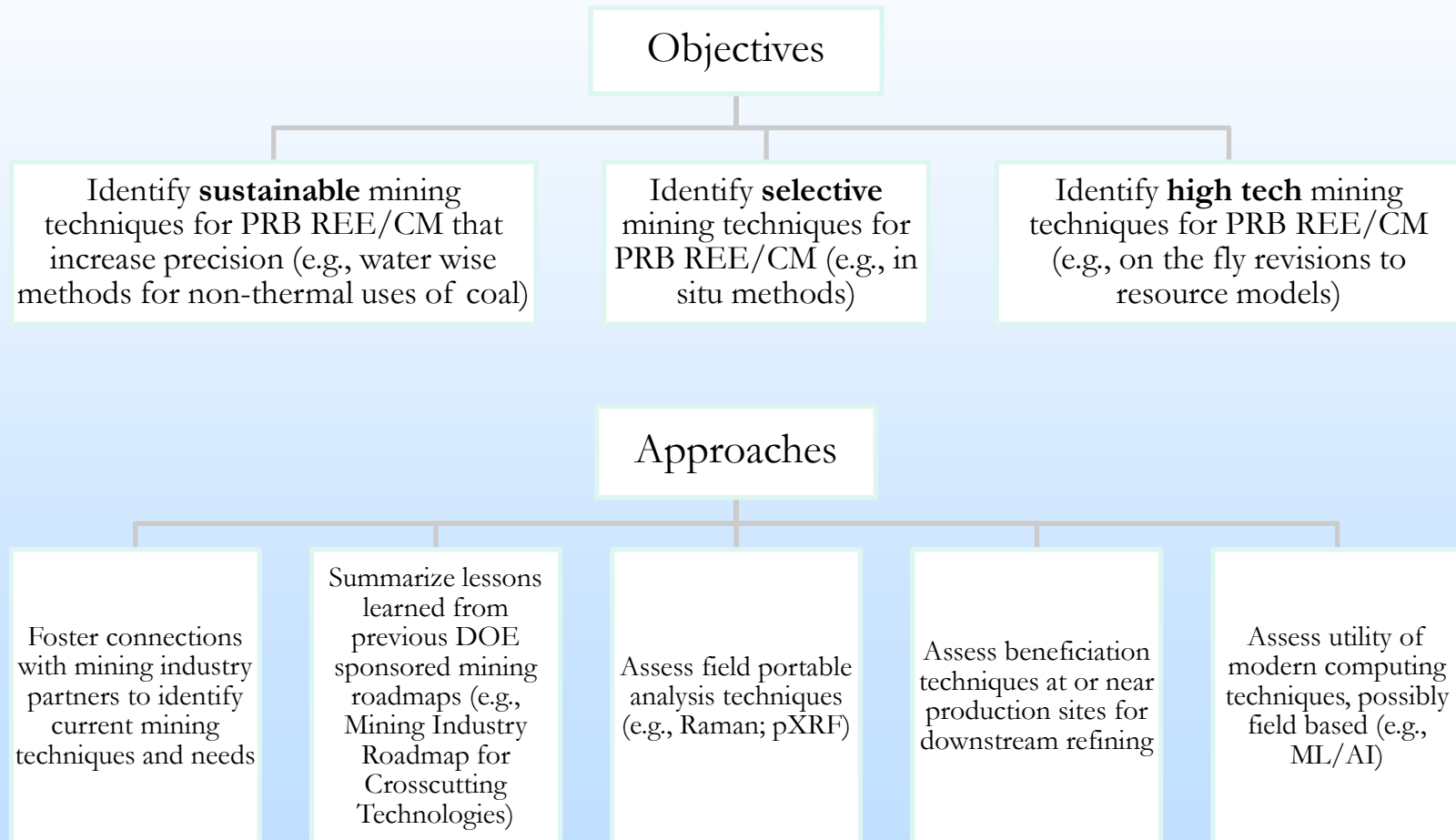
NAICS Code 2123 - Nonmetallic Mineral Mining and Quarrying

- 112 businesses in Wyoming
- More than 4,235 employees
- Heat map symbology accounts for number of businesses and reported number of employees



Progress and Current Status

Technology Development – Innovative Mining Techniques



Progress and Current Status

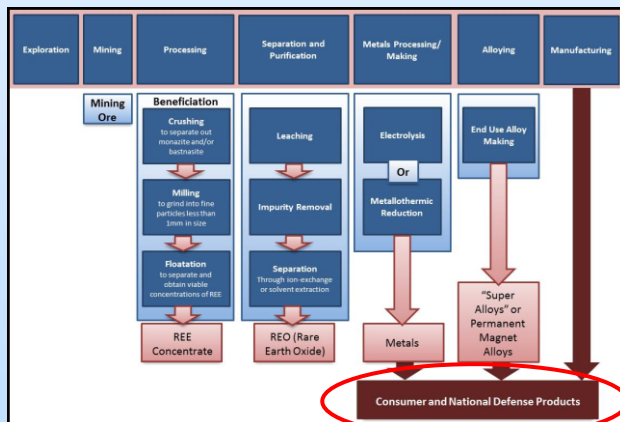
Technology Development – Carbon Ore and Critical Minerals to Products

Approaches

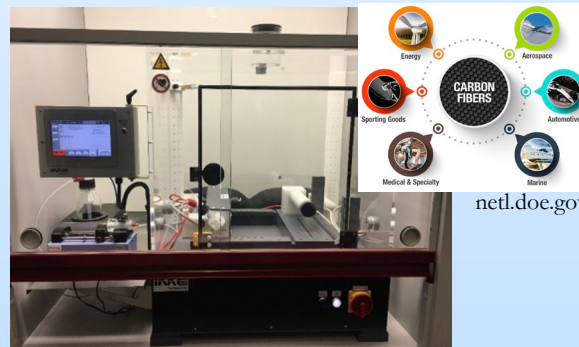
Identify regional manufacturing partners that could contribute to buildout of rare earth element and critical mineral industry in the Powder River Basin

Develop products that utilize Powder River Basin coal (e.g., carbon fibers)

Collaborate with private and public organizations in the Powder River Basin developing products from carbon ore

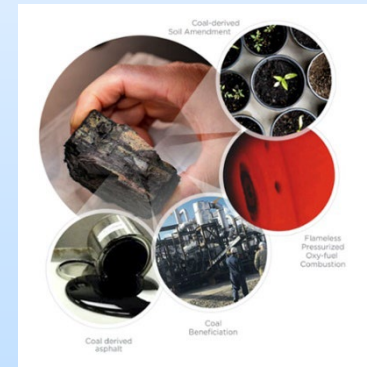


netl.doe.gov¹⁶



Pilot-scale electrospinning line

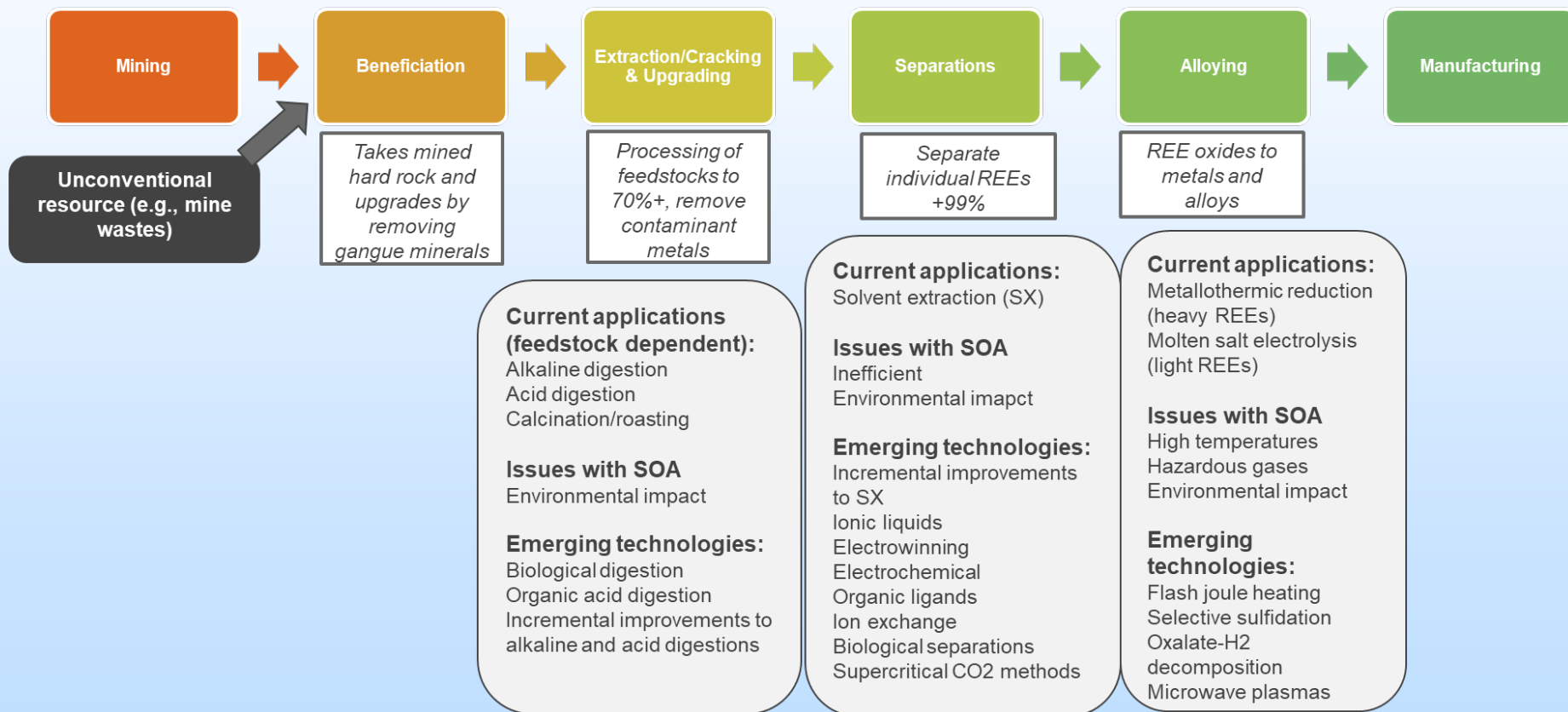
- UW Engineering Department CORE-CM project partners developing carbon fibers from PRB coal
- Unique surface and pore structures due to nature of PRB coal



UW SER Center for Carbon Capture and Conversion developing products from PRB coal, including high volume building materials

Progress and Current Status

Technology Development – REE Processing



SOA = state-of-the-art

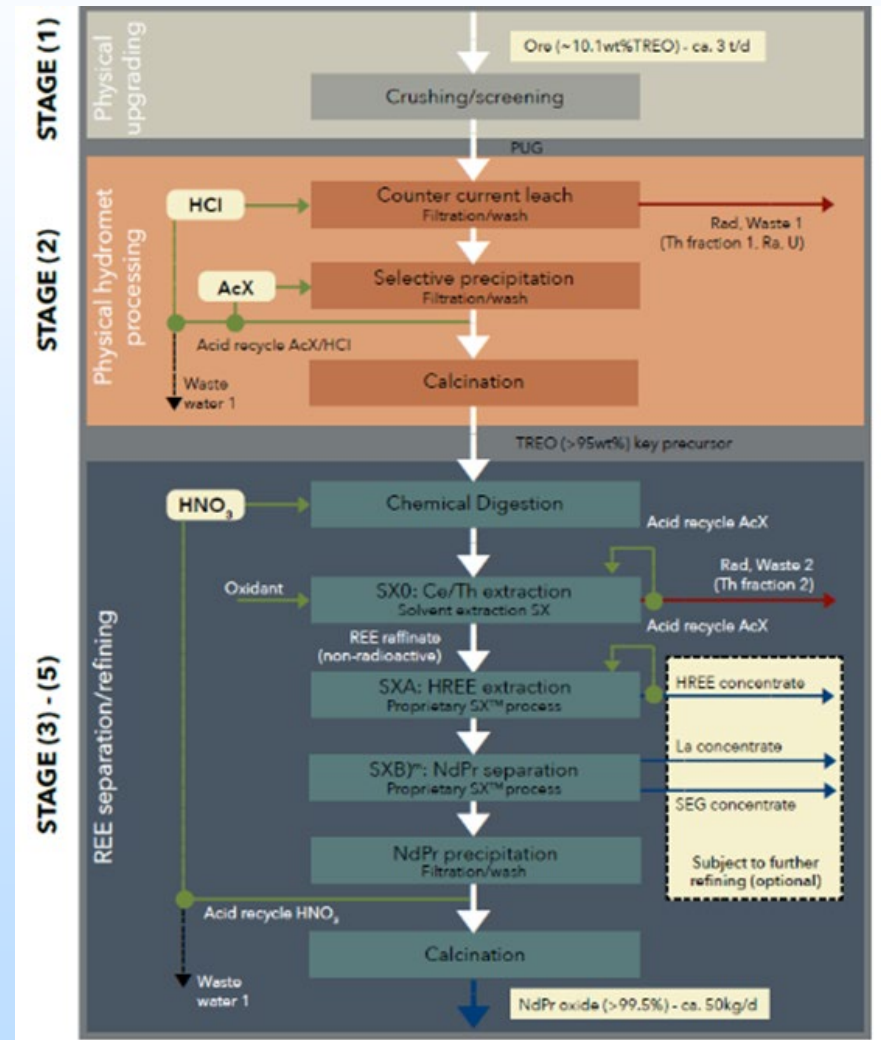
Progress and Current Status

Technology Development – Bear Lodge

- Rare Element Resources and UIT (General Atomics)
- HCl leaching < 60 °C
- Th and Ce precip. early
- SX separation of La early from desired NdPr product

¹⁷Scott, R. and R.E. Resources, 2021

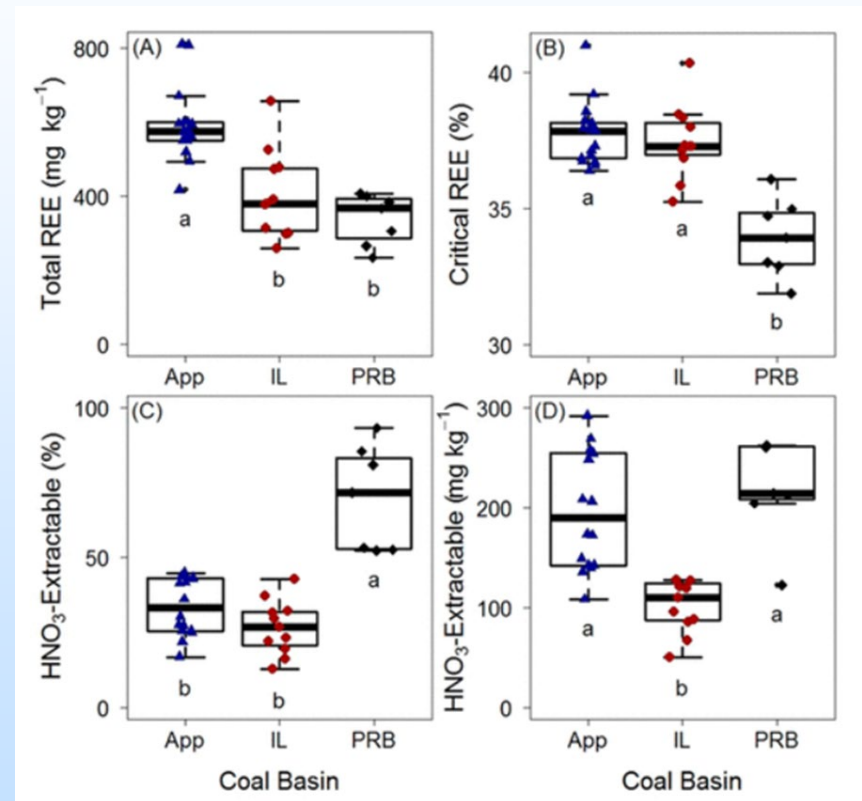
US 20180320248 A1 and US
20170260606 A1



Progress and Current Status

Technology Development – Coal/byproducts

- 9.8 mt of unused coal ash in the PRB⁷
- PRB coal ash is more extractable (with HNO₃) than samples of Appalachian or Illinois Basin coal ashes^{7,9}
- App: Ca content <4 wt% and median 29.6% extraction rate^{7,9}
- PRB: Ca content ~25 wt% and 70% extraction rate⁹



⁷Taggart et al., 2016

⁹Bagdonas et al., 2022

Progress and Current Status

Technology Development – Coal/byproducts

Department of Energy Technology Commercialization Fund (TCF-20-21358) Pilot-scale rare earth element extraction from Powder River Basin coal ash

- Project led by the National Energy Technology Laboratory (NETL)
- Project partners University of Wyoming, Campbell County Wyoming, city of Gillette Wyoming, and Energy Capital Economic Development
- Scale up of patent-pending rare earth element extraction technology from Ca-rich PRB coal, developed by NETL
- Will result in pilot-scale production facility at the Wyoming Innovation Center in Gillette Wyoming
- Provides synergistic opportunities with the PRB CORE-CM project



The Wyoming Innovation Center is a research-to-commercialization facility operated by CORE-CM project partner Energy Capital Economic Development in Gillette Wyoming
www.energycapital.com

Progress and Current Status

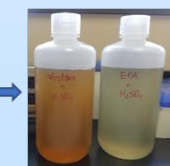
Technology Development – Coal/byproducts

Achievement: Targeted Rare Earth Extraction (TREE)

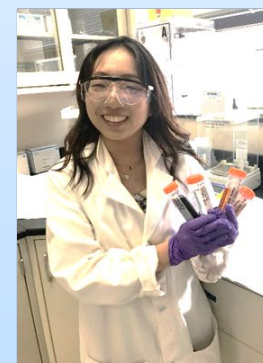
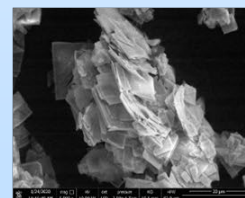
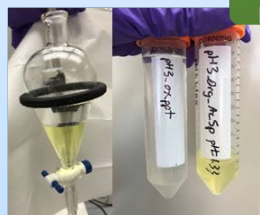
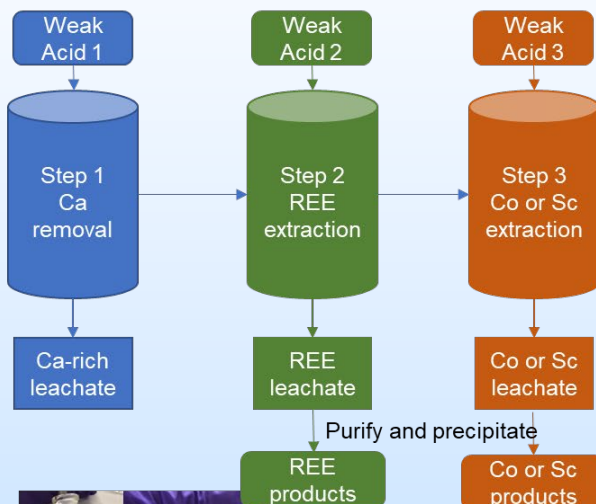
Reduce Extraction Steps & Conditions

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. No solvent use or reduced solvent use
6. Less waste management cost
7. Additional value streams such as cobalt, nickel or scandium



Clean REE leachate



*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>

See Christina Lopano's talk, 1145am Wednesday

Progress and Current Status

Technology Development – U Roll Fronts

- 113/2366 samples had REE 5x crustal average¹⁸
- REE leach with U when using acidic lixiviants
 - REE location during processing is not known
 - May be concentrated if aqueous, or removed before U-ion exchange steps
- V accompanies U and can range 1:1 to 1:10 concentrations
 - Extraction by reducing V to 4+, or using ion exchange resins

¹⁸Sutherland and Cola, 2016

¹⁹Bokovoya et al., 2014

²⁰Rychkov et al., 2016

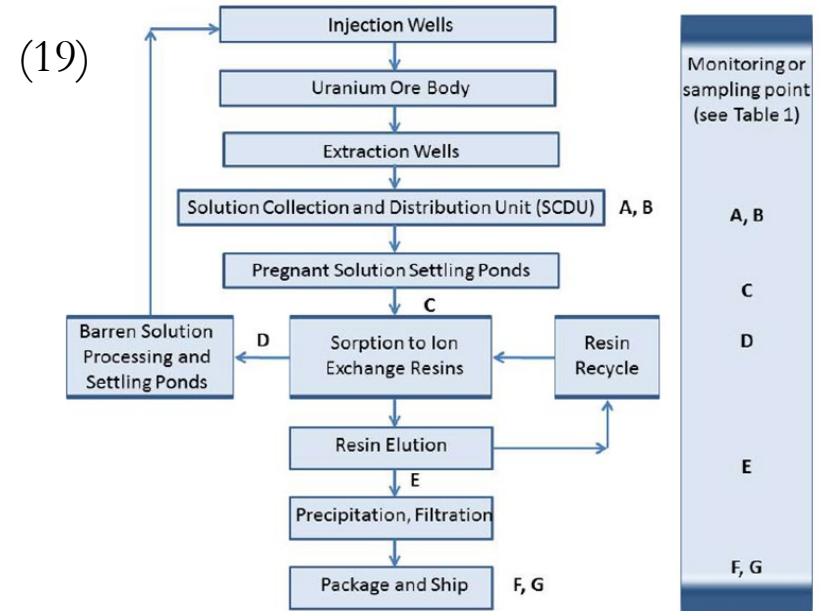


Figure 2. Block Diagram Representing Process Flow at the Mine and Processing Plant [1]

(20)

Element	Concentration (mg/L)
Fe	1122
Al	2416
Ca	439
Na	1328
Ti	9.44
Th	1.79
U	1.87
ΣLn+Y	31.9

Plans for Future Testing and Development

In this project

- Collect additional geochemical data and complete initial geologic model
- Secure permissions to share geochemical data
- Continue to expand stakeholder network across supply chain
- Explore regulatory and permitting topics around rare earth element and critical mineral mining and processing
- Complete strategic plans across all tasks

After this project

- Expand resource assessment to other feedstocks
- Expand workforce development programs
- Support existing and future technology innovation centers

Technology Innovation Center (TIC) Strategic Plan

Leveraging existing infrastructure and capabilities

Powder River Basin Asset	Capabilities	Examples
Private and Public Technology Centers	REE and CM technology development; Pilot and demonstration plant development and scale-up; Engineering skills	UW Center for Carbon Capture and Conversion; Ramaco Carbon; Wyoming Innovation Center; Upton Industrial Park/Rare Element Resources Demonstration Facility
Coal Mines	REE, CM, and carbon ore feedstocks; Processing, handling, and bulk transport	Mines in Powder River Basin
Power Plants	Utility service supply; Energy production and export	Power plants in Powder River Basin
Uranium Mines	Expertise in solution mining and processing; Potential REE and CM feedstocks	Uranium mines in Powder River Basin
Universities and Colleges	REE, CM, and carbon ore research and development	University of Wyoming, Montana State, Montana Tech, Gillette College, Miles Community College
Metals Recycling Cluster	Processing technologies; Metals handling	Montana
Opto-photonics Industry	Utilization of REE and CM; Growth aspirations	Montana

Guiding principals and selection criteria for future TICs

- Sustainability
- Leverages strengths of basin
- Considers water availability and management
- Potential for economic development and job creation
- Novelty and newness
- Techno-economically sound with deliberate market impact
- Counters shortages and reduced foreign dependence for supply
- Reduces carbon emissions and waste
- Sufficient feedstock availability
- Potential to co-process different feedstocks
- Leverage existing infrastructure and capabilities

Outreach and Engagement

Annual Forums

Carbon Ore, Rare Earth and Critical Minerals (CORE-CM) Initiative
Powder River Basin
Annual Forum
September 1, 2022
Gillette, Wyoming

- First annual forum held in Wyoming
- Next year's forum to be held in Montana
- Over 70 people attended in-person and online from across the Powder River Basin
- Strengths and areas of improvement were identified
- Recordings of the event are available on the University of Wyoming School of Energy Resources website

Contact: Christine Reed, Christine.Reed@uwyo.edu

Virtual Technology Roundtable

POWDER RIVER BASIN
CORE-CM Technology Roundtable
10 AM - 12 PM

Resource Guides

CORE-CM
Carbon Ore, Rare Earth and Critical Minerals
Advancing Strategies for Carbon Ore, Rare Earth Element, and Critical Mineral Resource Development in Wyoming's Largest Coal Producing Basins

WHAT ARE RARE EARTH ELEMENTS?
Rare Earths refer to the 17 elements (15 in the lanthanide series plus scandium and yttrium) that are abundant in the earth's crust, but whose concentrations are less common. Rare Earth Elements can be divided into light, heavy, and critical.

CRITICAL MINERALS
Critical minerals are a list of 50 mineral commodities including the REE group. They are considered vital for the economic well-being of the world's major and emerging economies.

CARBON ORE
Coal, coal by-products, coal waste streams, and coal ash.

WHY COAL?
The feasibility of recovering REE from the nation's vast coal-based resources has been explored through efforts led by the U.S. Department of Energy and the National Energy Technology Laboratory. The state of Wyoming, and particularly the PRB and GGB-WB, are well-positioned to support carbon ore, REE and CM research, by developing technologies that can help recover REE from coal and coal by-products, making it possible to recover REE in a way that's economical and environmentally friendly.

RARE EARTH ELEMENT KEY APPLICATIONS

CONTACT US
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UW School of Energy Resources
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Outreach and Engagement

Webinar Series



Tribal Engagement



- Provides an accessible resource for stakeholders and the public on Rare Earth Elements and Critical Minerals
- Webinars are archived as an online resource
- Conducted jointly in collaboration with the CORE-CM project in the Greater Green River and Wind River Basins

- Connections with Tribal Leadership on the Wind River Reservation to establish channels of communication and learn about tribal governance system
- Next steps include connecting further with tribal business councils, energy and water committees, and expanding network to include the Crow and Northern Cheyenne Nations in the Powder River Basin

Workforce Development

Rare-Earth Elements and Critical Minerals

Next



Home

How MAP works

Workshop.org

Navigation

Course Checklist

Related Courses



Career Knowledge Badge Series

Why are rare-earth elements and critical minerals important?

An increasing number of products we personally use or otherwise rely upon today require the use of Rare-Earth Elements and/or Critical Minerals to produce. Many of these substances are related to energy use and generation, such as the creation of turbines, batteries, fuel cells, conventional and electric cars, certain chemicals, and the semiconductors used to create modern electronics.

As of 2022, the US Department of Energy defines the **Rare-Earth Elements** as a set of elemental substances in Group 3 of the Periodic Table of Elements, specifically: everything in Group 3 other than the Actinide Series elements. **Critical Minerals** are defined as the Rare-Earth Elements, plus Lithium, Cobalt, Gallium, Germanium, and the Group-10 elements, also known as the Platinum Group. This makes for a grand total of 25 elements.

Rare Earth Element and Critical Minerals Makerspace Badges

- Online mini-courses aimed at educating students about careers and importance for critical minerals in the US
- The Makerspace is open to anyone to gain online credentials for enhanced employment opportunities
- Provides ways to connect employers with employees across the rare earth element and critical mineral supply chain

Additional Workforce Development

- Support for two University of Wyoming graduate students
 - Sophia Stuart, Geology MS
 - Anastasia Barnes, Engineering PhD
- Partnership with Gillette College and other community colleges to identify workforce training needs
- Future work to provide resources for K-12 Education



**FOR EVERY STUDENT.
IN EVERY MAKERSPACE.**

Makers Educators Leaders

LET'S GET YOU ON THE MAP

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Social and Environmental Justice



SOCIAL AND ENVIRONMENTAL JUSTICE
AN EXAMINATION OF CARBON ORE, RARE EARTH AND CRITICAL MINERAL (CORE-CM) COMMUNITIES

Panelists:

- Savannah Rice**
Science, Technology, and Policy Fellow,
US Department of Energy
- Matthew Henry**
Assistant Instructional Professor,
University of Wyoming Honors College
- Bonnie Petersen**
Executive Director, Associated Governments of Northwest Colorado (AGNC)
- Daniel Cardenas**
Chief Executive Officer, Knowledge River
- Kipp Coddington**
Senior Analyst, University of Wyoming School of Energy Resources
- Selena Gerace**
Associate Research Scientist, University of Wyoming School of Energy Resources
Panel Moderator

WEBINAR PANEL DISCUSSION

Tuesday, April 5, 2022
10:00 AM - 12:00 PM (MT)

Register Online
www.uwyo.edu/ser/events

Discussion Topics Include:

- What is Social and Environmental Justice?
- Cultural, Social and Environmental Impacts
- Regional Perspectives
- Community and Basinal Impacts
- Native Community Perspectives
- Legal and Policy Issues

UNIVERSITY of WYOMING
School of Energy Resources

Ensuring engagement and equity

- Assessment of potential environmental impacts of CORE-CM industries and associated mitigation strategies
 - Air pollution
 - Water pollution
 - Land disturbances
 - Loss of biodiversity
- Assessment of Environmental Justice considerations
 - Tribal energy sovereignty
 - Impacts to low-income communities

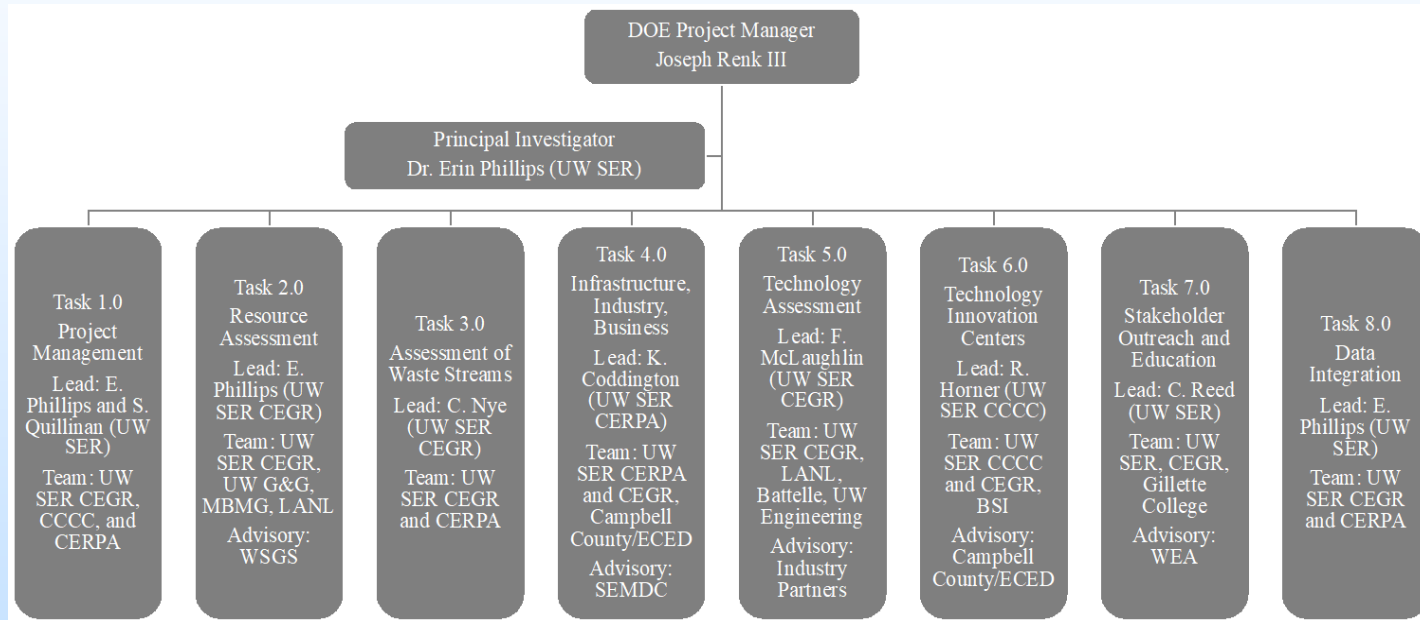
Take-Away

The Powder River Basin has promising rare earth element and critical mineral resources, abundant coal resources, engaged stakeholders, and energy infrastructure to support build-out of CORE-CM industries.

Foundational data are available for the Powder River Basin and expanded assessment efforts are necessary to fully characterize the rare earth element and critical mineral resource in the basin.

Appendix:

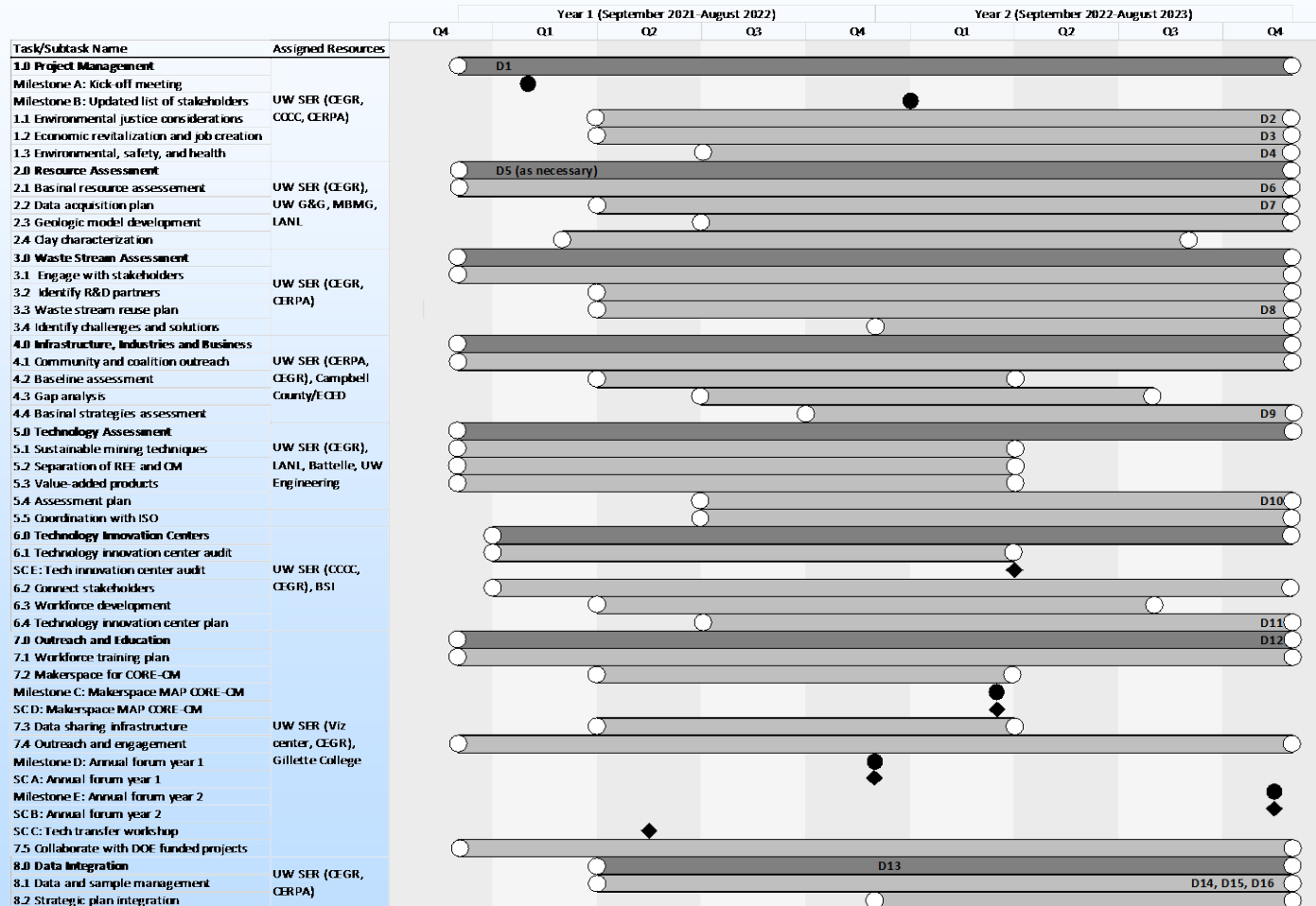
Organization Chart



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



UW SER = University of Wyoming School of Energy Resources; CEGR = Center for Economic Geology Research; COCC = 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:

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

¹www.eia.gov

²Luppens et al., 2015, Coal Geology and Assessment of Coal Resources and Reserves in the Powder River Basin, Wyoming and Montana, USGS Professional Paper 1809.

³Wyoming State Geological Survey, 2022, Critical Minerals in Wyoming.

⁴USGS open file report 2021-1045

⁵Bagdonas et al., 2019, Rare Earth Element Occurrence and Distribution in the Powder River Basin Coal Core, Wyoming, International Pittsburgh Coal Conference, University of Pittsburgh.

⁶Montross et al., 2022, On a Unified Core Characterization Methodology to Support the Systematic Assessment of Rare Earth Elements and Critical Minerals Bearing Unconventional Carbon Ores and Sedimentary Strata, Minerals 12.

⁷Taggart et al., 2016, Trends in the Rare Earth Element Content of U.S.-Based Coal Combustion Fly Ashes. Environmental Science & Technology, 50(11): p. 5919-5926. DOI: 10.1021/acs.est.6b00085.

⁸Stuckman et al., 2019, Characterization and Recovery of Rare Earth Elements from Powder River Basin Coal Ash, International Pittsburgh Coal Conference.

⁹Bagdonas et al., 2022, Rare earth element resource evaluation of coal byproducts: A case study from the Powder River Basin, Wyoming. Renewable and Sustainable Energy Reviews, 158: p. 112148. DOI: <https://doi.org/10.1016/j.rser.2022.112148>.

¹⁰Seredin and Dai, 2012, Coal deposits as potential alternative sources for lanthanides and yttrium, International Journal of Coal Geology, 94.

¹¹Bagdonas and McLaughlin, 2017, Mineral diversity and alternative resource potential of Wyoming coal by-products, GSA Abstracts with Programs.

¹²rareelementresources.com

¹³Andersen et al., 2017, REE fractionation, mineral speciation, and supergene enrichment of the Bear Lodge carbonatites, Wyoming, USA, Ore Geology Reviews.

¹⁴Luppens et al., 2015, Coal Geology and Assessment of Coal Resources and Reserves in the Powder River Basin, Wyoming and Montana, USGS Professional Paper 1809.

¹⁵Haacke and Scott, 2013, Drill Hole Data for Coal Beds in the Powder River Basin, Montana and Wyoming, USGS Data Series 713.

¹⁶netl.doe.gov

¹⁷Scott, R. and R.E., 2021, Resources Bear Lodge Critical Rare Earth Project: Developing a Secure U.S. Supply of Critical Minerals for Green Technology and Defense.

¹⁸Sutherland and Cola, 2016, A comprehensive report on rare earth elements in Wyoming, WSGS Report 71.

¹⁹Bokovoya et al., 2014, Improving Process Controls at In-Situ Leaching Uranium Mines, Brookhaven National Lab, Upton, NY, US.

²⁰Rychkov et al., 2016, Selective ion exchange recovery of rare earth elements from uranium mining solutions, AIP Conference Proceedings, 1767(1): p. 020017. DOI: 10.1063/1.4962601.