Technology Innovation Centers

University of Wyoming | School of Energy Resources

Technology Innovation Centers
Guiding Principles

GUIDING PRINCIPLES

- Technology selection offers sustainable advantages.
- Should leverage geographic, geological & resource strengths of the basin.
- Has potential to deliver competitive advantage.
- Addresses (& considers) local water availability & management concerns
- Must have material prospects for growing /diversifying local economic development & job creation.
- Are associated with a degree of novelty & newness.
- Are outwardly techno-economically sound & has positive & deliberate market impact

Technology Innovation Centers
Selection Criteria

SELECTION CRITERIA

- Counters anticipated shortages & reduces foreign dependence for supply.
- Preferentially addressing scarcity challenges that cannot be fulfilled from other sources.
- Reduced carbon emissions & ‘waste’ compared to the current situation.
- Feedstock availability in sufficient quantity to address long term US. projected demand.
- Potential to co-process different source feedstocks.
- Economic viability, job creation prospects together with business & Investors interests.
- Leveraging existing resources, asset capabilities & competencies available within the region

Overall Goals from Year 1

- **Primary**: to recover REE's and Critical Materials of specific interest determined by:
  - Supply, Demand & Economic attractiveness.
  - Countering anticipated supply shortages (scarcity)
  - Reducing foreign dependence
- **Secondary**: Manage feedstock residual carbon, in case of carbon-ore.
- **Tertiary**: manage & use remaining mineral matter.

CORE-CM: Carbon Ore, Rare Earth and Critical Minerals Initiative
Technology Innovation Centers

Adjusted Goals in Year 2

- **Primary**: Explore feedstocks for carbon-ore potential
- **Secondary**: Manage carbon-ore feedstock residuals to recover REE's and Critical Materials of specific interest determined by:
  - Supply, Demand & Economic attractiveness.
  - Countering anticipated supply shortages (scarcity)
  - Regional Development that may support REE/CM industry
- **Tertiary**: manage & use remaining mineral matter.

Challenge is where is the value and is it extractable economically!

Targeted Rare Earths*
Cerium
Dysprosium
Erbium
Europium
Gadolinium
Holmium
Lanthanum
Lutetium
Neodymium
Praseodymium
Samarium
Scandium
Terbium
Thulium
Ytterbium
Yttrium

Other Critical Minerals**
aluminum (bauxite)
antimony
arsenic
barite
beryllium
bismuth
cesium
chromium
cobalt
fluorspar
gallium
germanium
graphite (natural)
hafnium
helium
indium
lithium
magnesium
manganese
niobium
platinum group metals
potash
rhenium
rubidium
scandium
strontium
tantalum
tellurium
tin
titanium
tungsten
uranium
vanadium
zirconium

* Per DOE-NETL's Feasibility of Recovering Rare Earth Elements Program

** Additional critical minerals identified in Executive Order 138172

CORE-CM: Carbon Ore, Rare Earth and Critical Minerals Initiative
Value Chain Evaluation Ranking Matrix

Economic Evaluation Criteria

Goal	Criterion	Metric	Unit of Measure	Weight
Be a player in large and growing markets	US Demand (US)	Total US market sales of each Component used for each Application	Millions of Dollars	0%
Long-run local economic benefit	Basinal Supply (US)	Maximum (capacity-constrained) potential sales of each Component for each Application	Millions of Dollars	30%
Short-run local economic benefit	Capital Expenditure	Total Invested Capital (TIC)	Millions of Dollars	30%
Return on investment	Payback Period	Time to pay back TIC	Years	10%
Indicate local job creation potential	Employment	Jobs	Full-Time Equivalents	12.5%
Minimal environmental externalities	Carbon Footprint	CO_2, CH_4, N_2O	Tons of CO_2 Equivalent	12.5%
Intellectual capital growth	Scientific Complexity	1-10, with 1 being the current coal mining industry and 10 is high-tech “clean room” manufacturing	1-10 Scale	5%

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Emerging Industry Suggestions for the Region

Technology Focus Areas

- Selective Mining for Carbon-Ore, REE, and Critical Minerals targets
- Extractive metallurgy
- Carbon-Ore Manufacturing
- Recovery Processes/supply chain development for EV components
- REE-CM Goods Production

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Location Considerations

LEVERAGING EXISTING INFRASTRUCTURE& CAPABILITIES THAT EXIST ACROSS THE BASIN

- Coal Mines, CO & WY (Carbon-ore, Feedstock processing, handling & bulk transport)
- Power Plants, CO & WY (Carbon-ore, utility service supply, energy production & export)
- Metals Recycling Cluster, CO (Processing technologies, metals handing)
- Magnet Manufacturers, CO (Product and Applications Development)
- Universities & Colleges, CO & WY (Existing REE & CM research & development activity)
- Private Technical Centers, CO & WY (REE & CM Technology development, Pilot plant, scale-up & engineering skills)
- Opto-photonics industry, CO (REE & CM user industry with growth aspirations)
- Uranium Mines, WY (Source of REE & CM, expertise in solution mining & above ground processing)
- Advanced Manufacturing e.g. biotech (Seeding new ideas for technology innovation)

Center for Carbon Capture and Conversion

Through technology, leverage coal resources & competitive strengths in sustainable ways to:

1. Create new **non-energy,** opportunities for coal
    - High Volume emphasis
        - Asphalt Binder
        - Building Materials
        - Soil Amendment

2. Grow presence of Wyoming coal in thermal markets
    i. Clean combustion & carbon capture

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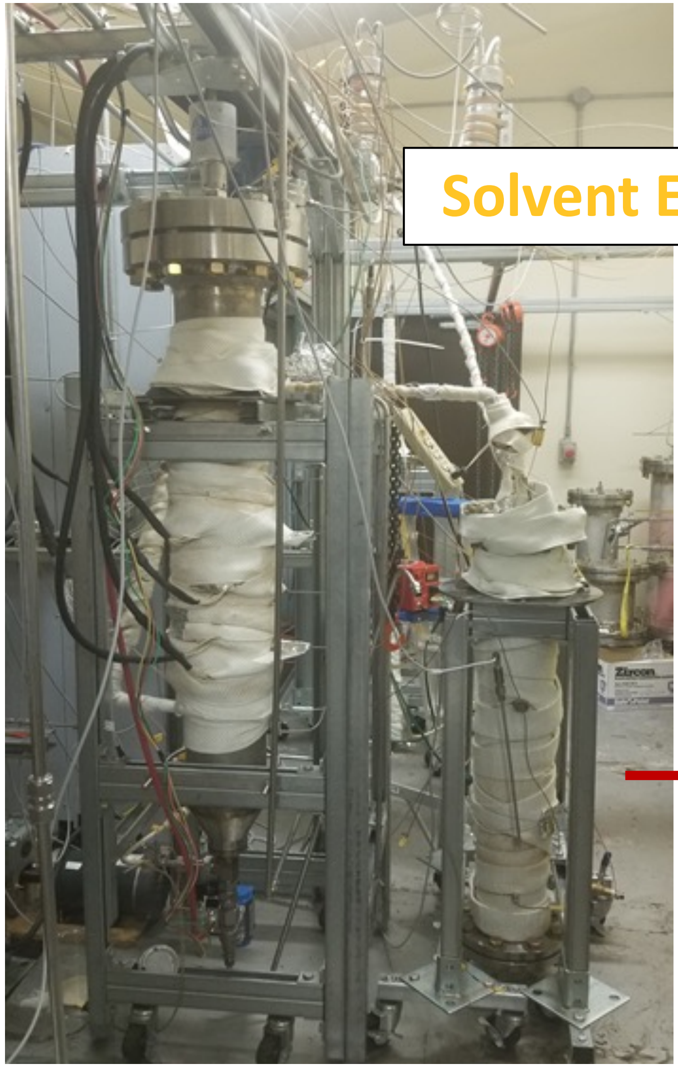
Carbon-Ore Project: Carbon Engineering Initiative

- Started in 2016
  - Funded by Wyoming Legislators to explore non-thermal uses of coal
  - Several projects funded to explore what was possible
- 2023 Update
  - Wyoming Legislators still funding coal to product research
  - 11 areas of research: 2 upstream processes and 9 downstream product areas
    - Asphalt binder from coal
    - Building materials
    - Soil Amendment
  - Field demonstration plant for upstream processes being built in Gillette, WY

Coal Refinery Upstream Process Development

Solvent Extraction Pilot Plant



Coal Extract

Pyrolysis Pilot Plant

Coal-based Asphalt CO_2 Emissions

Upstream CO_2 Emissions (Extraction to Refinery, Cradle-to-Gate)

Wyoming Powder River Basin (PRB) Coal **3 times less upstream CO_2 emissions** vs. conventional crude

$$\frac{60\ Kg\ CO2e}{ton\ PRB\ Coal}$$

$$\frac{233\ Kg\ CO2e}{ton\ Conventional\ Crude}$$

Source: Congressional Research Service, with data from U.S. Department of Energy, National Energy Technology Laboratory, "Life Cycle Analysis of Natural Gas Extraction and Power Generation," DOE/NETL-2014/1646, May 29, 2014, Figure 4-3, p. 36, and Table D-3, p. D-6.

https://crsreports.congress.gov/product/pdf/R/R44090, Calculated from Table 4.4

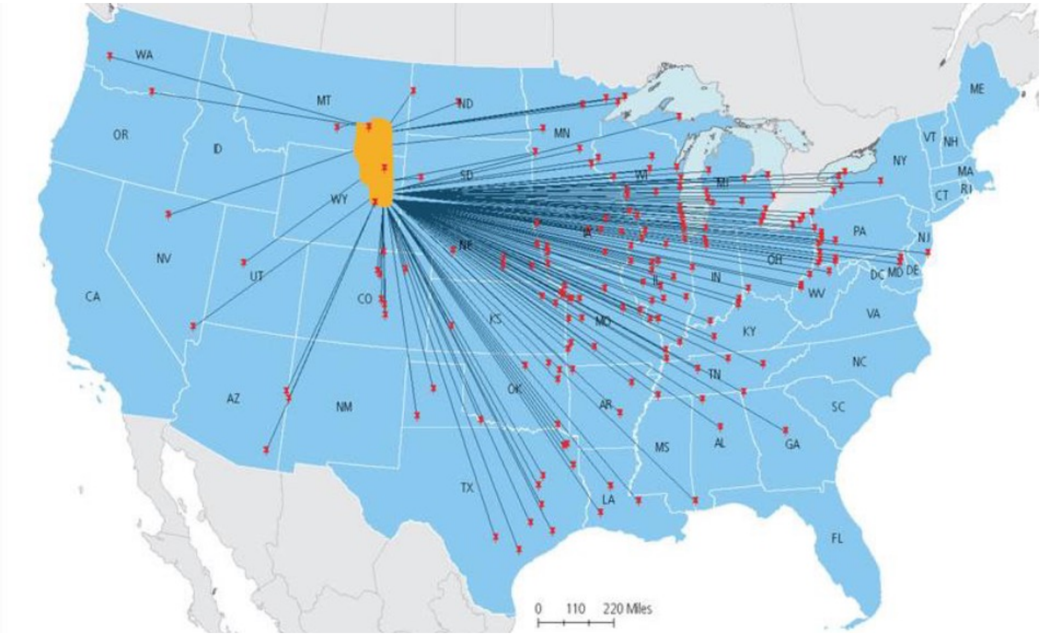
https://carnegieendowment.org/2016/02/09/breaking-down-barrel-tracing-ghg-emissions-through-oil-supply-chain-pub-62722

E.B. Association, Life Cycle Inventory: Bitumen, Eurobitume, Brussels, Belgium, 2012.

Wyoming Powder River Basin (PRB) Coal

- 23.1 billion tons economically recoverable (surface, thick seams)[1], domestic feedstock “Buy America”
  - 25 million tons of asphalt per year in North America = **>900 years of asphalt supply**
- Low in carcinogenic polycyclic aromatic hydrocarbons (PAH)
- Oxygen content for selective chemistry: tailor make materials for climate zone and application
- Low cost (July 7, 2023 = $14.45/ton)[2], highly mobile, mature transport infrastructure

Transportation by Rail



Wyoming Coal Information Committee, 2016 Wyoming Coal Overview, Wyoming Mining Association

[1] Luppens, J. A. et. al. Coal resource Availability, recoverability and Economic Evaluations in the United States – A Summary, Chapter D. of The National Coal Resource Assessment Overview, US Geological Survey Professional Paper 1625-F, Table 3
[2] https://www.eia.gov/coal/markets/

Center for Carbon Capture and Conversion

Carbon-Ore Project: Carbon Engineering Initiative

Carbon Ore Bricks (Coal Char Bricks):

- Class ‘A’ Fire Rating
- Half the weigh of a traditional clay brick
- VOC’s are lower than clay brick
- CO_2 emissions are lower (naturally cured, does not use kiln)

Energy Required to Manufacture Bricks

Consumed energy (GJ/1000 brick)	Clay brick(GJ)	Char brick(GJ)
Raw material extraction	0.169	0.1
Raw materials transportation	0.083	0.0603
Drying/Firing	8.63	0
Preparation/ forming	6.487	1.239
Conveyance in plant	0.0928	2.682
Brick processing	15.21	1.443
Natural gas	3.674	1.803
Diesel road	0.147	0.711
electricity	2.761	0.323
Total :-	37.2538	8.3613
GJ Per brick	0.0372538	0.0083613
Kwh per brick	8.333 Kwh	2.31 kWh

VOC, CO, CO2 and PM2.5 Data

Contaminant VOC compound	Concentration limit (ug/m3)	Char house	Clay house
Formaldehye 50-00-0	20 (16 ppb)	19 ppb	19 ppb
Total Volatile organic compound (TVOC)	500	250	340
Carbon Monoxide (CO)	<9 ppm	<0 ppm	<0 ppm
Carbon Dioxide (CO2)	1127ppm	388ppm	421ppm
PM 2.5	12	2.7	3.1

PRB Coal to Building Products Demonstration Platform

- **Coal char bricks thermal efficiency is superior to conventional clay bricks over the summer months**

Soil Amendment

- Carbon rich coal char improves soil's physical, chemical and biotic properties, as a result it will increase plant growth and crop yield.

- Porous coal char increases soil water holding capacity, which will also reduce nitrogen leaching from the soil.

- Light weight char mixed in the soil will reduce soil bulk density allowing plant root expansion and uptake of more nutrients from the soil. Thus, increased soil moisture and decreased nitrogen leaching on the soil would lead to agricultural input savings for production.

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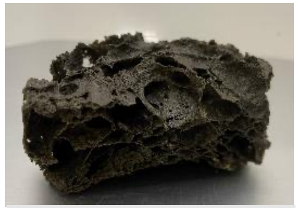
Carbon-Ore Project: Carbon Engineering Initiative


CHAR INSULATION FOAM (CIF)


(DOE) CARBON-BASED STRUCTURAL UNIT(CSU)


CHAR BRICK (CCB)


STONE VENEER


BLOCK PAVER


COAL DERIVED ASPHALT


GRAPHENE OXIDE (GO)


CHAR-BASE AGGREGATES

CHAR MORTAR

SOIL AMENDMENT AND RECLAMATION WORK

CHAR-BASED CEMENT GROUT (CCG)


CHAR PLASTER


GO IN CONCRETE

Technology Innovation Centers
Next Steps for Regional Development in Colorado & Wyoming

Metals Extractive Processes

- Mild-thermal Treatment and Solvent Extraction Processing of REE and CM rich Carbon Ore.
- Bio-leaching of REE/CM from coal & coal waste

Developing Li-ion Carbon Energy Storage Value Chain

- Fabrication of carbon- doped Membranes

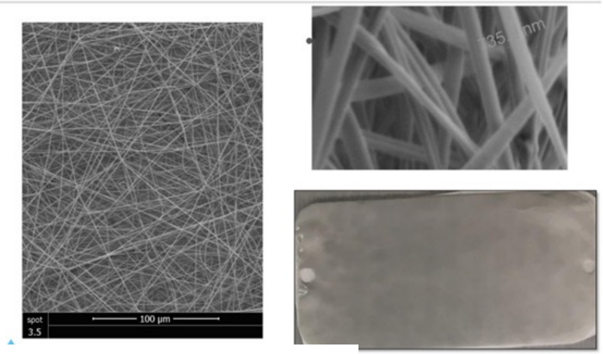
Coal Based Materials

- Graphite from coal – Exploring graphite from coal research
- High value products – carbon fibers, coatings, resins

Mineral wastes from non-coal Industries

- Phosphate and Trona waste streams
- Hydro-thermal Processing of mixed REE sources
- Uranium waste streams

Coal-PAN Composite Membrane



Method