The Illinois Basin Carbon Ore, Rare Earth, and Critical Minerals Initiative

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U.S. Department of Energy

National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
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Project Overview

- Funding Source
  - DOE: $1,999,942.00
  - Cost Share: $497,478.00
- Project Dates
  - Start: September 21, 2021
  - Finish: May 31, 2024

Project Objective: Evaluate the domestic occurrence of strategic elements in coal, coal-based resources, and waste streams from coal use.

Illinois Basin CORE-CM

Project Participants

ILLINOIS
Illinois State Geological Survey
PRAIRIE RESEARCH INSTITUTE

Center for Applied Energy Research

SIU Southern Illinois University
CARBONDALE

INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Kentucky Geological Survey
UNIVERSITY OF KENTUCKY

IOWA GEOLOGICAL SURVEY

TENNESSEE GEOLOGICAL SURVEY
ESTABLISHED 1831

OAK RIDGE National Laboratory

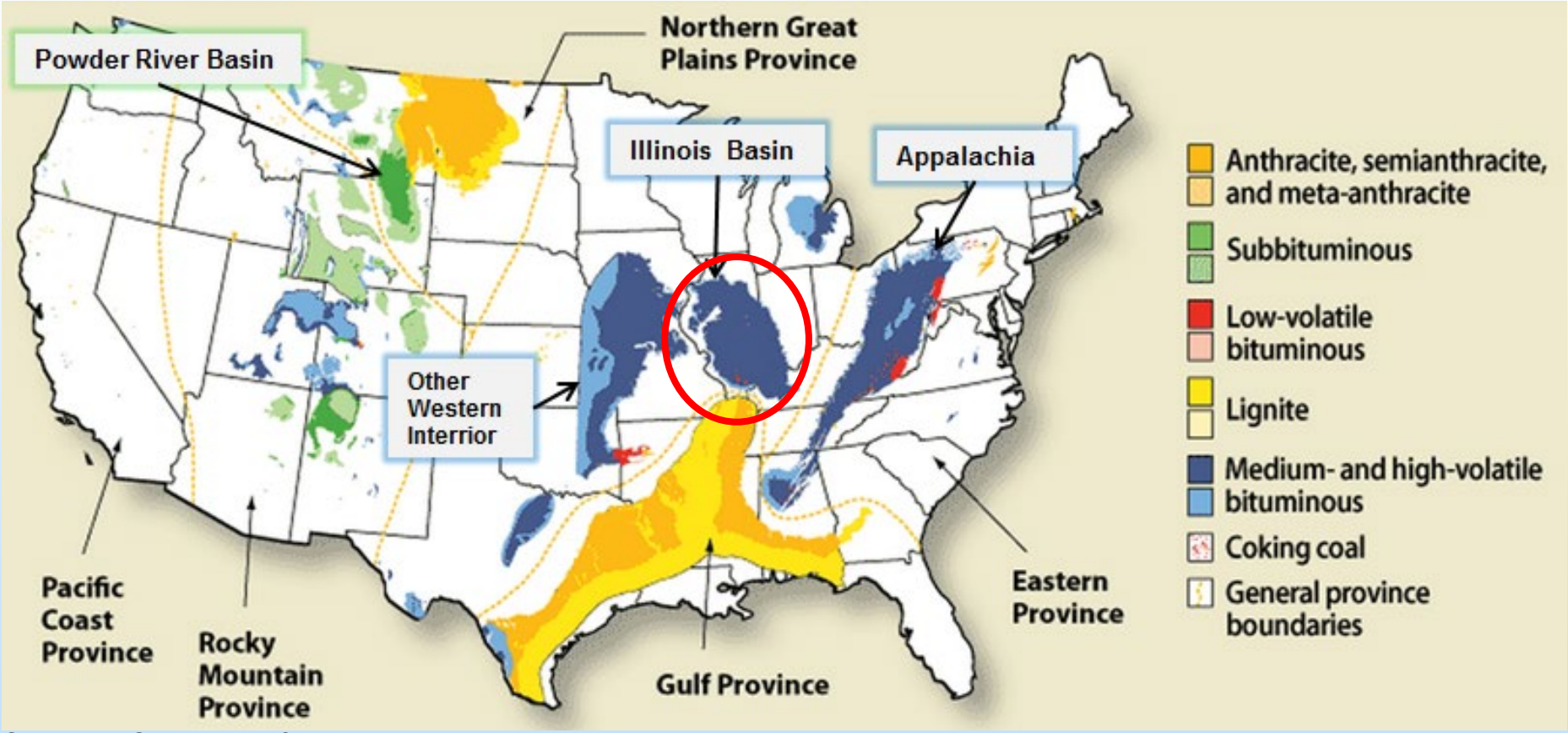
synTerra

Prairie Research Institute
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Project Scope

- Environmental Justice, Jobs Creation, and Product Safety
  - **Task 1**
- Basin-wide assessment of CORE-CM (*supplemental analysis)
  - **Task 2** Geology; **Task 3** Waste Streams
- Infrastructure, business, and industry evaluation
  - **Task 4**
- Mining and separation technologies and high-value carbon product development
  - **Task 5**
- Technology Innovation Center, Stakeholder Engagement, Outreach
  - **Task 6** TIC; **Task 7** Stakeholder

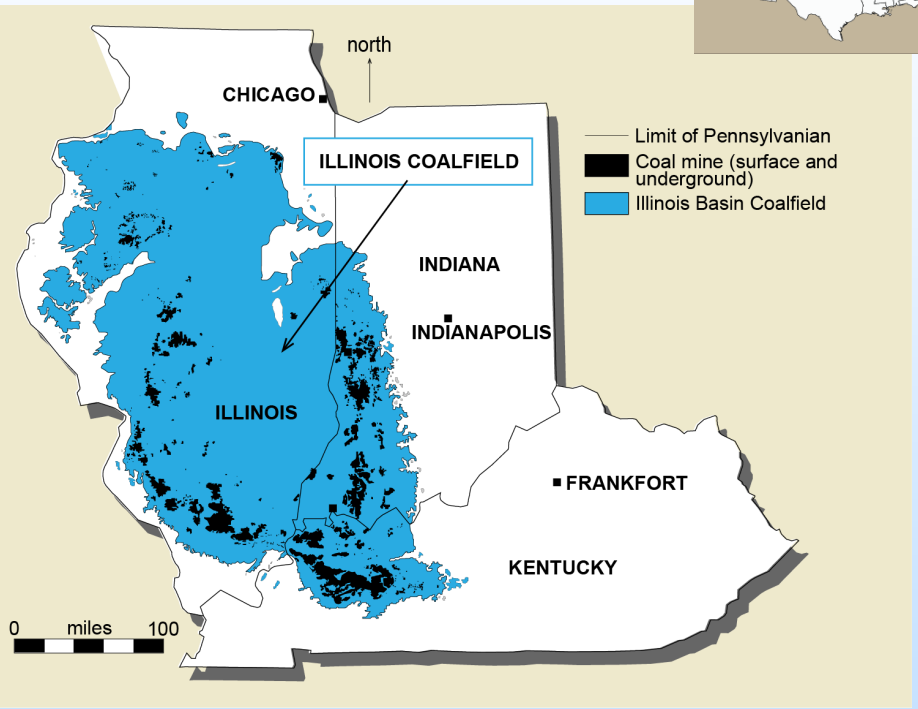
Illinois Basin CORE-CM



Source: U.S. Energy Information Administration

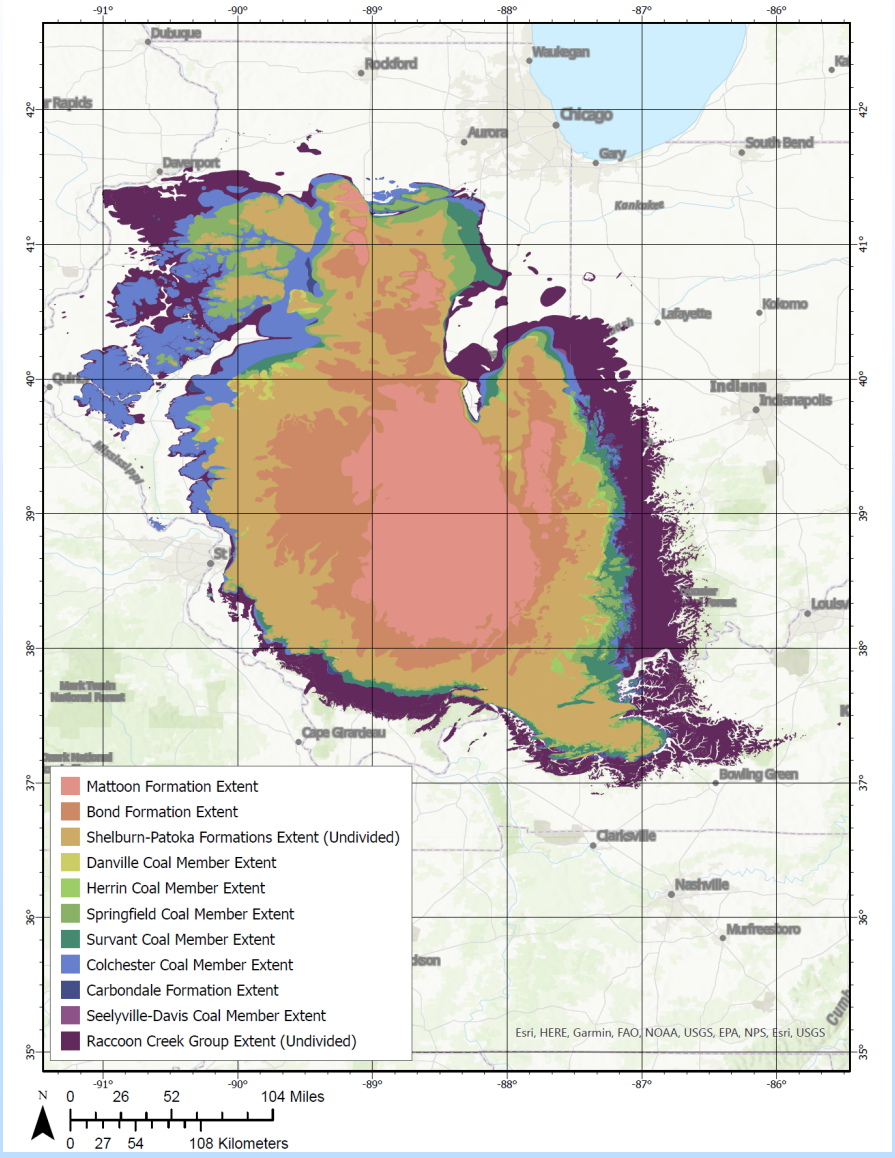
Project Background

Illinois Basin Coalfield



Modified from Korose and Elrick (2013)

- **150 billion short tons mined from Herrin and Springfield Coals**
- **103 billion short tons of reserves, estimated at 20 and 1,880 mil short tons for surface and underground minable coals**



Pennsylvanian Stratigraphy

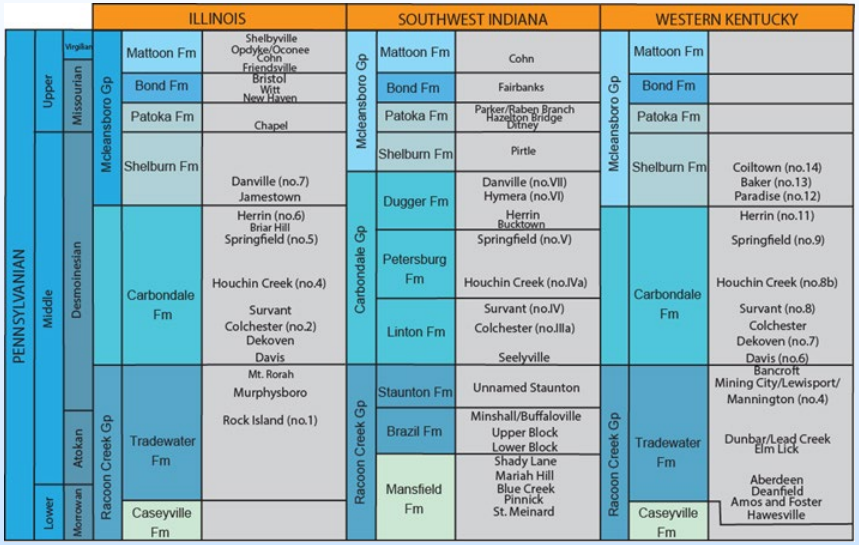


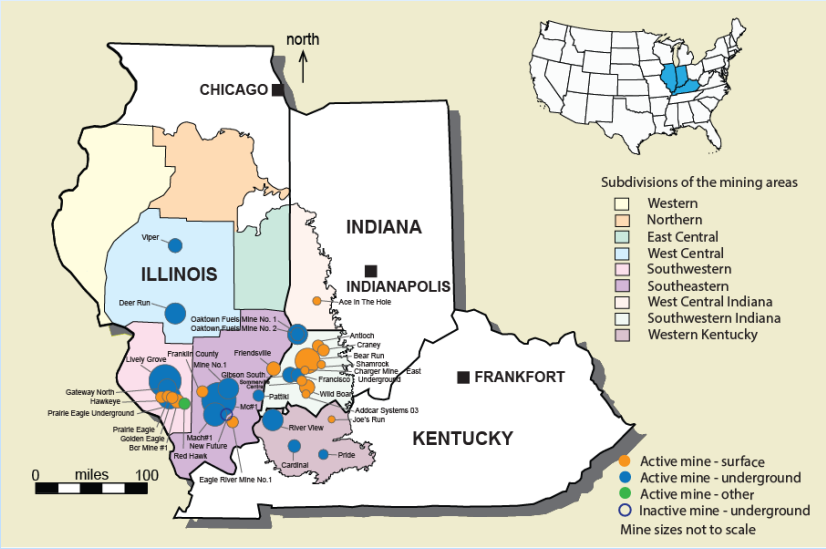
Figure 2. Stratigraphic chart of the Pennsylvanian System in the Illinois Basin, showing major coal members (modified from Greb et al.,1992, Mastalerz and Harper,1998, Mastalerz et al., 2018). Abbreviation: Fm., Formation; Gp., Group.

In the Illinois Basin, the **Pennsylvanian System is divided into the Raccoon Creek, Group the Carbondale Group or Formation, and the McLeansboro Group.** Formation and group nomenclature is the same in Illinois and western Kentucky (Jacobson et al., 1985; Tri-state committee, 2002). In Indiana, (1) the Raccoon Creek Group includes the Mansfield (oldest), Brazil, and Staunton (youngest) formations and the Caseyville Formation is not recognized, (2) the Carbondale Formation is a Group rather than a Formation, and the Carbondale Group in Indiana includes the Linton (oldest), and Dugger (youngest) formations, (3) the base of the Linton Formation of the Carbondale Group is defined at the base of the Seelyville Coal that is partly equivalent to Davis Coal in Illinois and western Kentucky, and (4) the top of the Dugger Formation of the Carbondale Group is defined at the top of the Danville Coal, which is younger than the top of the Carbondale Formation in Illinois and western Kentucky (Tri-state Committee, 2002).

The Carbondale Formation or Group covers about 90% of the area in which Pennsylvanian strata are exposed at the surface in the basin. It includes the most extensively mined coals in the basin. These coals are the **Herrin and Springfield** in descending stratigraphic order. The Carbondale coals are commonly widespread and vary in thickness from a few inches to more than 6 feet in many areas in which the coals have been mined.

Illinois Basin Coal Mine

Operating Illinois Basin coal mines have produced a total of 68 million short tons annually (U.S. Energy Information Administration). **Annual coal production in individual mines ranges from 2,000 short tons to 9 million short tons**. The largest producing mines currently mining coal in the basin are (1) 9.4 million short tons per year for the River View Coal LLC. Mine in Union County, western Kentucky, (2) 6.4 million short tons per year for the Lively Grove Mine, Prairie State Generating Company LLC., in St. Clair County, Illinois, and (3) 5.2 million short tons per year for the Bear Run Mine, Peabody Energy LLC., in Sullivan County, Indiana (U.S. Energy Information Administration, 2022). **More than $4.2 billion is the annual economic impact of Illinois Basin coal production and generation**.



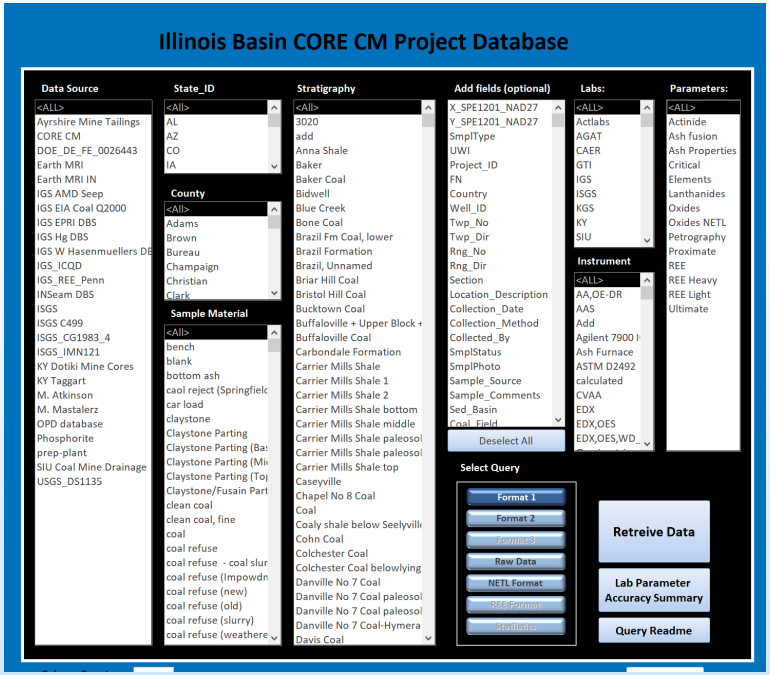
^*Map showing the active coal mines and coal preparation plants in the Illinois basin.*

>Table showing the active coal mines and coal preparation plants and coal production in the Illinois basin.

Mine name	MSHA ID	Coal Rank	Mine type	Mine status	Total production (short tons)
ILLINOIS					
Brc Mine#1	1103131	BIT	Refuse	Active	233,752
Deer Run Mine	1103182	BIT	Underground	Active	3,193,513
Eagle River Mine	1103212	PRP	Surface	Active	0
Franklin County Mine	1100601	PRP	Surface	Active	0
Friendsville Mine	1103064	BIT	Surface	Active	34,972
Friendsville Preparation Plant	1103296	PRP	Surface	Active	0
Gateway North Underground Mine	1103235	BIT	Underground	Active	1,728,891
Golden Eagle Mine	1103274	BIT	Surface	Active	339,836
Hamilton County Coal Mine	1103242	PRP	Surface/ Underground	Active	0
Hawkeye Mine	1103226	BIT	Surface	Active	7,212
Lively Grove Mine	1103193	BIT	Underground	Active	6,636,062
Mach#1 Mine	1103189	BIT	Underground	Active	6,713,341
Mc#1 Mine	1103189	BIT	Underground	Active	7,860,150
Mine No.1	1103203	BIT	Underground	Active	4,938,788
New Future Mine	1103232	PRP	Underground	Closed	0
Orient No.6 Mine	1100599	PRP	Surface	Closed	0
Pattiki Mine	1103058	PRP	Underground	Active	0
Prairie Eagle	1103143	PRP	Surface/Underground	Active	0
Prairie Eagle Underground Mine	1103147	BIT	Underground	Active	4,114,075
Preparation Plant	1102546	PRP	Surface/Underground	Active	0
Red Hawk	1103045	BIT	Surface	Active	34,170
Viper Mine	1102664	BIT	Underground	Active	1,012,847
Watco Transloading/Cahokia Te	1103225	PRP	Surface/Underground	Active	0
				Total	**36,613,857**
INDIANA					
Ace In The Hole Mine	1202460	BIT	Surface	Active	135,037
Addcar Systems 03	1518950	BIT	Surface	Active	448,423
Antioch Mine	1202372	BIT	Surface	Active	52,998
Bear Run Mine	1202422	BIT	Surface	Active	6,039,988
Carlisle Preparation Plant	1202465	PRP	Surface	Active	0
Charger Mine East	1201616	BIT	Surface	Active	12,518
Carney Mine	1201732	BIT	Surface	Active	9,592
Francisco Mine	1202147	PRP	Surface/Underground	Active	0
Francisco Underground Mine	1202295	BIT	Underground	Active	1,485,344
Gibson North Preparation Plant	1202494	PRP	Surface	Active	0
Gibson North Mine	1202388	BIT	Underground	Active	3,290,186
Oaktown Fuels No.1 Mine	1202394	BIT	Underground	Active	3,488,773
Oaktown Fuels No.2 Mine	1202418	BIT	Underground	Active	2,147,021
Oaktown Fuels Preparation Plant	1202462	PRP	Surface/Underground	Active	0
Shamrock Mine	1202374	BIT	Surface	Active	7,741
Sommerville Central Mine	1202258	BIT	Surface	Active	12,604
Switz City	1202097	PRP	Surface	Closed	0
Wild Boar Mine	1202441	BIT	Surface	Active	2,340,211
				Total	**19,470,436**
WESTERN KENTUCKY					
Cardinal Mine	1517216	BIT	Underground	Active	4,141,430
Genesis Plant and River Loadou	1519345	PRP	Surface	Active	0
Joe's Run Mine	1518418	BIT	Surface	Abandoned	232,710
Joe's Run Processing	1519667	PRP	Surface	Abandoned	0
Midway Plant and Loadou	1519165	PRP	Surface	Active	0
Parkway Refuse	1519356	PRP	Surface/Underground	Active	0
Pride Mine	1519744	BIT	Underground	Active	2,069,342
River View Facilities	1503178	PRP	Surface/Underground	Active	0
River View Mine	1519374	BIT	Underground	Active	9,847,709
Warrior Preparation Plant	1514335	PRP	Surface/Underground	Active	0
				Total	**11,917,051**
				IB Total	**68,001,344**

Project Outcomes (highlights)

- Development of a comprehensive database with a user-friendly dashboard
- Data encompasses coal (+waste) samples collected and analyzed across the Illinois basin
- Basin Model developed for REE in-place (coal) and associated with waste
- Comprehensive waste re-use plan developed (led to a FEED-study award)
- Robust Stakeholder Relationships



Illinois Basin CORE-CM

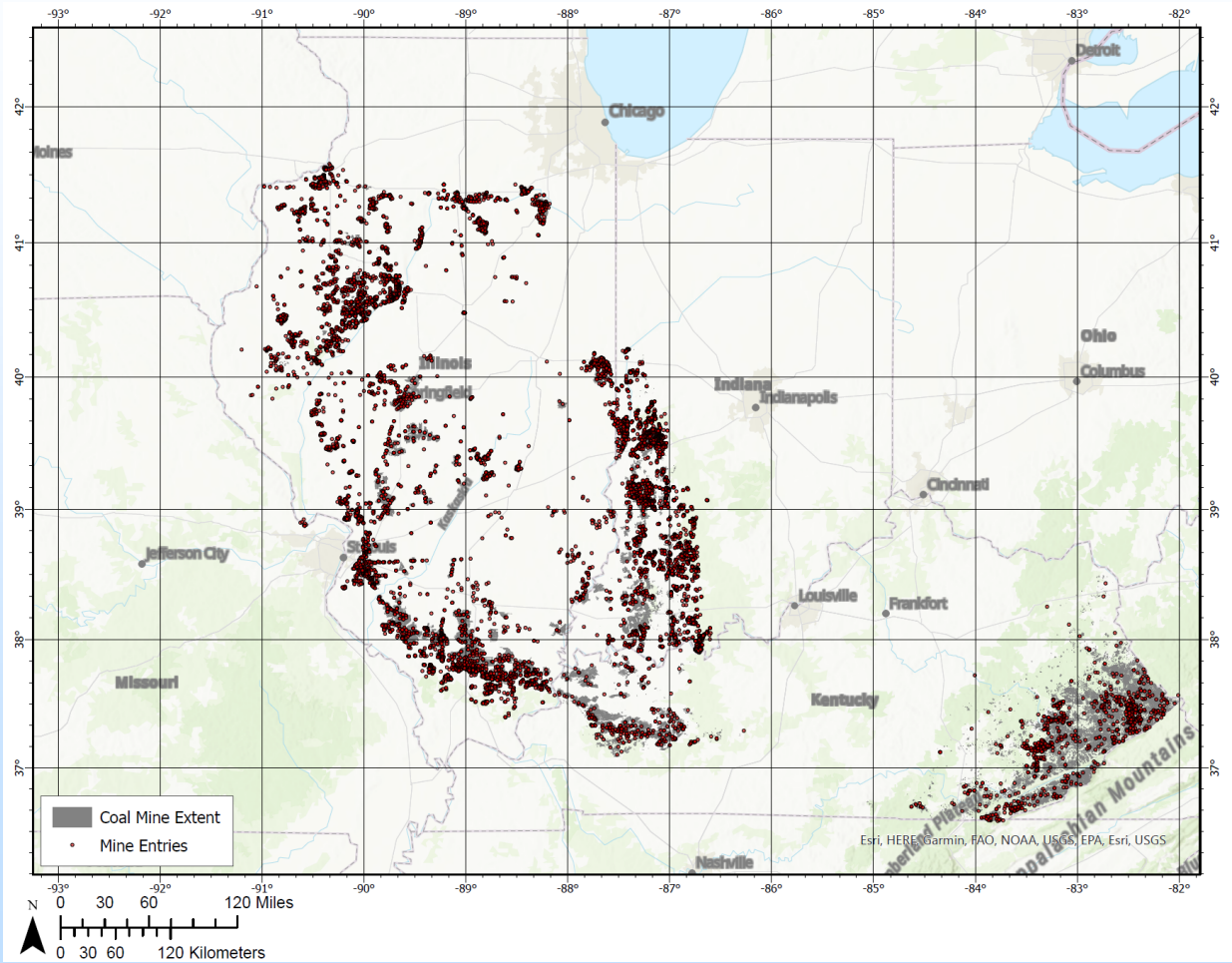
Historical and Active Coal Mines and Data

More than **12,000 data points** of Coal Quality and elemental geochemistry have been collected for IB CORECM.

In Illinois, 6,700 existing data have been assembled by the Illinois State Geological Survey from the Illinois Coal Quality Database, USGS Data Series 1135 (Kolker et al., 2018), Earth-MRI dataset, and scientific publications (Lefticariu et al., 2020; Kolker et al., 2021).

In Indiana, 3,300 data have been collected by the Indiana Geological Survey from Indiana Coal Quality Database, National Coal Resource Dataset, EC dataset, and Earth MRI dataset.

In western Kentucky, 3,200 coal information and assessing coal resources have been performed by the Kentucky Geological Survey from the USGS reports, National Coal Resource Data System Coop, Coal Availability and Recoverability, National Coal Quality Inventory, and National Coal Resource Assessment.



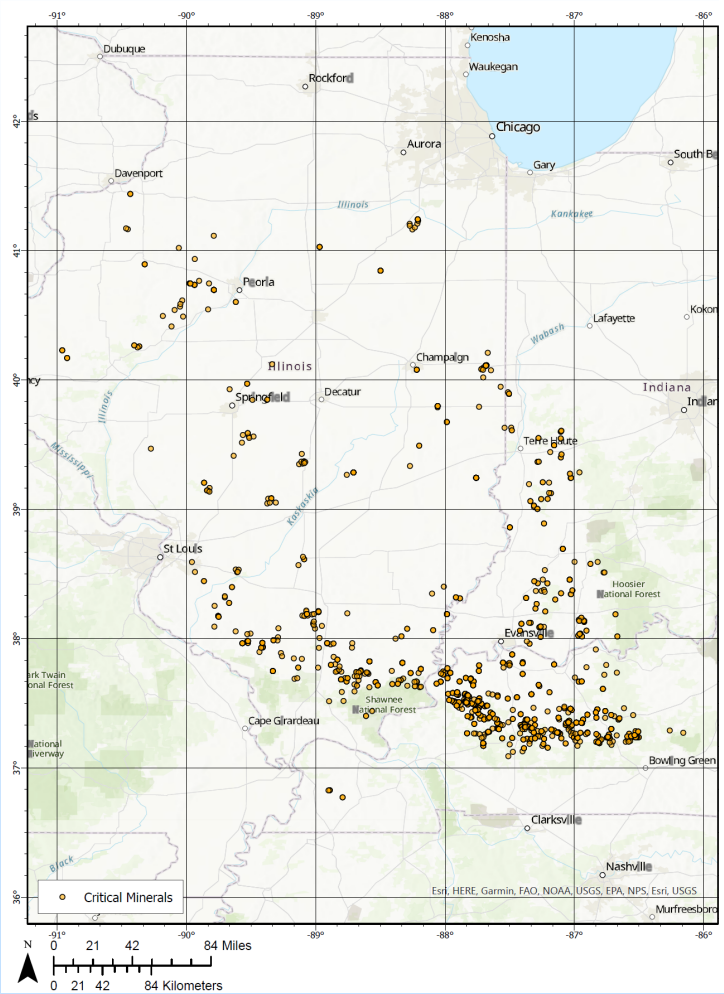
^Map showing the location of historical and active coal mines and coal preparation plants in the Illinois basin.

Critical Minerals and Rare Earth Elements

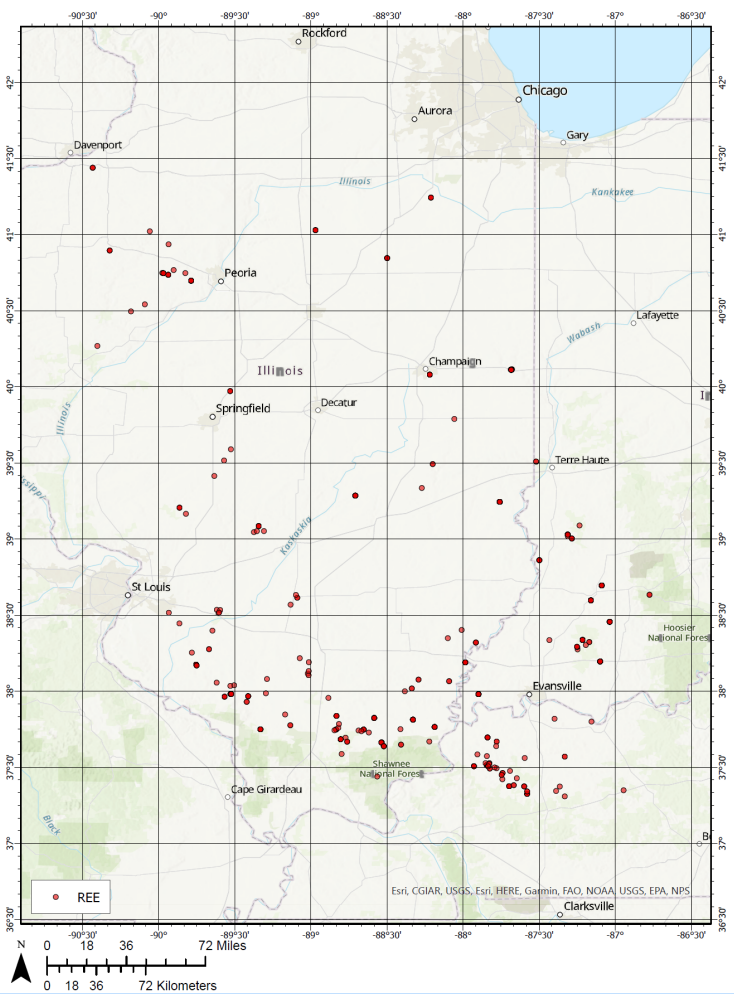
Illinois Basin CORE-CM

REE data based on :

- 363 whole-rock basis raw coal samples
- 116 full channel raw coal samples of all whole-rock basis samples
- 273 ash-basis raw and clean coal samples
- Coal waste data from Kolker et al. (2021), Lefticariu et al. (2020)



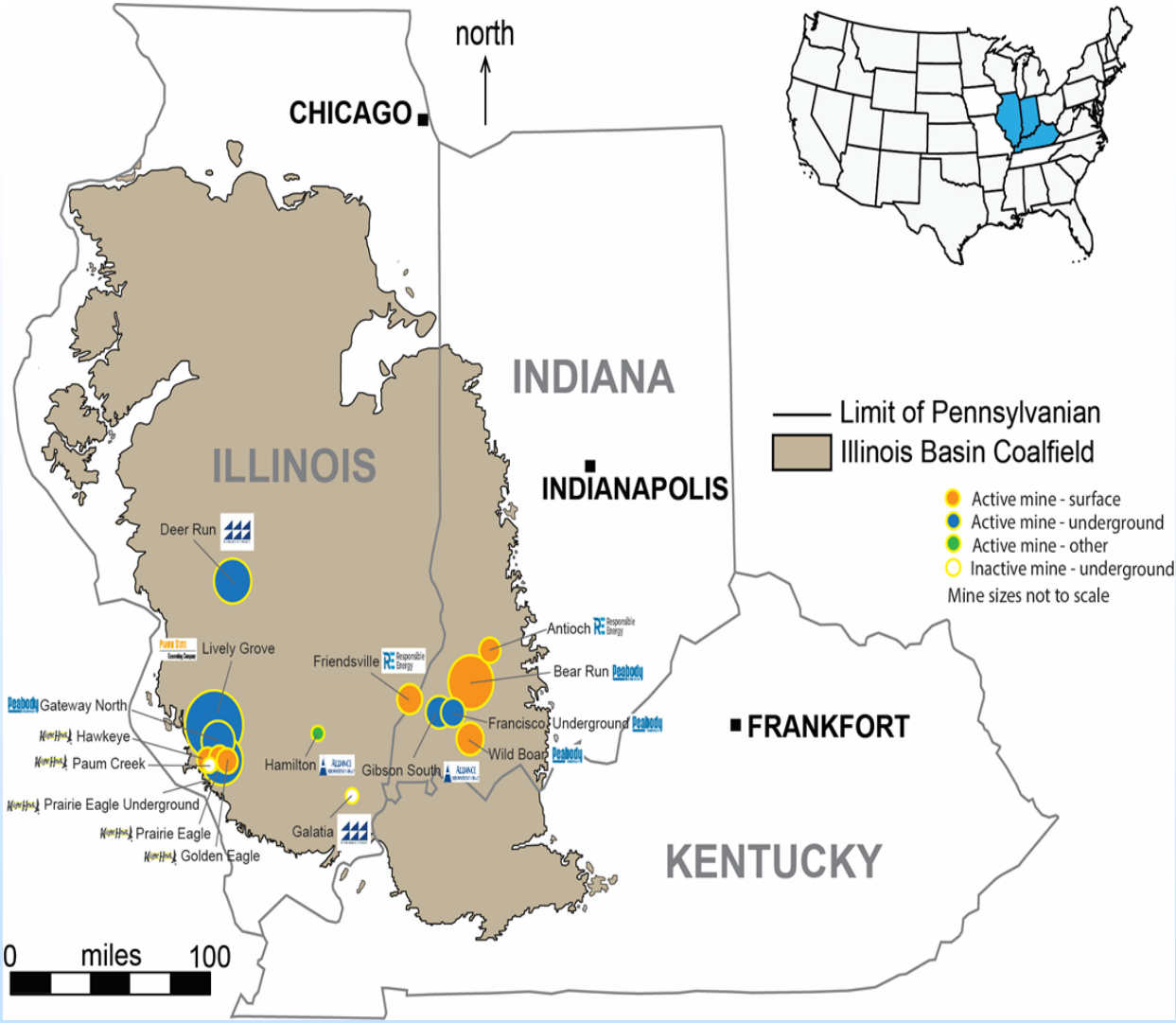
^Map showing the location of Critical Mineral data in the Illinois basin.



^Map showing the location of REE data in the Illinois basin

Data Acquisition

- 30 active coal sites on 51 coal mines and coal preparation plants were investigated for REE resource assessment
- sampling strategy focused on the stratigraphy, spatial distribution, analytical gaps, active production, and existing technologies
- new samples included core coal, seam floor and roof rocks, and partings of most extensively mined coals



^Map showing the previously analyzed coals and coal wastes from active coal mines and coal preparation plants in the Illinois basin.

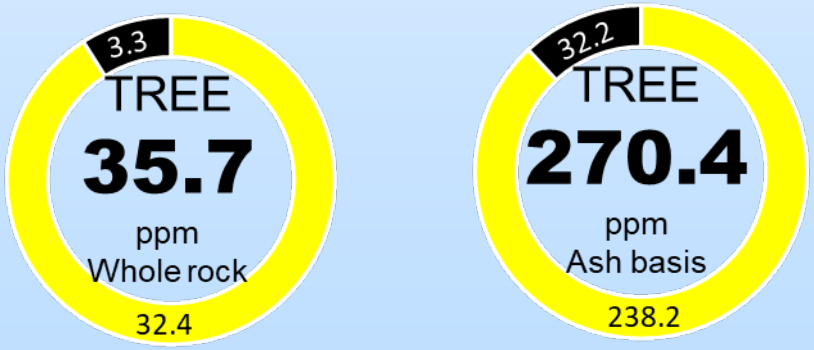
PRAIRIE STATE Generating Company · Peabody ENERGY · ALLIANCE RESOURCE PARTNERS, LP · KnightHawk · FORESIGHT ENERGY · RE Responsible Energy

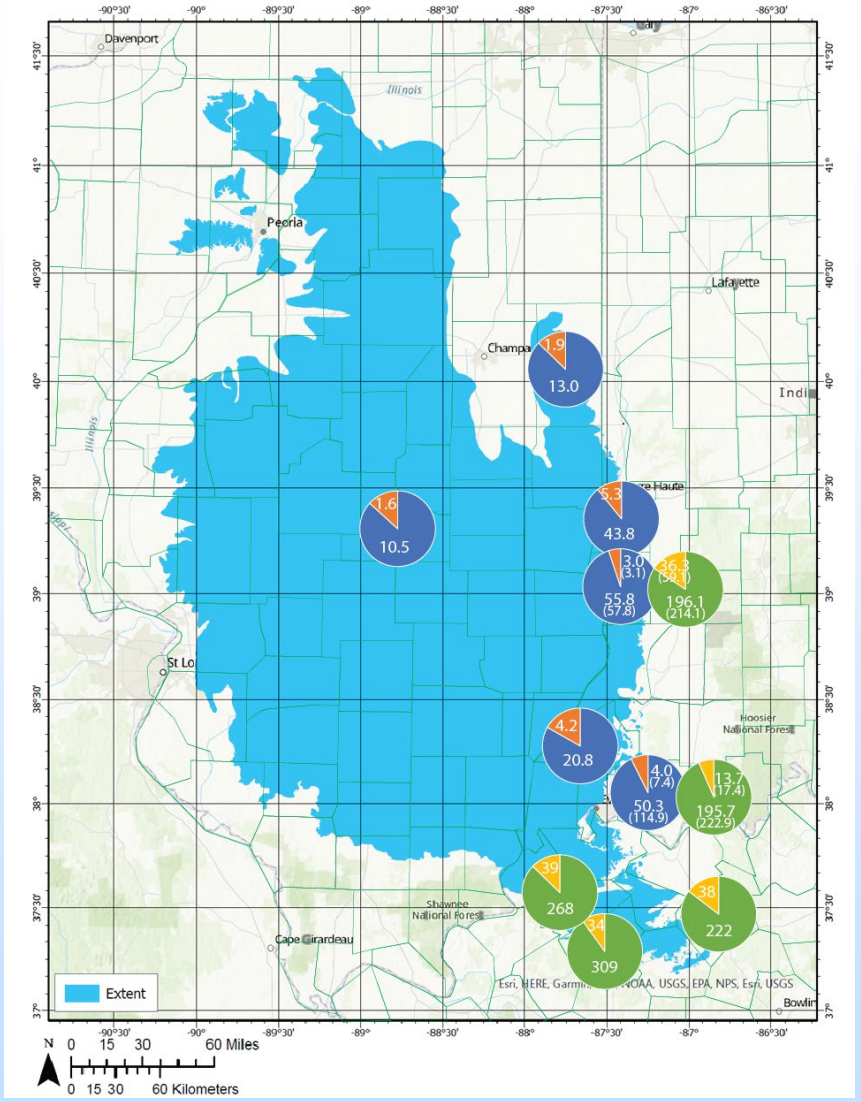
Danville Coal (IL no.7, IN no.7)/Baker Coal (WKY no.13)

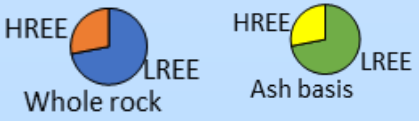
The Danville Coal is part of the Shelburn Formation in Illinois, and the Dugger Formation of the Carbondale Group in Indiana. The coal has been extensively mined in east central Illinois and in the western and southwestern Indiana. In much of the basin, the Danville Coal is thin, generally from a few inches to less than 3.5 feet thick, however, in Indiana, the coal is as much as 6.5 feet thick (Hatch and Affolter, 2002). The Danville Coal in southern Indiana is stratigraphically correlated with an upper bench of the Baker Coal of the Shelburn Formation in western Kentucky (Hatch and Affolter, 2002). The Baker coal is thin across much of western Kentucky but is locally as much as 7 feet thick (Greb et al., 1992; Hatch and Affolter, 2002).

Estimated Remaining Coal Reserves: 40.5 billion short tons (Smith and Brant, 1980; Damberger, 2000).

Rare Earth Element (average)





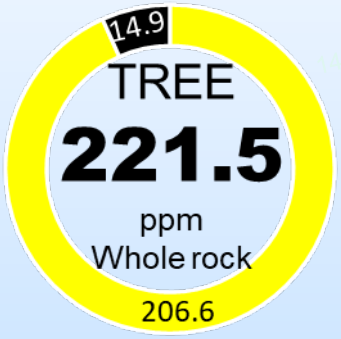


^Map showing the extent of the Danville Coal/Baker Coal and location of REE data in the Illinois basin.

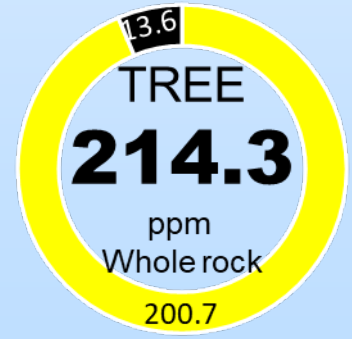
Danville Seam Floor and Roof

The **floor rock of the Danville/Baker coals** consists of underclay or seat earth (rooted mainly of shale, siltstone, or sandstone). The Baker is commonly overlain by gray shale or sandstone. The **roof rock of the Danville Coal** is generally 1-2 feet thick, gray dark fissile shale with very impure limestone, and, locally, gray silty mudstone, or sandstone. Sandstones are part of paleochannels.

Rare Earth Element (average)

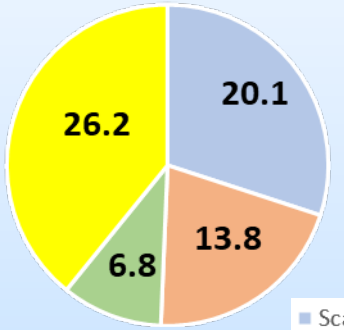


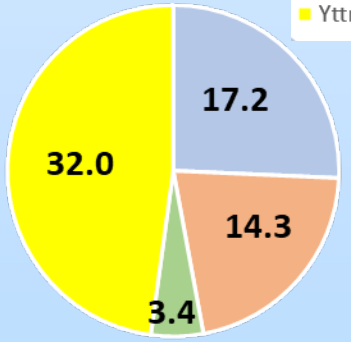
Roof rock



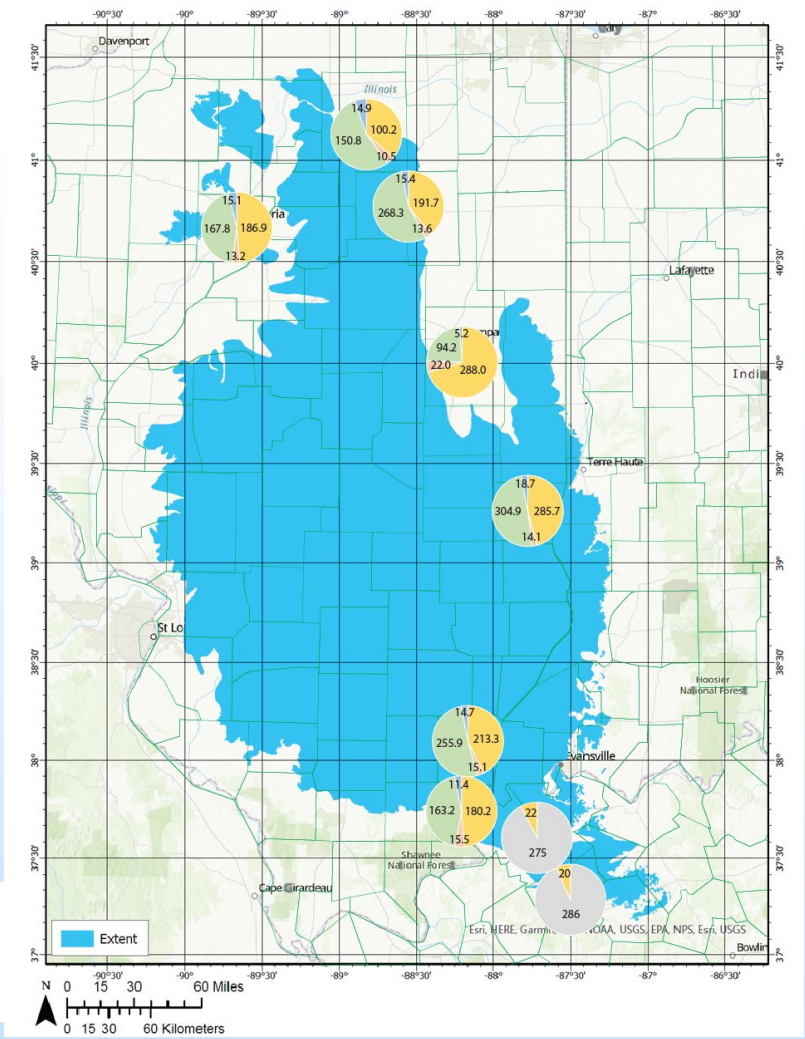
Floor rock

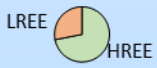
Other Critical Elements (average)





Scandium (ppm)
Thorium (ppm)
Uranium (ppm)
Yttrium (ppm)





Whole Rock

Ash Basis

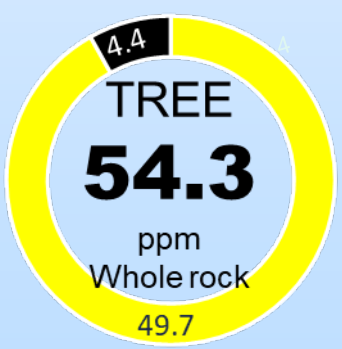
^Map showing the extent of the Danville Coal/Baker Coal and location of REE data in the Illinois basin.

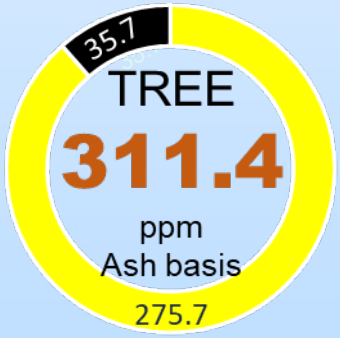
Jamestown Coal (IL), Hymera Coal (IN no.VI) and Paradise Coal (WKY no.12)

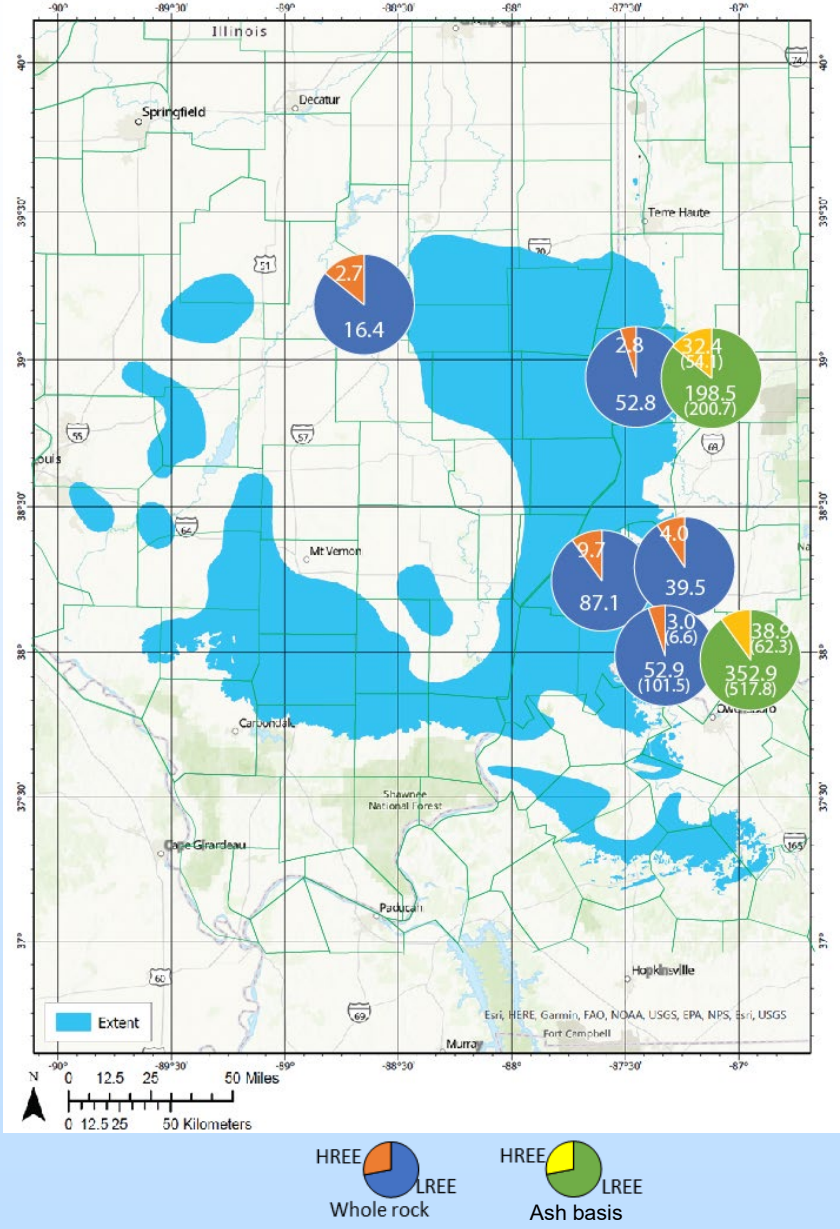
The **Jamestown Coal in Illinois**, the **Hymera Coal in Indiana**, and the **Paradise Coal in western Kentucky** are stratigraphically equivalent (Greb et al., 1992). In Illinois and western Kentucky, the Jamestown and Paradise coals are placed in the Shelburn Formation of the McLeansboro Group. In Indiana, the Hymera Coal is within the Dugger Formation of the Carbondale Group. The Jamestown-Hymera-Paradise coals are commonly 20 to 50 feet below the Danville Coal and 1 to 10 feet above the Herrin Coal. The Jamestown Coal is a thin, widespread coal in southern Illinois, which has never been mined. In Indiana, the Hymera Coal is thicker (as much as 11 feet) and has been extensively mined (Spencer, 1953). The Paradise Coal of western Kentucky is locally thick (as much as 7 feet) and was surface mined along with the underlying Herrin Coal along the southern margin of the basin (Greb et al., 1992)

Estimated Remaining Coal Reserves: 15.7 billion short tons (Spencer, 1953; Smith and Brant, 1980; Damberger, 2000).

Rare Earth Element (average)







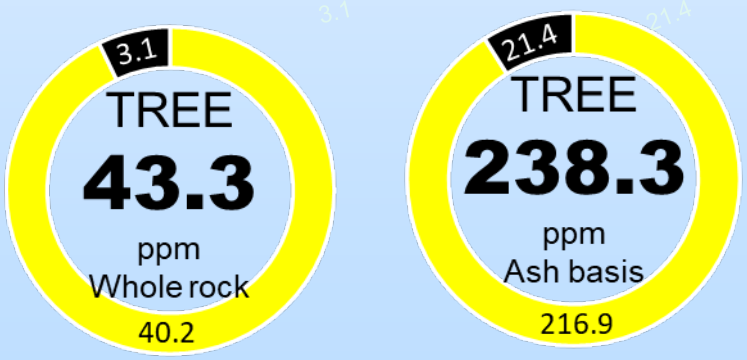
Map showing the extent of the Jamestown Coal/Hymera Coal and location of REE data in the Illinois basin.

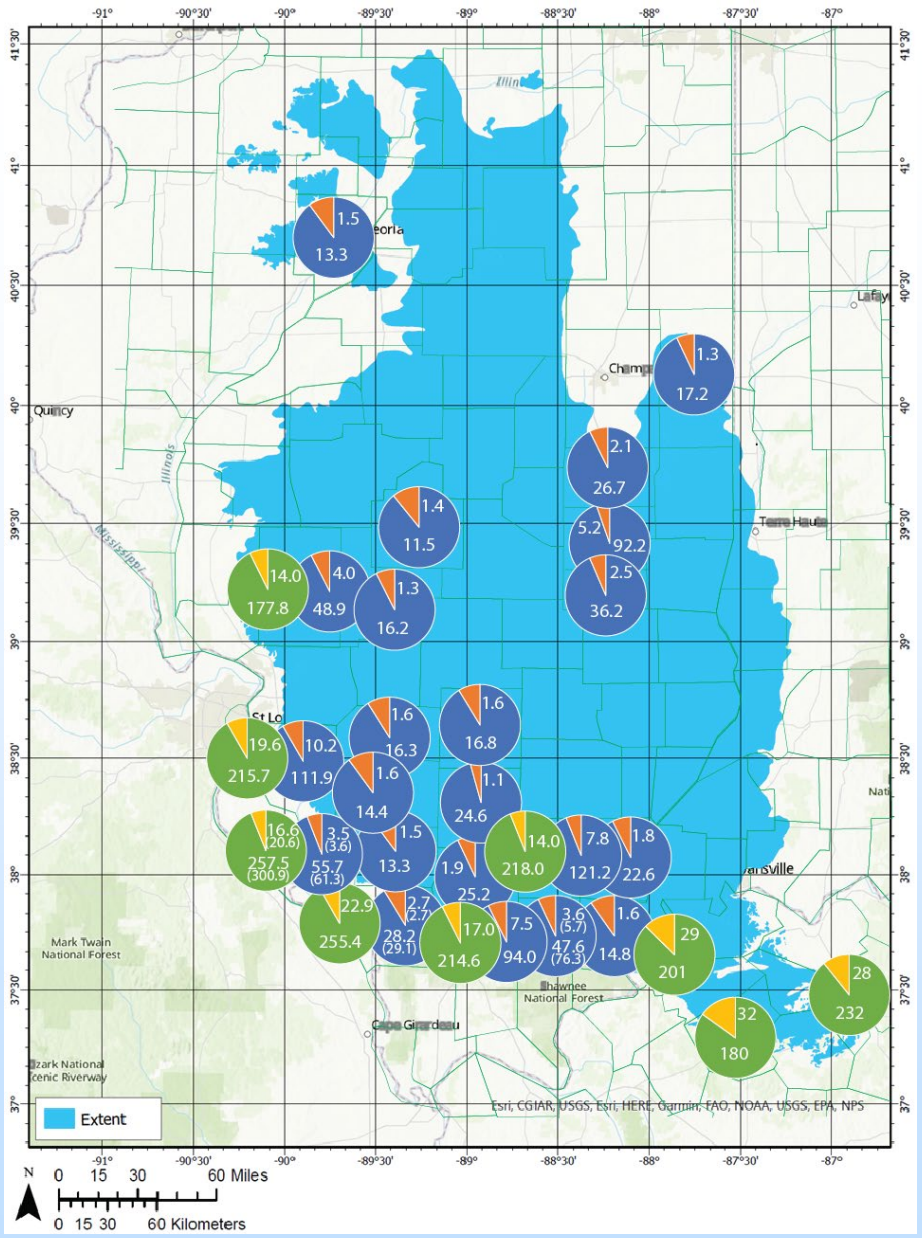
Herrin Coal (IL no.6, WKY no.11)

The **Herrin Coal** is widespread in Illinois and parts of western Kentucky, but not well developed in Indiana. In Indiana, the Herrin Coal has been considered to be a lower bench of the Hymera Coal (Treworgy et al., 1999). The coal is a normal bright-banded coal where it occurs in the basin and commonly a claystone parting called the “Blue Band” in the lower part of the seam (Hopkins and Simon, 1975). In some places, the coal is cut out by the sandstone channels of the Anvil Rock Sandstone (Potter et al., 1961; Nelson, 1983; Greb et al., 2020). Most of the **Herrin Coal** in Illinois is 6 feet thick over extensive areas and locally reaches 15 feet thick just south of Springfield, Illinois. In east-central and extreme northern Illinois Basin, the coal is thin or absent. The coal is also absent across a broad band in western Kentucky but thickens to as much as 10 feet thick along the southern edge of the basin (Weisenfluh, 2011).

Estimated Remaining Coal Reserves: 82 billion short tons (Korose and Elrick, 2010; Weisenfluh, 2011).

Rare Earth Element (average)



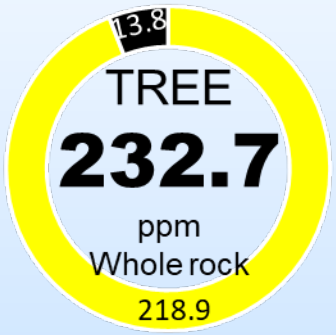


^Map showing the extent of the Herrin Coal and location of REE data in the Illinois basin.

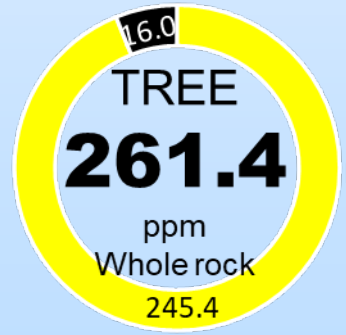
Herrin Seam Floor and Roof

The floor rock of the Herrin Coal is a gray fissile shale seat earth or a green claystone. Underclays are locally thick beneath the coal. The roof rock varies from silty gray shale to black fissile shale of the Anna Shale, to limestone of the Providence (Brereton) Limestone.

Rare Earth Element (average)

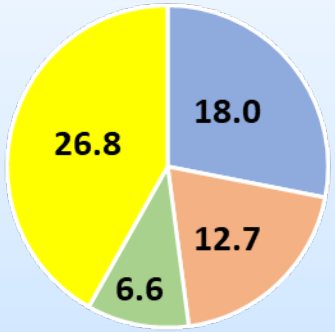


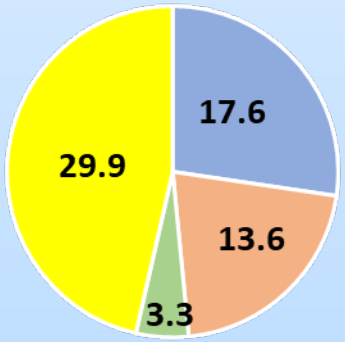
Roof rock



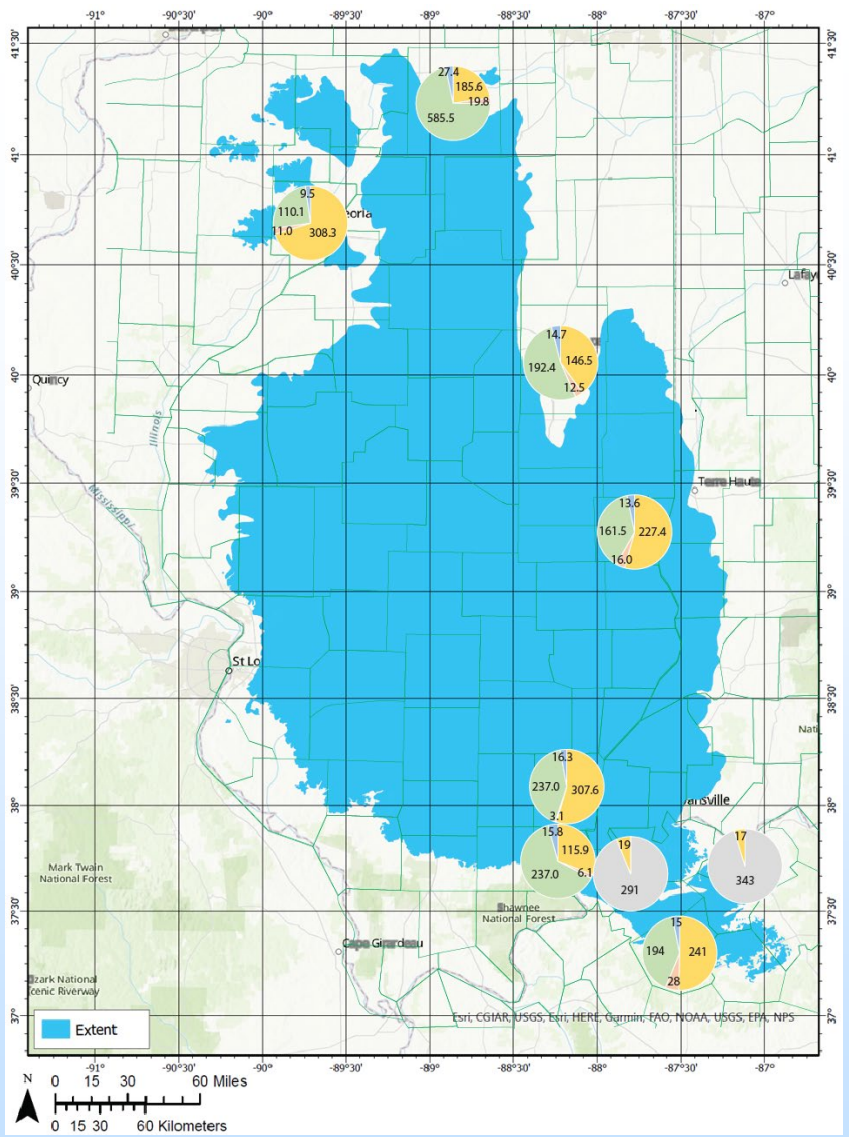
Floor rock

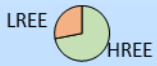
Other Critical Elements (average)





Scandium (ppm)
Thorium (ppm)
Uranium (ppm)
Yttrium (ppm)





Whole rock

Ash basis

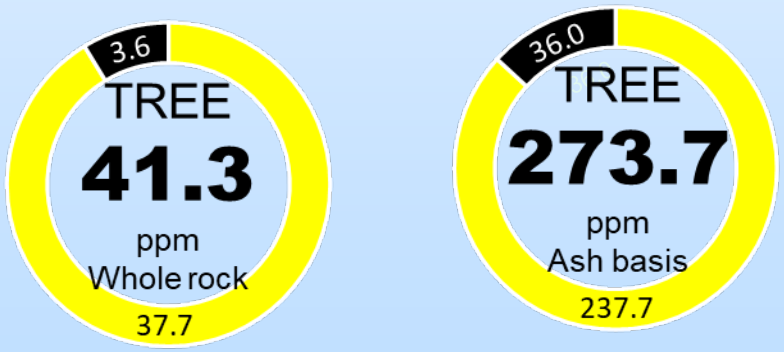
^Map showing the extent of the Herrin Coal and location of REE data in the Illinois basin.

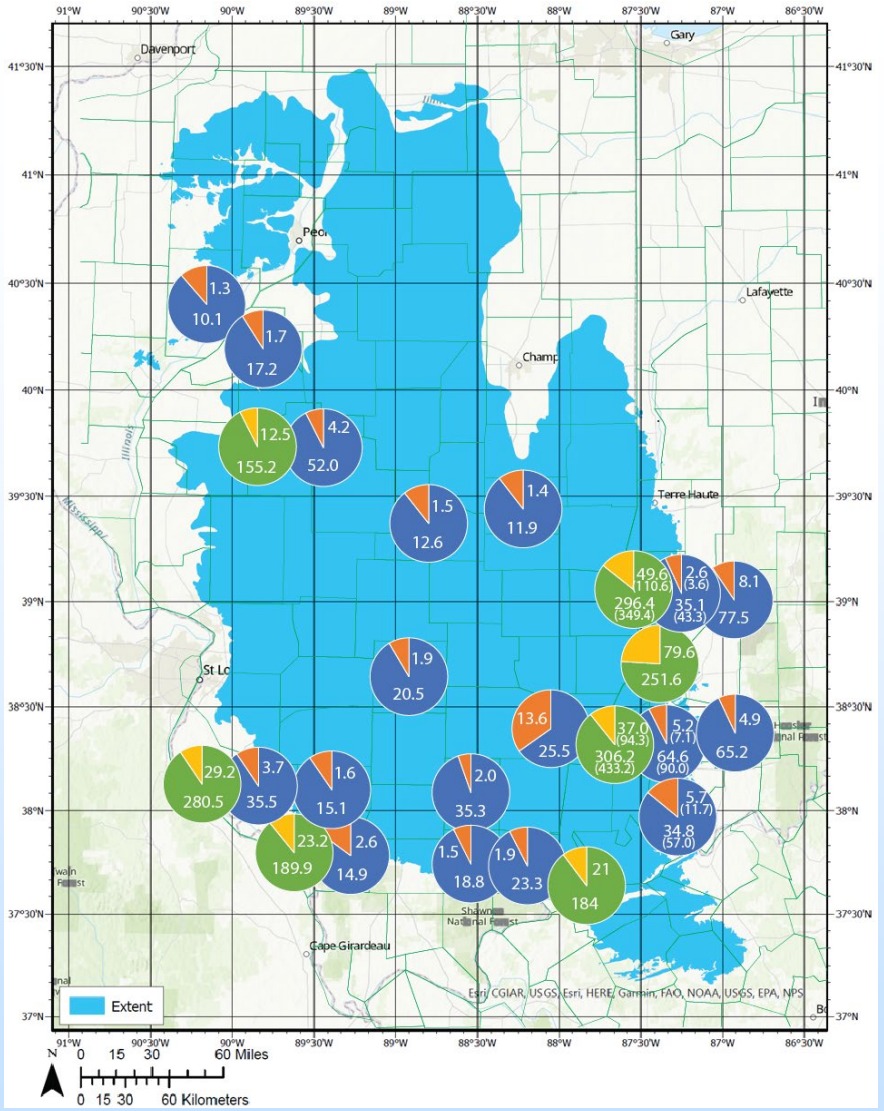
Springfield Coal (IL no.5, IN no.V, WKY no.9)

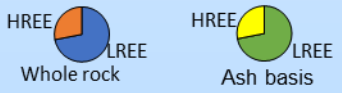
In Illinois and western Kentucky, the **Springfield Coal** is included in the Carbondale Formation, but the Coal in Indiana is within the Petersburg Formation of the Carbondale Group. The coal underlies about two-thirds of Illinois as well as portions of west central Indiana and western Kentucky. The Springfield Coal has actively been mined in the basin for more than 100 years. Its thickness is usually between 4.5 and 6 feet. However, the coal has variable thickness along paleochannels. In Indiana, the coal locally reaches 13 feet thick along the Galatia paleochannel. The coal is also cutout by paleochannels in parts of Illinois and Indiana (Hopkins, 1968; Bear and Williamson, 1979; Eggert, 1982, 1984; Greb et al., 2020; Nelson et al., 2020). The coal is thin or absent in the southwestern and extreme northern portions of the basin.

Estimated Remaining Coal Reserves: 82 billion short tons (Hatch and Affolter, 2002; Korose and Elrick, 2010; Weiselfluh, 2010).

Rare Earth Element (average)





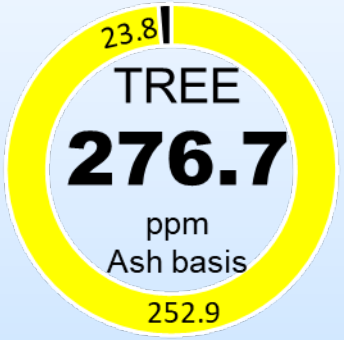


^Map showing the extent of the Springfield Coal and location of REE data in the Illinois basin.

Springfield Seam Floor and Roof

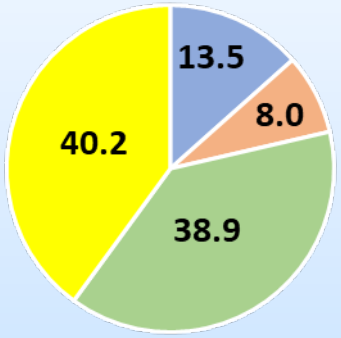
The Springfield Coal is normally overlain by a 6 to 24 inches of black, fissile shale, termed the Turner Mine Shale Member, but in some places extending from Saline County (IL) to Gibson County (IN), a silty gray shale or sandstone, i.e., the Galatia paleochannel system, directly overlies the coal. The coal is locally split and cutout along the Galatia paleochannel in Illinois and cutout by the Henderson paleochannel in Kentucky (Hatch and Affolter, 2012). Floor rocks generally consist of a seat-earth or underclay. Underclay's are locally thick beneath the Springfield Coal.

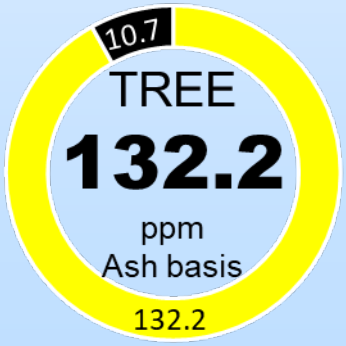
Rare Earth Element (average)



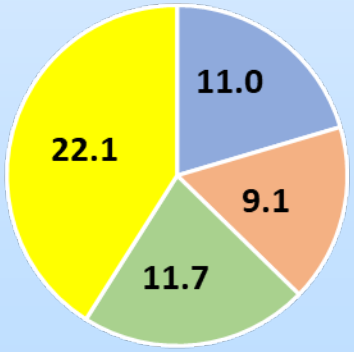
Roof rock

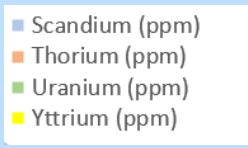
Other Critical Elements (average)

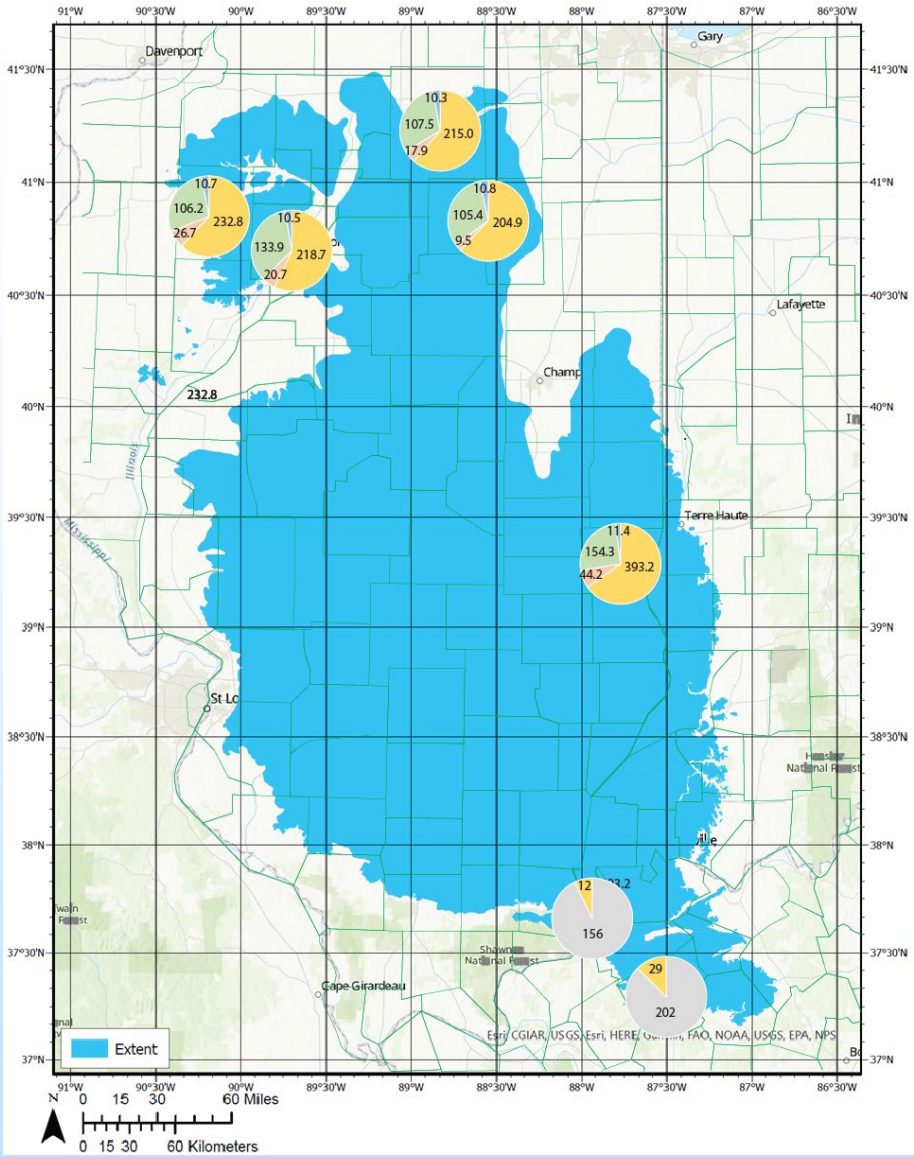


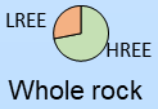


Floor rock









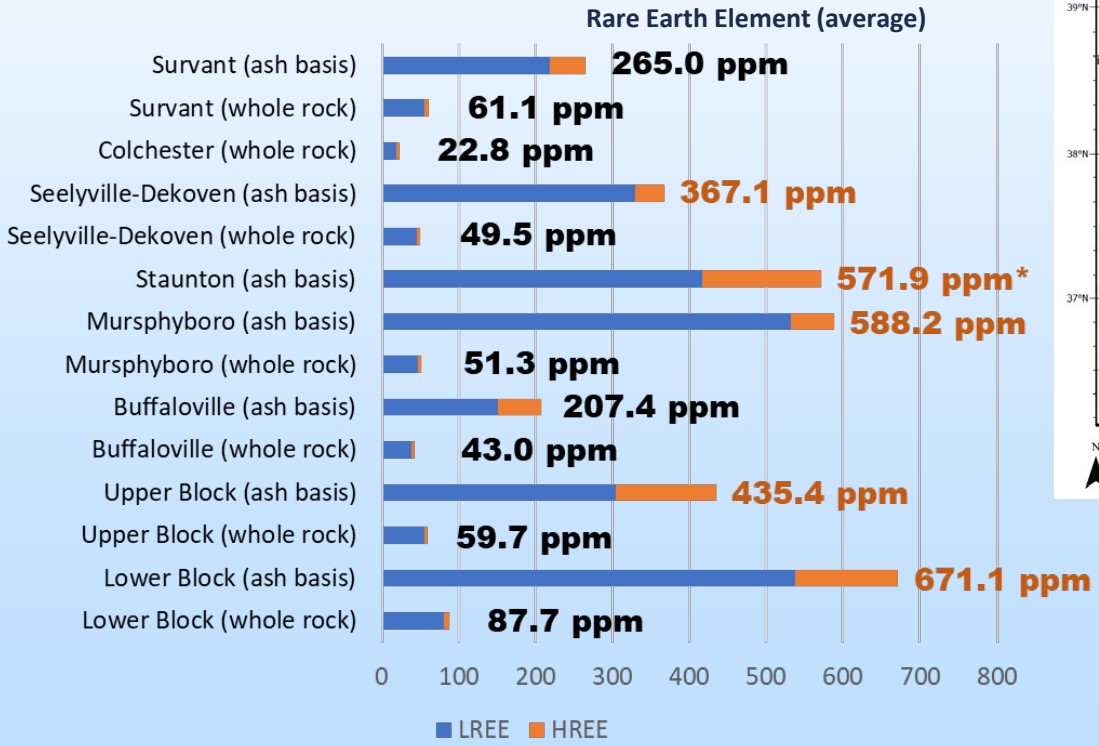
Whole rock

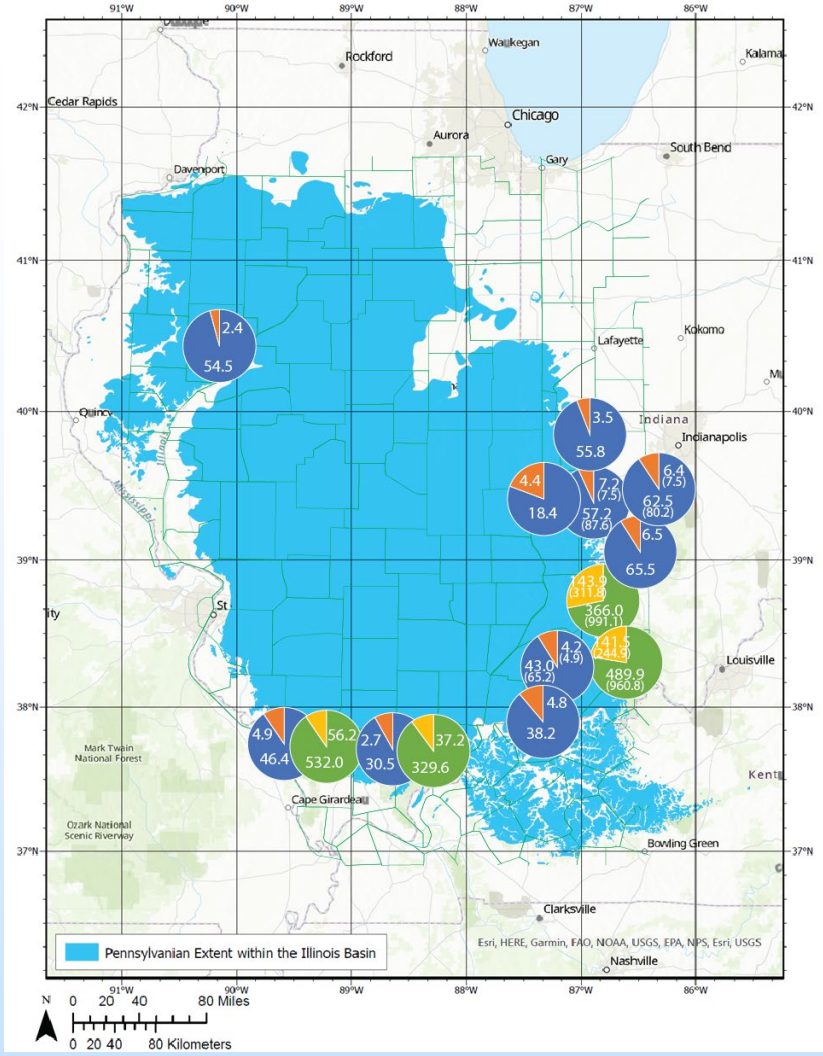
Ash basis

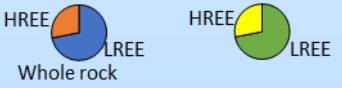
^Map showing the extent of the Springfield Coal and location of REE data in the Illinois basin.

Carbondale Fm/Gp and Tradewater Fm Coals

Many coals occur in Pennsylvanian strata beneath the lower part of the Carbondale Formation (Illinois and western Kentucky) or Group (Indiana) that includes the **Survant, Colchester, and Davis-Dekoven-Seelyville coals**. Coals of the Tradewater (Illinois and western Kentucky) and Brazil (Indiana) Formations are generally less extensive and have fewer resources than the coal beds in the overlying Carbondale Formation/Group. Most economically coal seams are the **Murphysboro, Rock Island, Buffaloville, Upper and Lower Block Coals**.





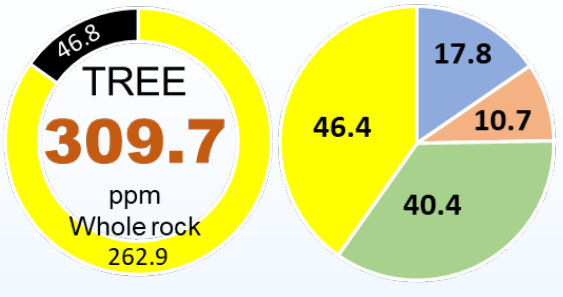


^Map showing the extent of the Pennsylvanian Coal and location of REE data in the Illinois basin.

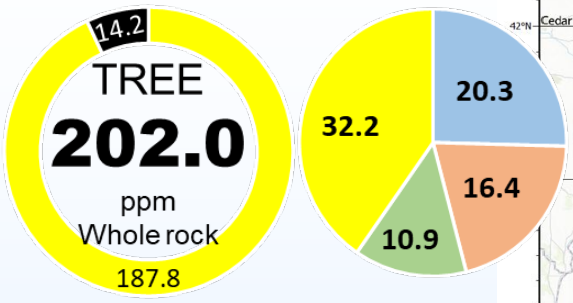
*1,302 ppm (LREE: 991.1 ppm, HREE: 311.8 ppm) (Antioch Mine, Indiana)

Roof and Floor of the Colchester Coal

Mecca Quarry Shale

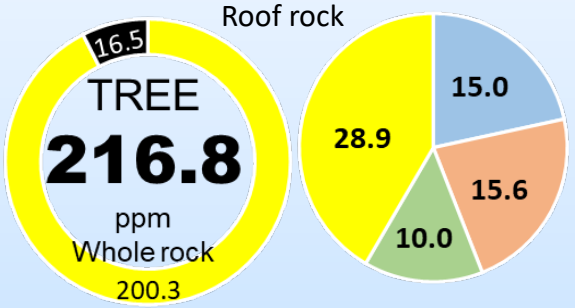


Floor rock

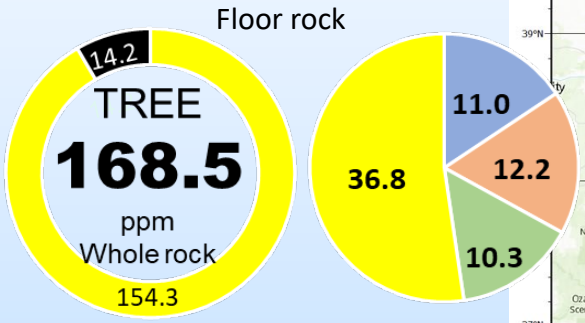


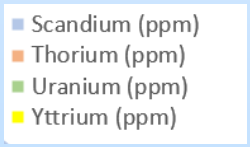
Roof and Floor of the Seelyville-Dekoven Coal

Roof rock

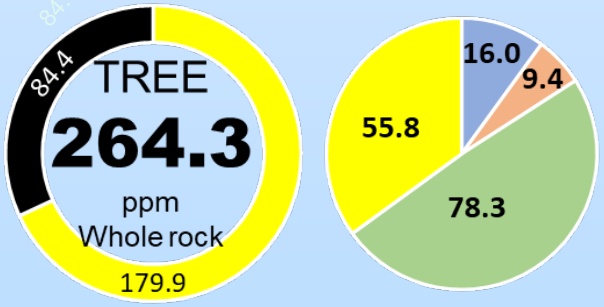


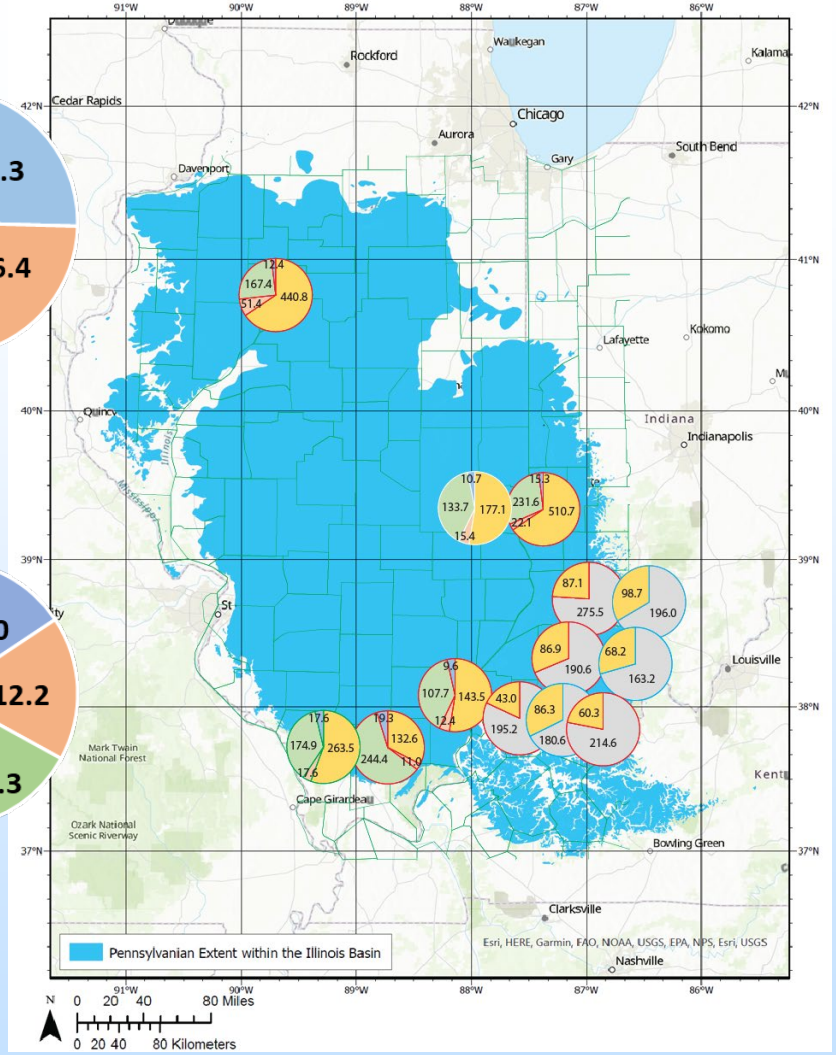
Floor rock





Excello Shale





Whole rock

Ash basis

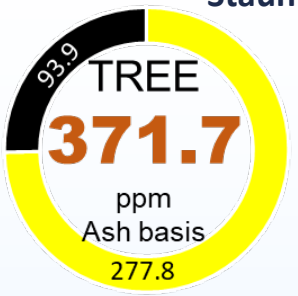
^Map showing the extent of the Pennsylvanian Coal and location of REE data in the Illinois basin.

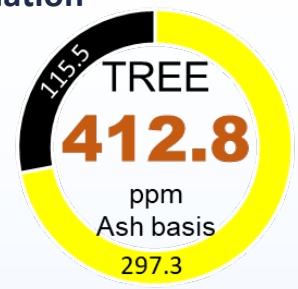
REE and Critical Minerals (average)

Carrie Mills Shale

Veale Shale

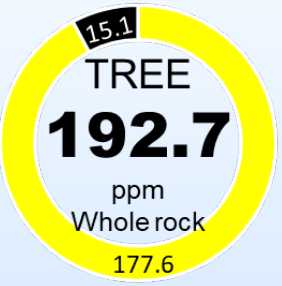
Staunton Formation

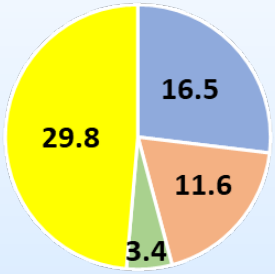




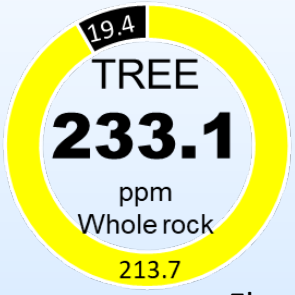
Scandium (ppm)
Thorium (ppm)
Uranium (ppm)
Yttrium (ppm)

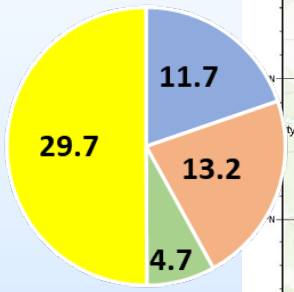
Roof and Floor of the Murphysboro Coal





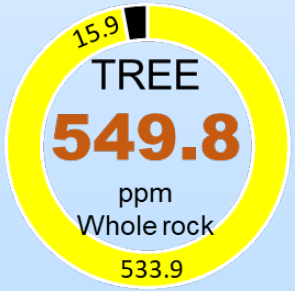
Roof rock

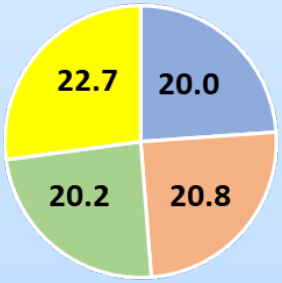




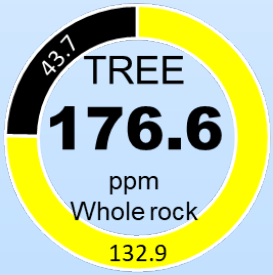
Floor rock

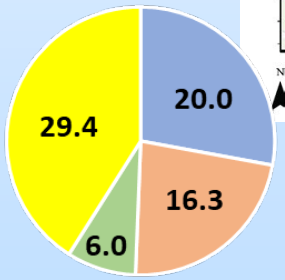
Roof and Floor of the Rock Island Coal



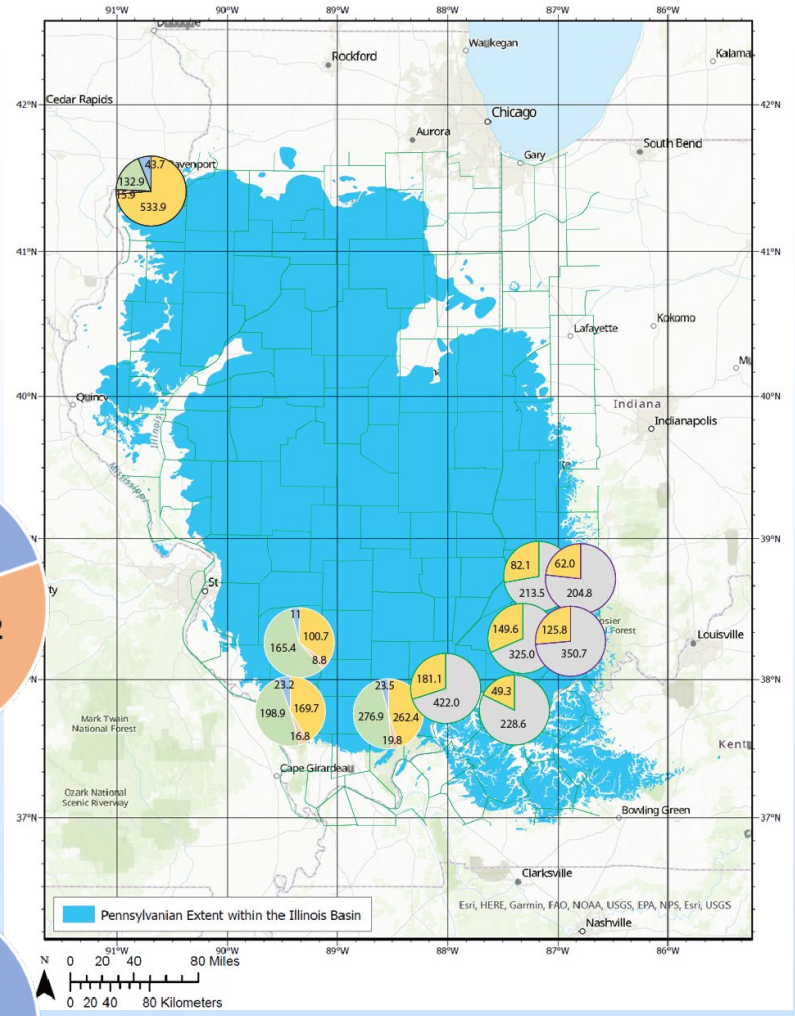


Roof rock





Floor rock



Whole rock

Ash basis

^Map showing the extent of the Pennsylvanian Coal and location of REE data in the Illinois basin.

REE and Critical Minerals (average)

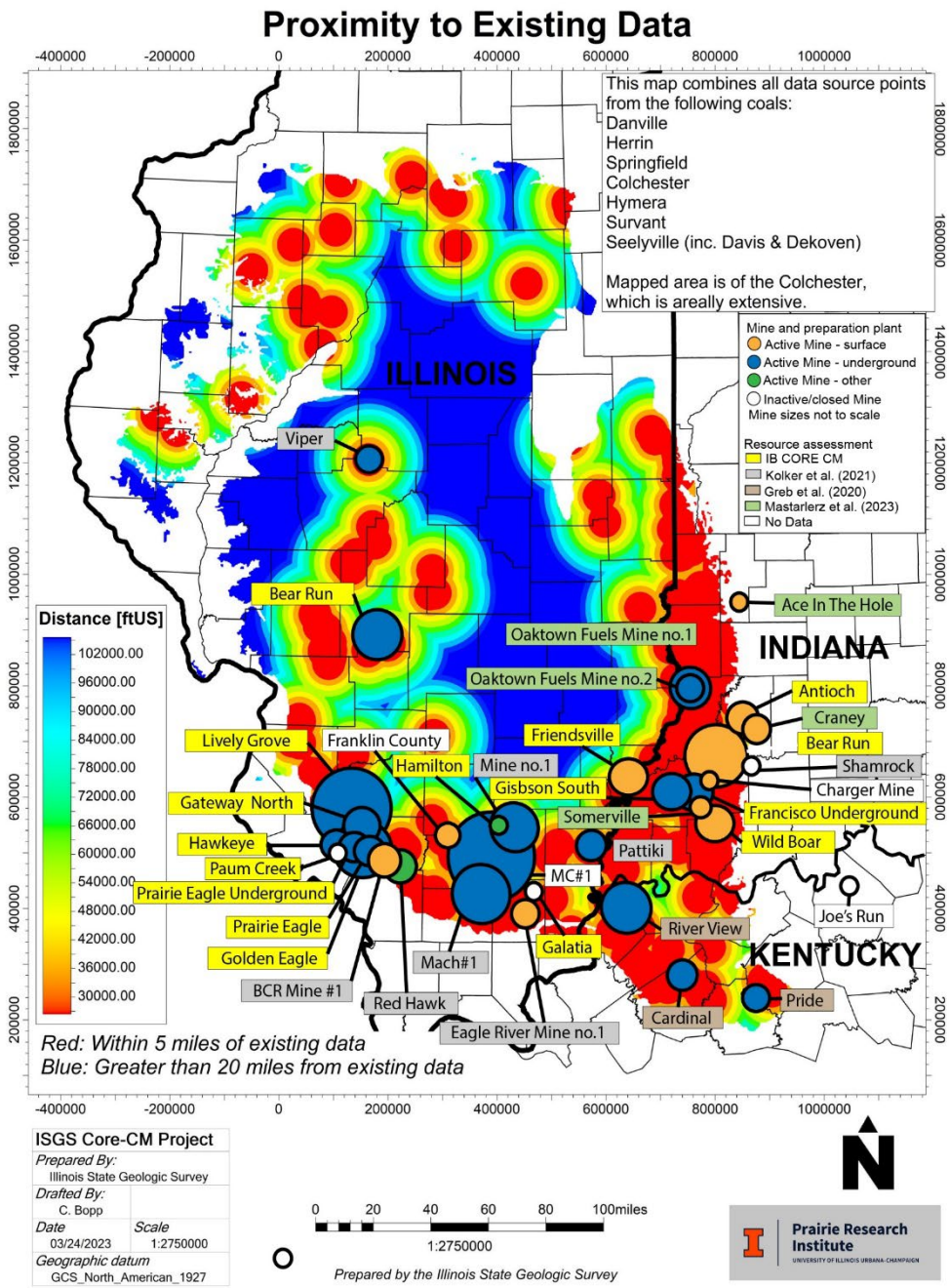
Gap Analysis

- Illinois Basin has 51 active coal mines and coal preparation plants, and numerous associated gobs and slurry ponds, 67 abandoned or inactive AMD sites, and 186 identified coal ash impoundments.

- Largest spatial distribution of existing data in SE Illinois

- IB CORE-CM sampling focused on a systematic collection of detailed raw coal, clean coal, partings, seam floor and roof rocks, fine (slurry) and coarse refuse coals.

> Map showing the extent of the Pennsylvanian Coal location of active Coal mines and Coal preparation plants in the Illinois basin, and extent of data.

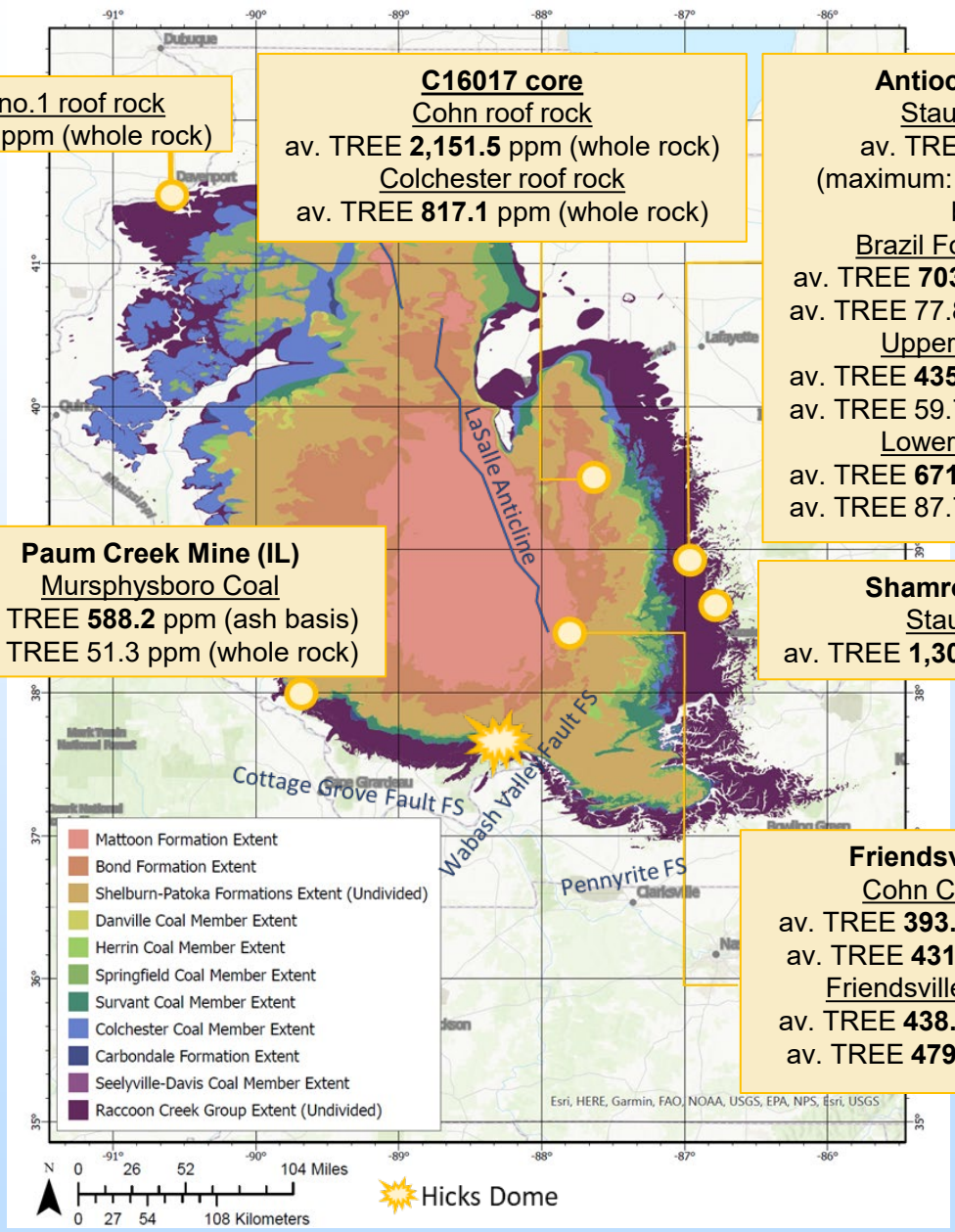


Summary

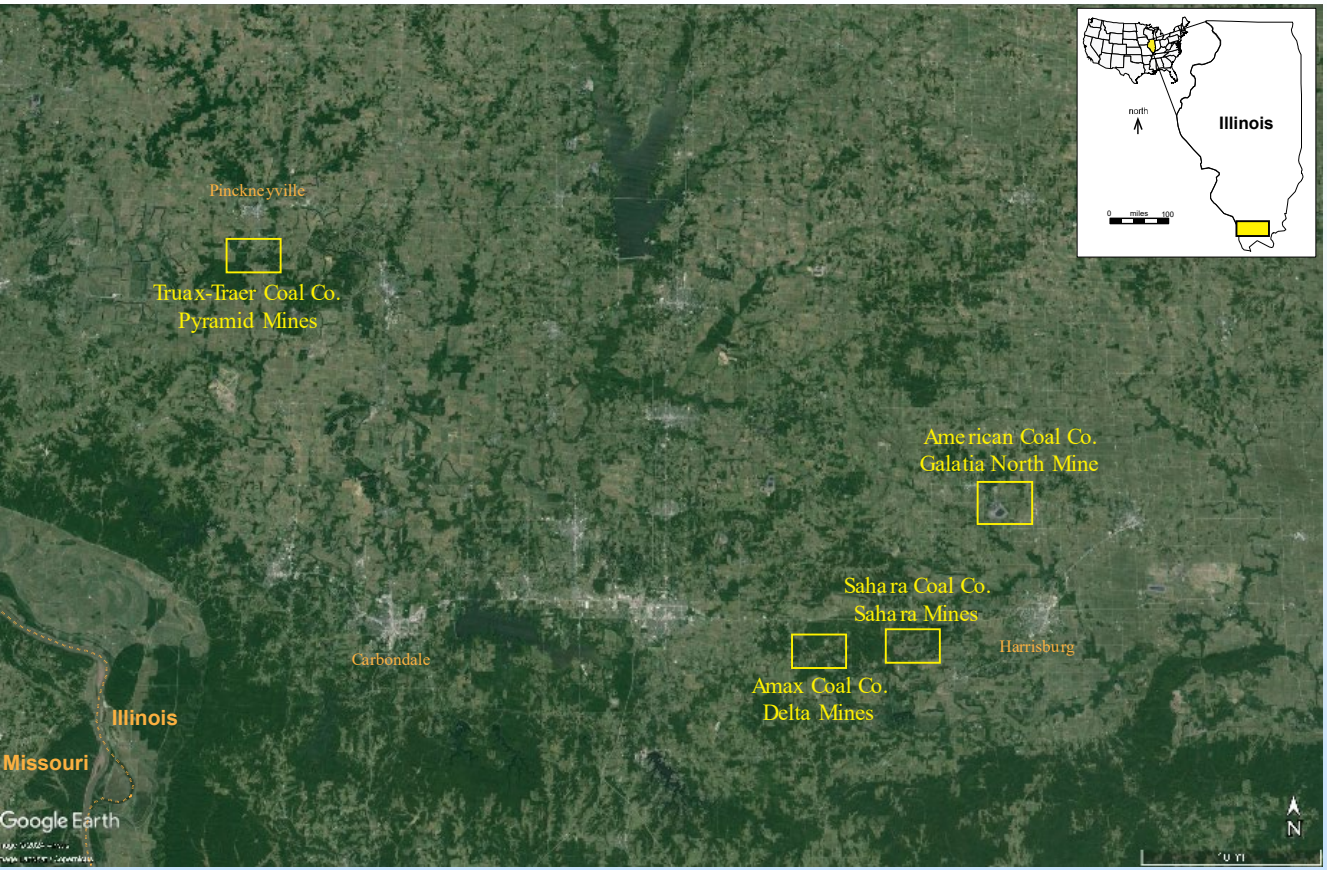
- The highest TREE (whole-rock) roof rocks with values more than 400 ppm.
- The highest TREE concentrations (ash-basis) Lower and Upper Blocks, Staunton, and Brazil Formation Coal in Indiana with values between 435.4 and 1,302.9 ppm.

Recommendations

- Understand why the high TREE concentrations are located on the Basin Margin
- Influence of the detrital materials (margin, Galatia Channel, etc.) Study the possible influence of hydrothermal alteration from tectonic structures (anticlines, synclines, faults, Hicks Dome).
- Understand the connection between type of deposition and REE contents.



Supplemental Characterization Funding



^Map showing the locations of IB CORE-CM drilling

- 6-month extension to further implement a sampling and characterization program
- Drilling campaign in old and inactive coal mine sites. Sites selection based on volume of coal waste, coal seams, and production age
- Core samples will be analyzed for geochemistry, carbon, and mineralogy to update and build models on coal waste resources and potential economic viability

Illinois Basin CORE-CM

Illinois Basin CORE-CM

Sahara North Mountain#1
N37.713244°
W088.676679°
Depth: 40 feet
(recovery 91%)
40 samples
(interval: 1')

Sahara North Mountain#2
N37.714108°
W088.675854°
Depth: 40 feet
(recovery 87%)
40 samples
(interval: 1')

Sahara South#1
N37.704188°
W088.687998°
Depth: 40 feet
(recovery 75%)
40 samples
(interval: 1')

Sahara Office Park#1
N37.706016°
W088.669397°
Depth: 40 feet
(recovery 95%)
40 samples
(interval: 1')

Sahara Office Park#2
N37.703547°
W088.669969°
Depth: 40 feet
(recovery 79%)
40 samples
(interval: 1')

Illinois Basin CORE-CM

Galatia North Mine

Illinois Basin
CORE-CM


Galatia Mine Coal Waste#1
Galatia Mine Coal Waste#2
TERRASONIC


Galatia Mine Coal Waste#1


Galatia Mine Coal Waste#2


Galatia Mine Coal Waste#3

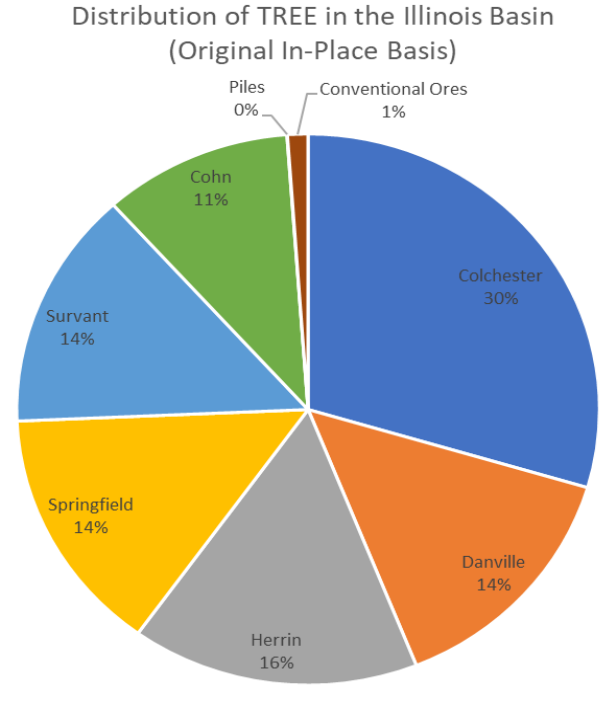

Galatia Mine Coal Waste#3

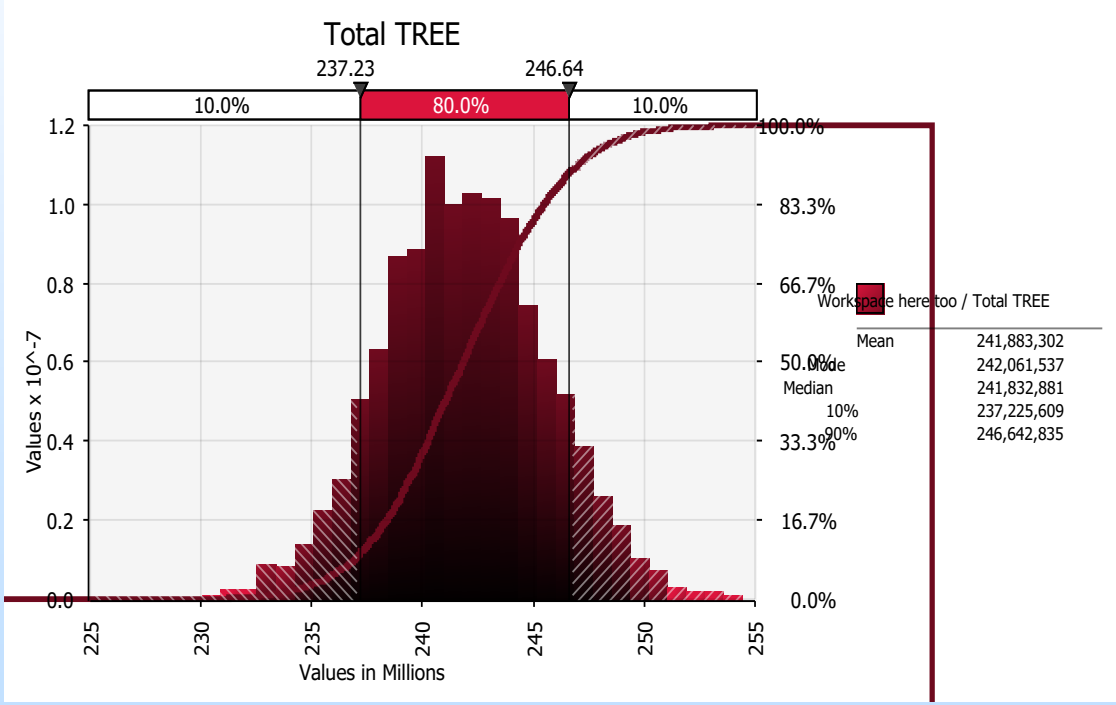

Galatia North Mine Pile
Galatia North Mine Preparation Plant
Galatia North Mine Pile

Probabilistic Resource Model

Total REE Originally In-Place

- Includes most prospective basin-wide and regional coal seams, mine waste piles, & identified conventional deposits
- Total of ≈240 million elemental short tons



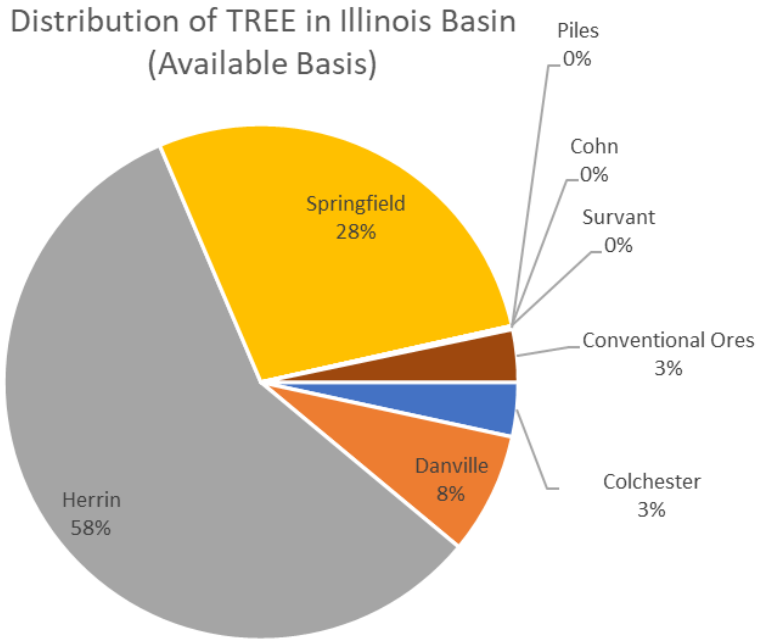


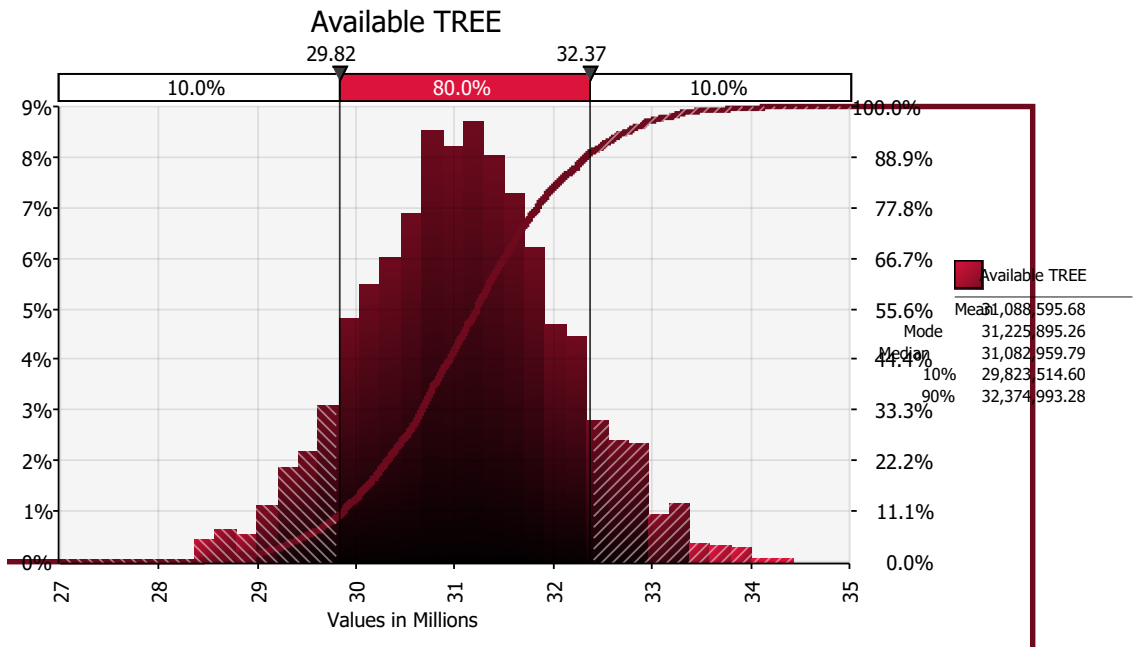
Illinois Basin CORE-CM

Models prepared by C. Bopp, Illinois State Geological Survey

Total REE in Available Resources

- Includes all sources originally in-place assessment
  - Cohn and Survant coal were not evaluated for available resources in legacy studies
  - Mine waste piles and conventional resources available by surface mining are considered “available”
- TREE in available sources: ≈31 million elemental short tons





TREE Distribution Trends in the Illinois Basin Coal Field

- Most coals show relative depletion of TREE in the coal itself vs. floor & ceiling
- Colchester coal (lower Pennsylvanian) is a notable exception:
  - Generally higher TREE compared to other coal seams
  - Near parity between TREE in coal vs. floor & ceiling
- Causes of this difference is an area of active investigation

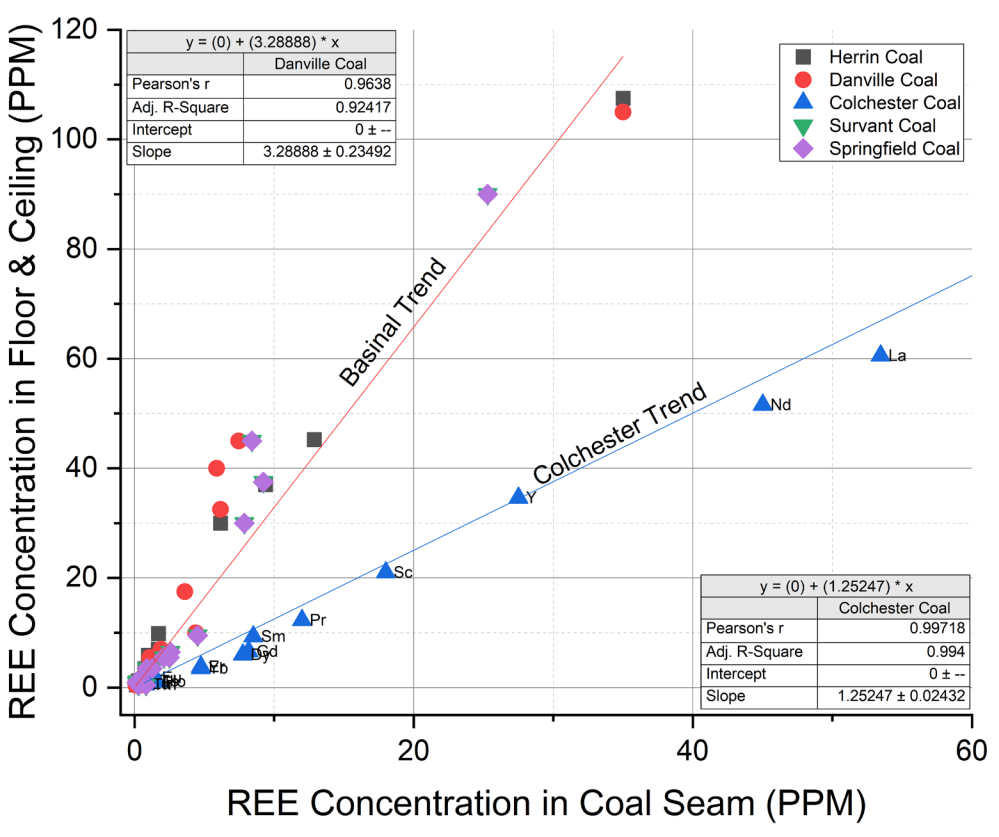
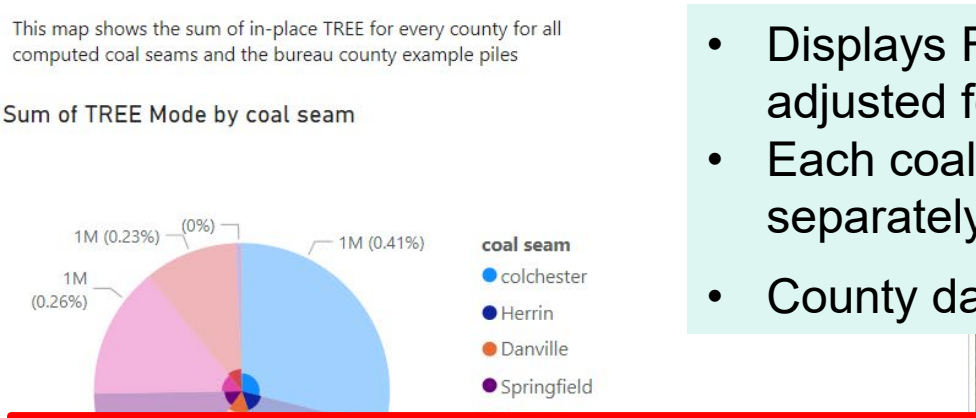
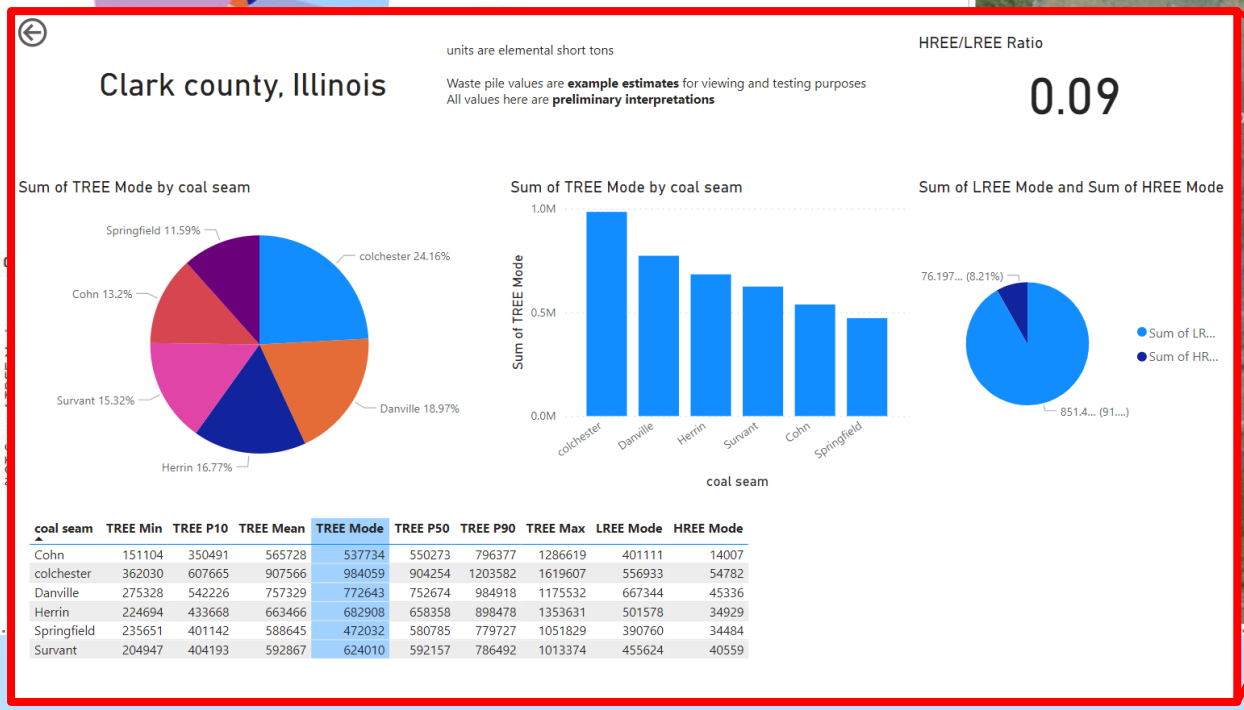


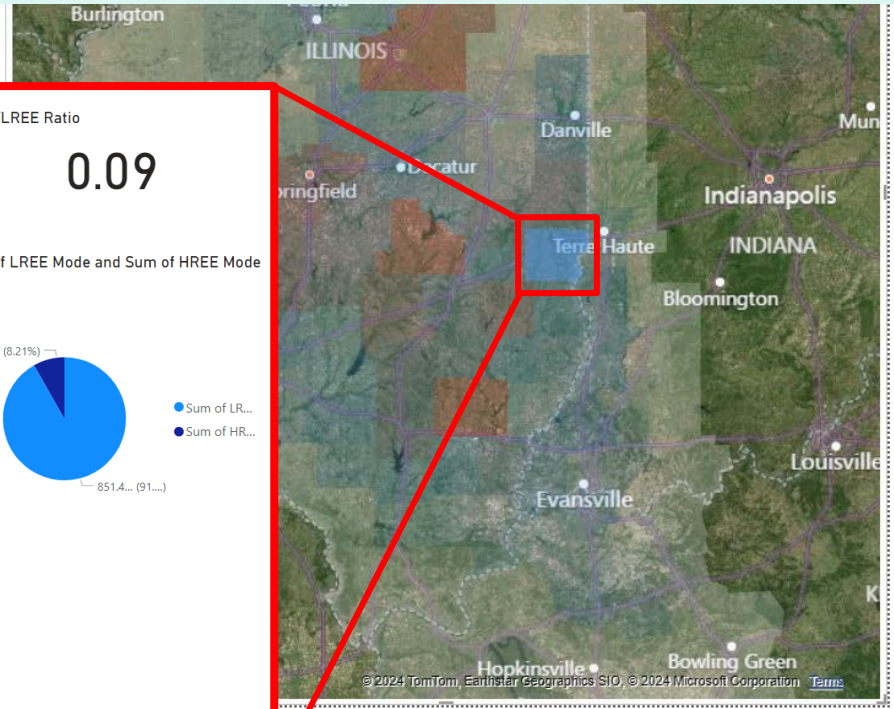
Figure reference:
APPLYING PROBABILISTIC METHODS TO ESTIMATE IN SITU RARE EARTH METAL RESOURCES IN ILLINOIS BASIN COAL SEAMS; Charles Bopp, Franck Delpomdor, Mingyue Yu, and Jared Freiburg; Geological Society of America Abstracts with Programs. Vol. 55, No. 6, 2023

Illinois Basin REE Dashboard



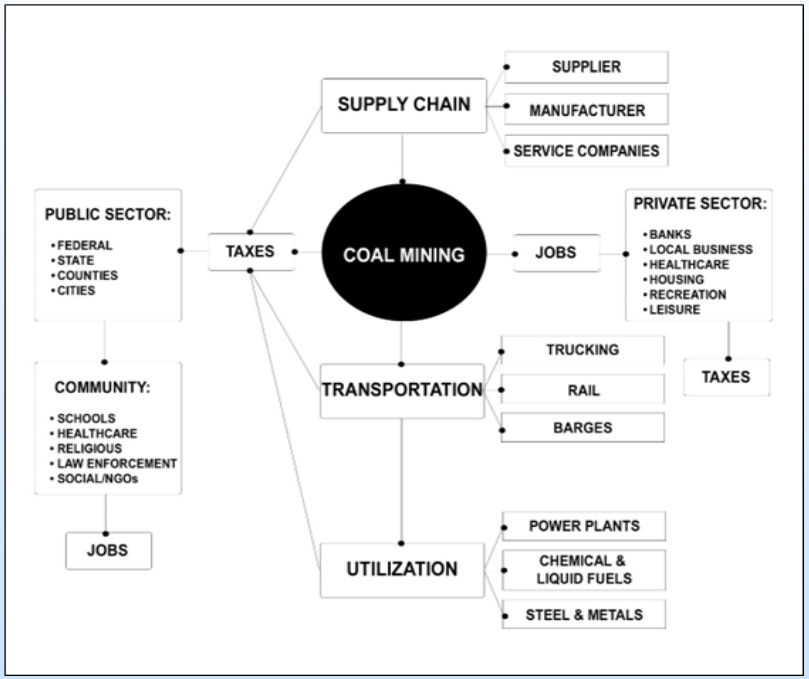
- Displays REE original in-place data and REE adjusted for availability
- Each coal seam/source or county may be called separately
- County data includes tabular, pie, bar chart views

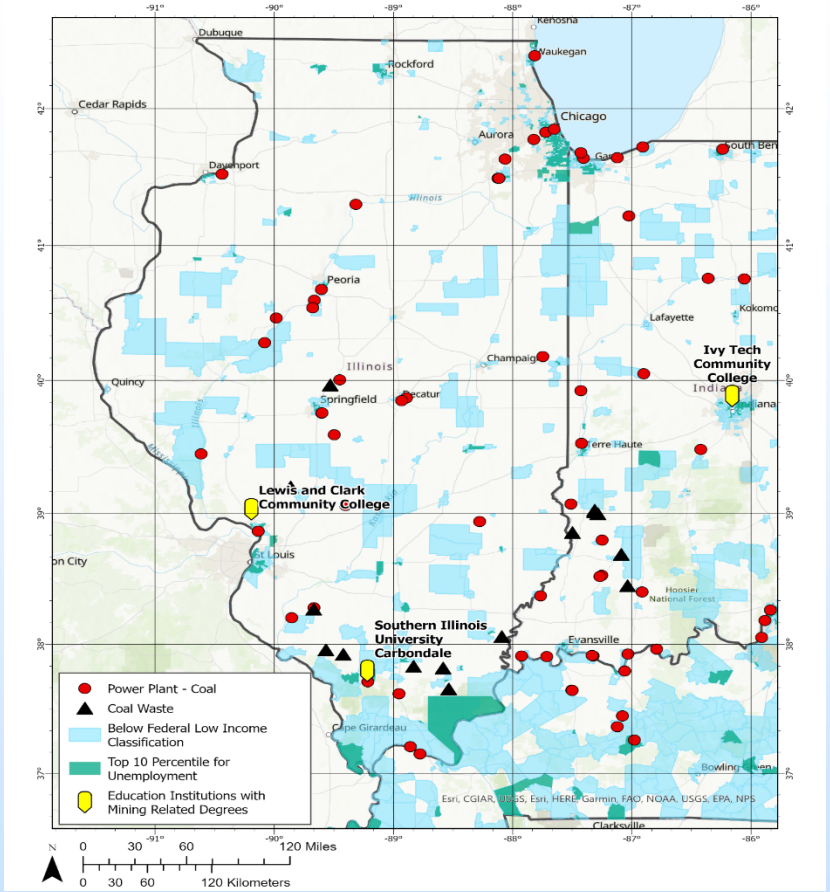




Infrastructure, industries, and businesses (Task 4)

- Coal Industry Ecosystem
- Regional Infrastructure Needs
- Economic Challenges

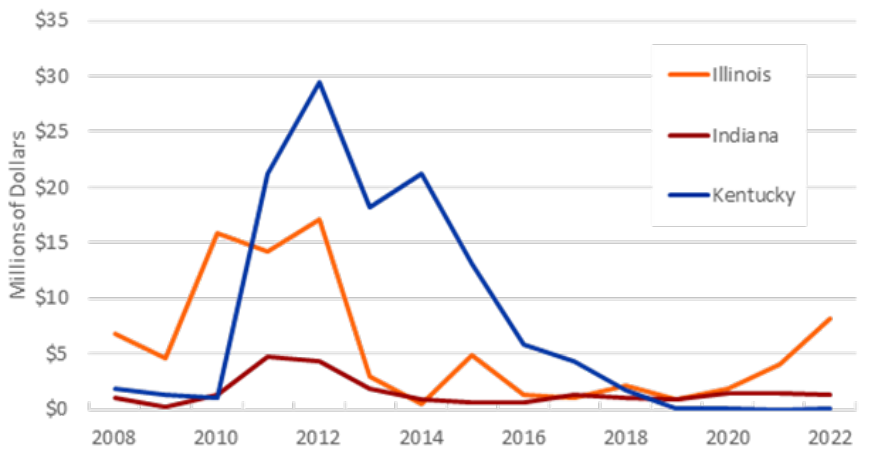


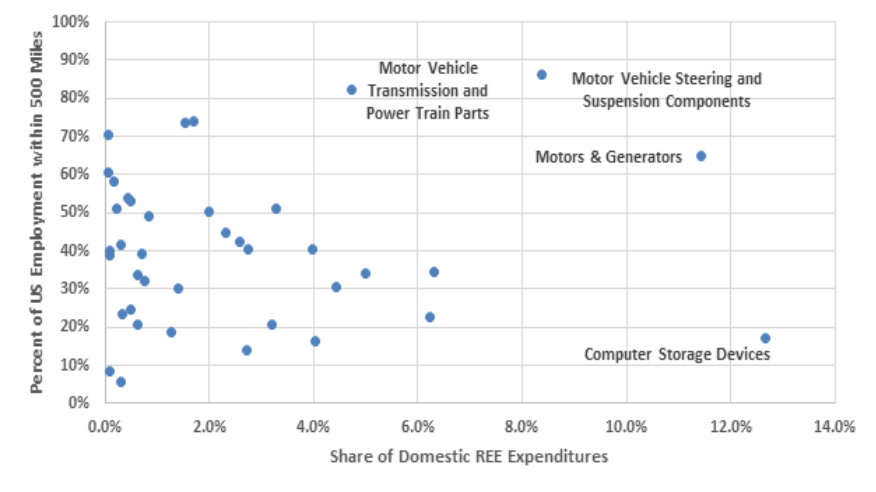


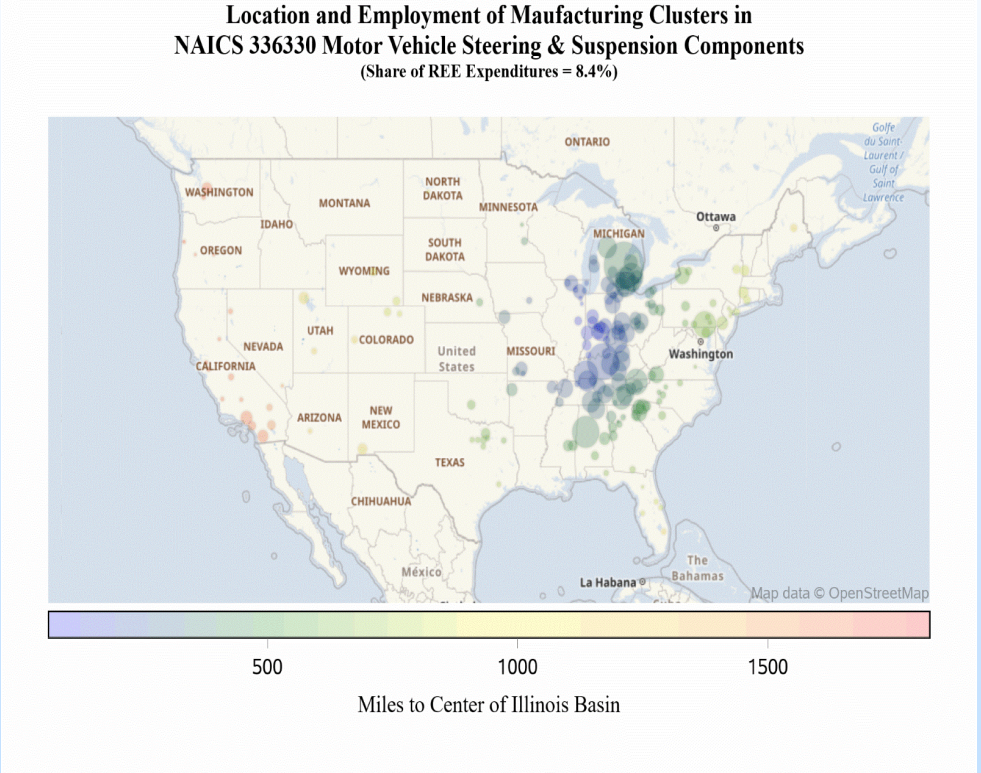
Major & Institution	Associate's	Certificates	Bachelor's	Master's	Doctorate's
Mining & Mineral Engineering					
Southern Illinois University-Carbondale	-	-	2	-	-
University of Kentucky	-	-	19	1	5
Mining & Petroleum Technologies/Technicians					
Ivy Tech Community College (Indiana)	-	7	-	-	-
Lewis and Clark Community College (Illinois)	7	4	-	-	-

In-Depth Supply Chain Assessment and Strategic Development Opportunities

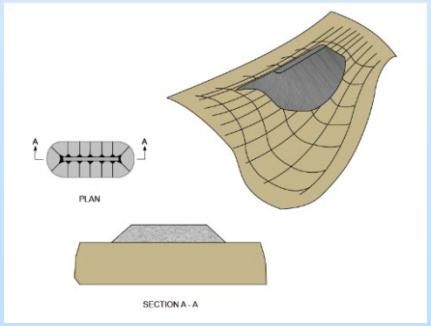
Imports of REE Illinois Basin

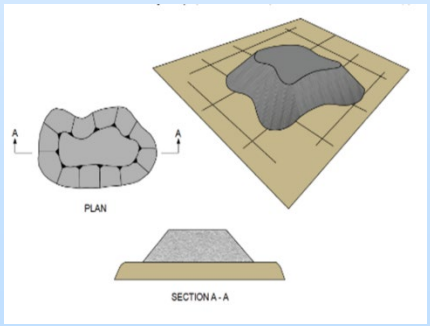


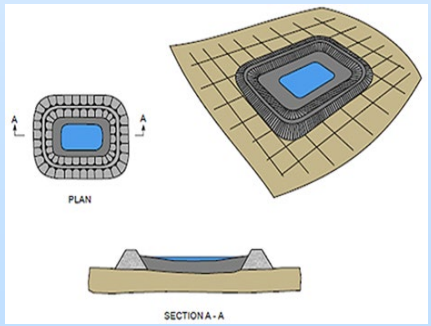


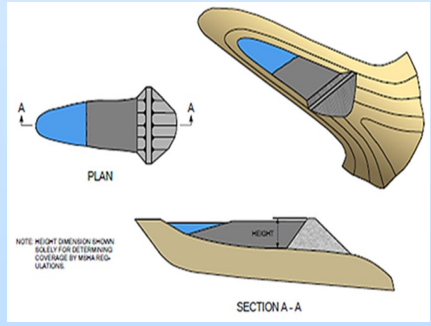


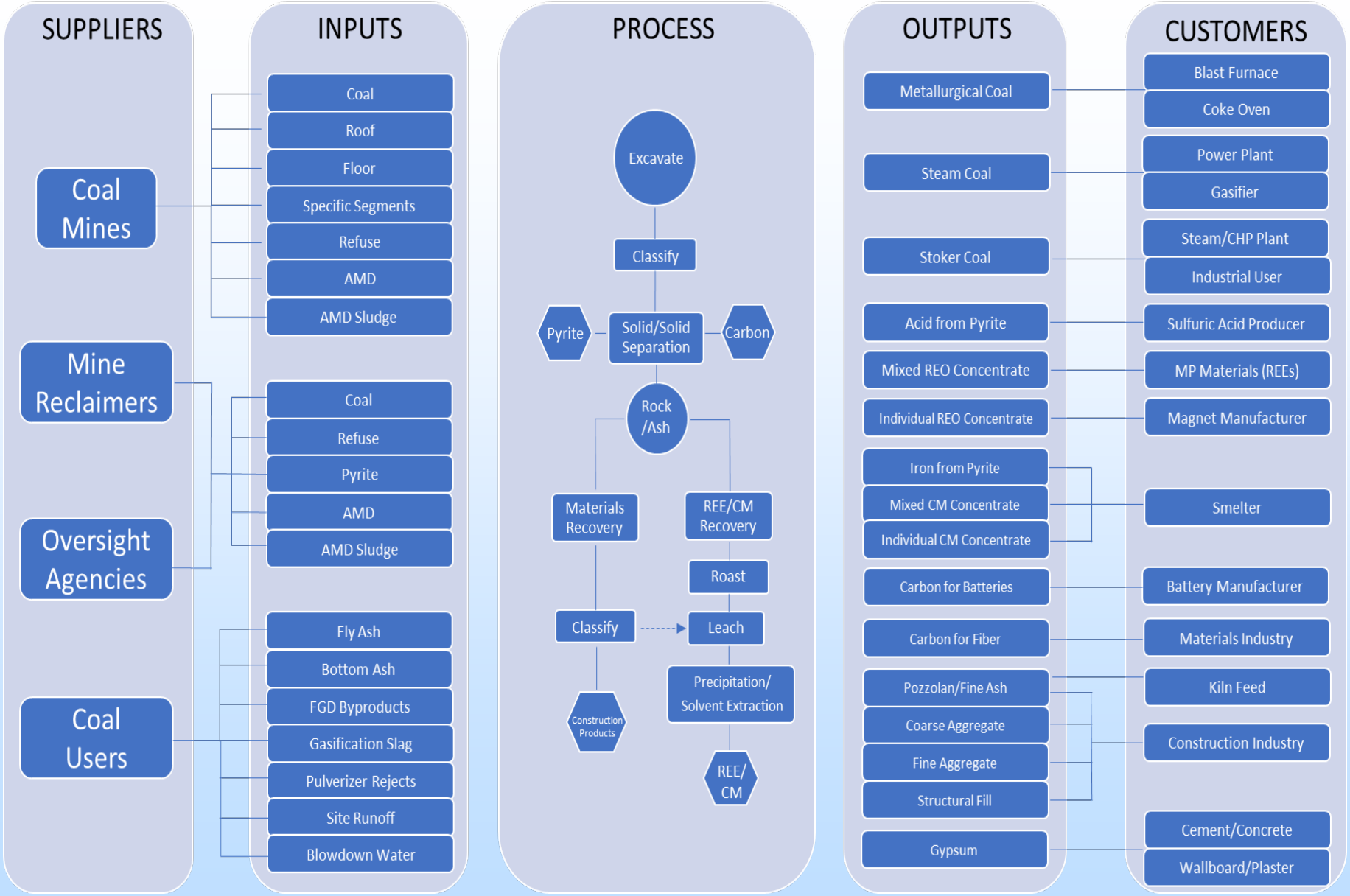
Refuse Disposal and Impoundment Infrastructure










SUPPLIERS
INPUTS
PROCESS
OUTPUTS
CUSTOMERS
Coal Mines
Mine Reclaimers
Oversight Agencies
Coal Users
Coal
Roof
Floor
Specific Segments
Refuse
AMD
AMD Sludge
Coal
Refuse
Pyrite
AMD
AMD Sludge
Fly Ash
Bottom Ash
FGD Byproducts
Gasification Slag
Pulverizer Rejects
Site Runoff
Blowdown Water
Excavate
Classify
Pyrite
Solid/Solid Separation
Carbon
Rock /Ash
Materials Recovery
REE/CM Recovery
Roast
Classify
Leach
Construction Products
Precipitation/ Solvent Extraction
REE/ CM
Metallurgical Coal
Steam Coal
Stoker Coal
Acid from Pyrite
Mixed REO Concentrate
Individual REO Concentrate
Iron from Pyrite
Mixed CM Concentrate
Individual CM Concentrate
Carbon for Batteries
Carbon for Fiber
Pozzolan/Fine Ash
Coarse Aggregate
Fine Aggregate
Structural Fill
Gypsum
Blast Furnace
Coke Oven
Power Plant
Gasifier
Steam/CHP Plant
Industrial User
Sulfuric Acid Producer
MP Materials (REEs)
Magnet Manufacturer
Smelter
Battery Manufacturer
Materials Industry
Kiln Feed
Construction Industry
Cement/Concrete
Wallboard/Plaster

IB-CORE-CM Coal Waste Reuse Plan

Illinois Rare Earth Novel Extraction & Supply (IRENES)

DE-FE0032489 IRENES FEED to deploy proven, innovative, and novel technologies to build a vertically integrated, modular REE and CM supply chain in the state of Illinois that will minimize waste and emissions while maximizing coproduction of useful materials.

APL Engineered Materials, Inc.

ILLINOIS
Illinois State Geological Survey
PRAIRIE RESEARCH INSTITUTE

Prairie State Generating Company

Center for Applied Energy Research

TPG ENGINEERS

Argonne NATIONAL LABORATORY

wsp

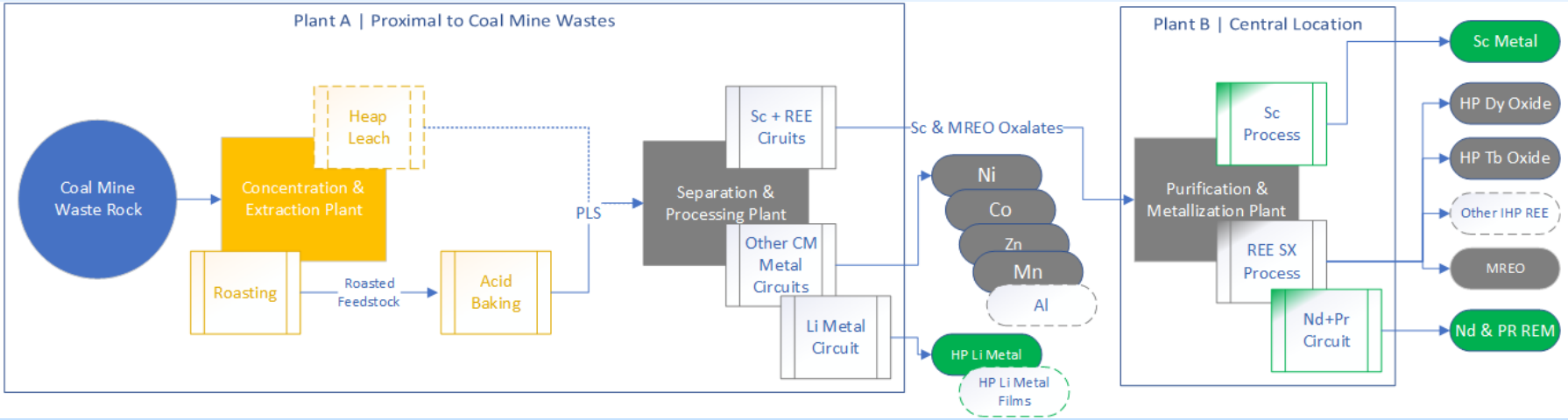
Sargent & Lundy

DYNAMIC 3D SOLUTIONS

Koch Modular PROCESS SYSTEMS

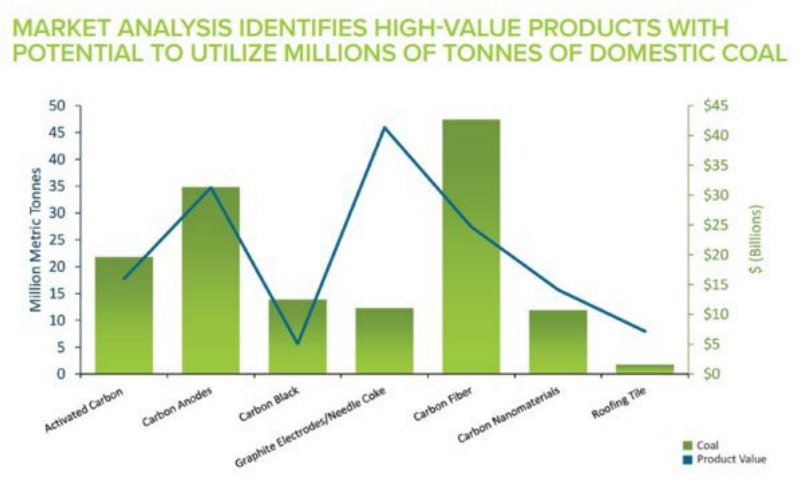
IRENES | Illinois Rare Earth Novel Extraction and Supply

Plant A is an extraction facility, and Plant B is a refining facility. Plant A will be resource-site or resource-proximal facilities that produce MREO for further processing while “Plant B” will be facilities with final refining capability to transform MREO into HP REO or HP REM.



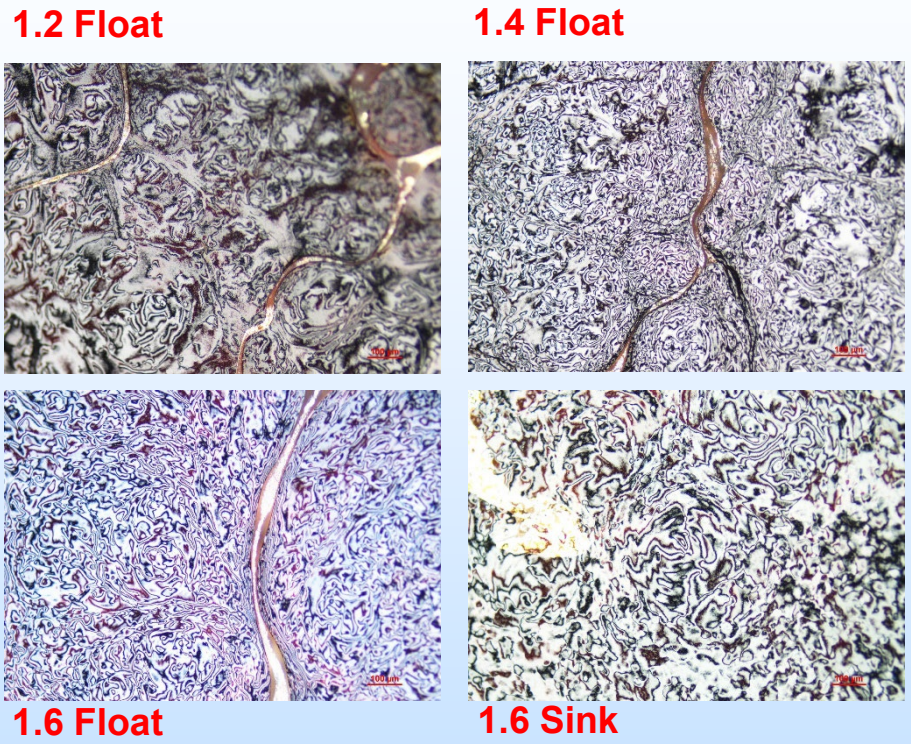
IRENES Illinois Rare Earth Novel Extraction and Supply

High Value Carbon Products from Illinois Coal



Source: NETL *S&T Accomplishments 2020*

- Illinois Basin Coals, even when high in ash, demonstrated conversion to liquids and mesophase formation. Mesophase pitch is a nematic liquid crystal, meaning it is a liquid with structure.
- Mesophase pitch can be spun into high performance carbon fiber, a material with applications in the aerospace industry as well as of interest for electric vehicle manufacturing.
- Mesophase formation also suggests that the samples may be converted to graphite, a high value carbon product used in lithium-ion batteries.



Above: Polarized light microscopy showing the anisotropic texture of mesophase pitch generated from liquefied Illinois Basin coal.

Construction Products from Coal Waste

- Coal mine tailings include a high % of reactive aluminosilicates which are a viable candidate for metakaolin replacement
- Treated coal waste can substitute more than 40 wt.% of metakaolin while sacrificing less than 10% off the compressive strength
- Coal waste geopolymers could be utilized to produce pavements and substitution for many conventional materials

Na GP – 75 wt.% Heat-Treated Coal Mine Tailing & 25 wt.% Metakaolin

Na GP – 40 wt.% Heat-Treated Coal Mine Tailing & 60 wt.% Metakaolin

GP TYPE	Heat-Treatment Status	Materials wt.%		Samples Comp. Strength (MPa)			Average Comp. Strength (MPa)
		MK	CMT	1	2	3	
Na-GP	Before HT	100	25	35.2	33.1	34.2	34.1
		25	75	6.9	8.6	9.2	8.2
	After HT	25	75	26.1	25	25.7	25.6
		60	40	40.5	42	41.4	41.3
K-GP	Before HT	25	75	8.1	7.5	7.9	7.8

Reference Samples	Comp. Strength (MPa)
Composite Na-GP - 7 Days	42
Composite K-GP - 7 Days	43

Major Partnerships

- Technical Advisory Board
- Prairie State Generating Company
- APL Engineered Materials
- Community Colleges
- State Government (i.e Department of Commerce and Economic Opportunity contributed $500,000 towards IRENES)
- Economic Development Interest Groups (i.e. Southern Illinois Now)

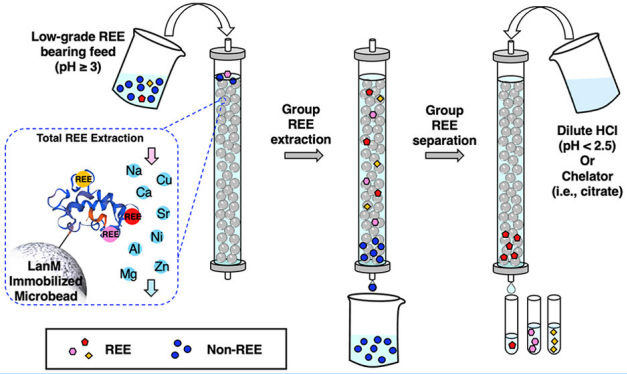
Prairie State Generating Company

"together we can do great things"

Technologies/Gaps Reviewed

Technologies

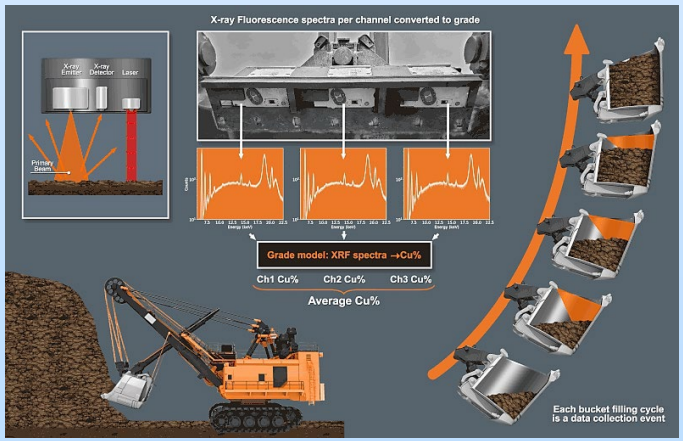
- Selective Sensor-based Mining and Sorting
- Selective Lixiviants for REE and CM Leaching (Acid, Alkaline, Bio)
- Selective Recovery of REE and CM from Dilute Solutions with High Contaminations (SX, Chromatography, Bio, Chem. Precip.)
- Advanced High Purity Metal Production (Metallothermy, Electrowinning, metal Purification)



Dong et al., 2021)

Gaps

- Mining Techniques (AI/ML, micro-tunneling, selective mining, re-mining, mine to mill)
- Separation and Purification of CM (high-density coal refuse, combustion byproducts, iron oxidation, leach solutions, REE purification
- Production of Carbon Products (coal liquefaction, coal liquid distillation, mesophase production)



ShovelSense® Image Courtesy of MineSense

CORE-CM Regional Technology Innovation Center

Three Main Functions:

- Connecting Industrial and Commercial Partners with Researchers from Participating States and Institutions

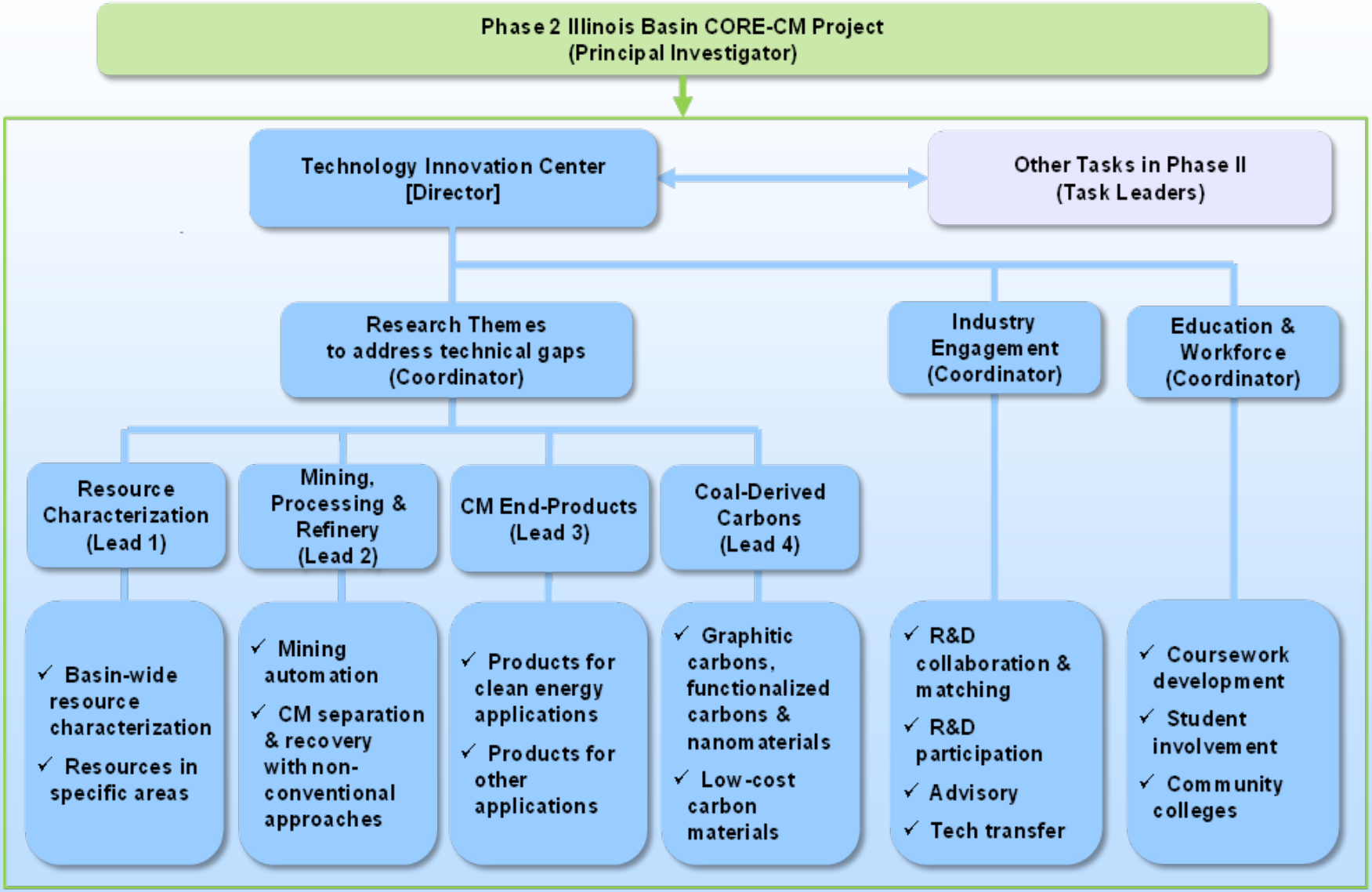
- Connecting Industrial and Commercial Partners with Available Physical Facilities (labs and pilot facilities in CM space)

- Issuing Small Research Grants to Address Key Questions and Problems Arising from Unconventional CM Production and Product Development in the Region

Illinois Basin CORE-CM

- Assess needs and target trainees/workforce: students, miners, mineral processing professionals, other industry personnel
- Opportunities of coursework development at three campuses (e.g., Incorporating CORE-CM contents into engineering and other relevant courses)
- Opportunities of engaging with graduate students in future TIC research projects
- Potential opportunities of collaborating with community colleges in developing CORE-CM related certificate programs

CORE-CM Regional Technology Innovation Center



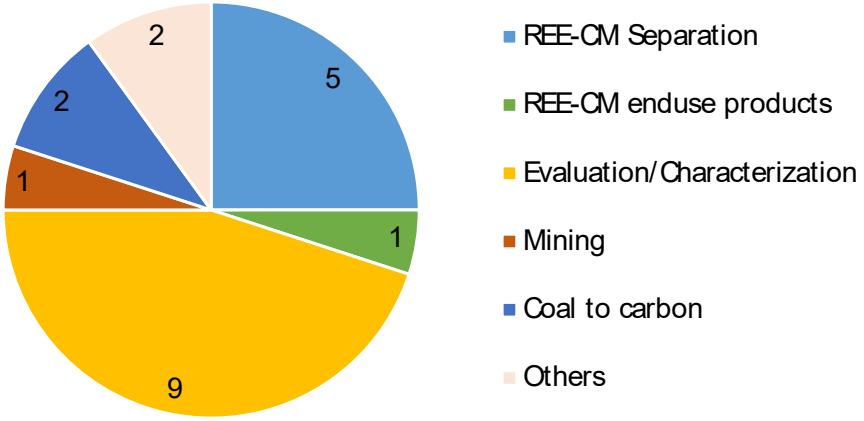
Survey on CORE-CM Research Capabilities & Resources at UIUC, UK and SIU

A breadth of R&D expertise at 3 campuses, including REE-CM separation, end uses, characterization, mining, carbon materials, etc.

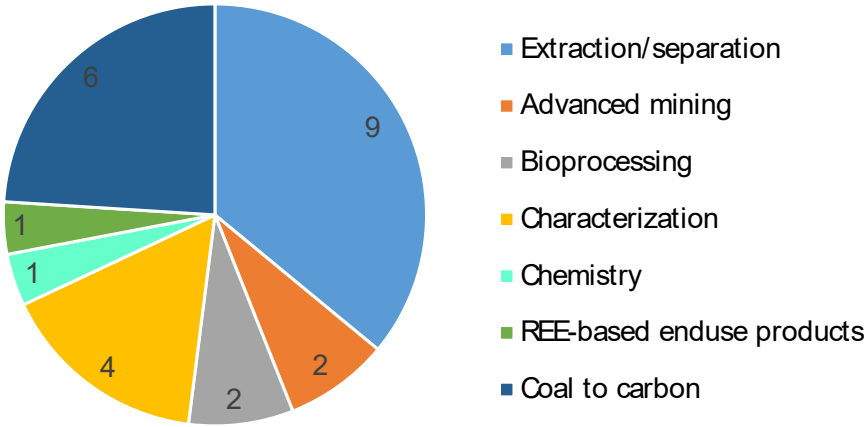
Existing R&D capabilities for characterizing and producing REE-CM and carbons (i.e composition/ surface/ microstructure characterization and lab test systems)

Areas of research interest for proposed TIC:

- Innovative/sustainable mining technologies
- New characterization techniques
- Next-generation technologies for REE-CM separation & purification (e.g., high-selectivity materials and approaches)
- New or alternative REE-CM end products (i.e., batteries, electrochemical catalysts).
- High-value, non-BTU carbon materials (graphite, graphene, fibers, etc.)



Expertise of CORE-CM research from a recent survey



Areas of interests for CORE-CM research & development

Summary

- IB-CORE-Cm Completed Initial Characterization Assessment and Developed a Broad Resource Model
- Identification of enriched strata with “economic” potential
- Several Business Partnership Opportunities have been Identified and in early stages of development
- A comprehensive waste reuse plan has been put forwarded (IRENES)
- The Illinois Basin Technology Innovation, Research, and Education Center
- Outreach, partnership, and collaboration!

The Illinois Basin provides major opportunities to develop new CORE-CM industries utilizing coal waste

ILLINOIS
Illinois State Geological Survey
PRAIRIE RESEARCH INSTITUTE

Center for Applied Energy Research

SIU Southern Illinois University
CARBONDALE

Illinois Basin CORE-CM

Kentucky Geological Survey
UNIVERSITY OF KENTUCKY

INDIANA GEOLOGICAL & WATER SURVEY
INDIANA UNIVERSITY

Thank You!

TENNESSEE GEOLOGICAL SURVEY
ESTABLISHED 1831

synTerra

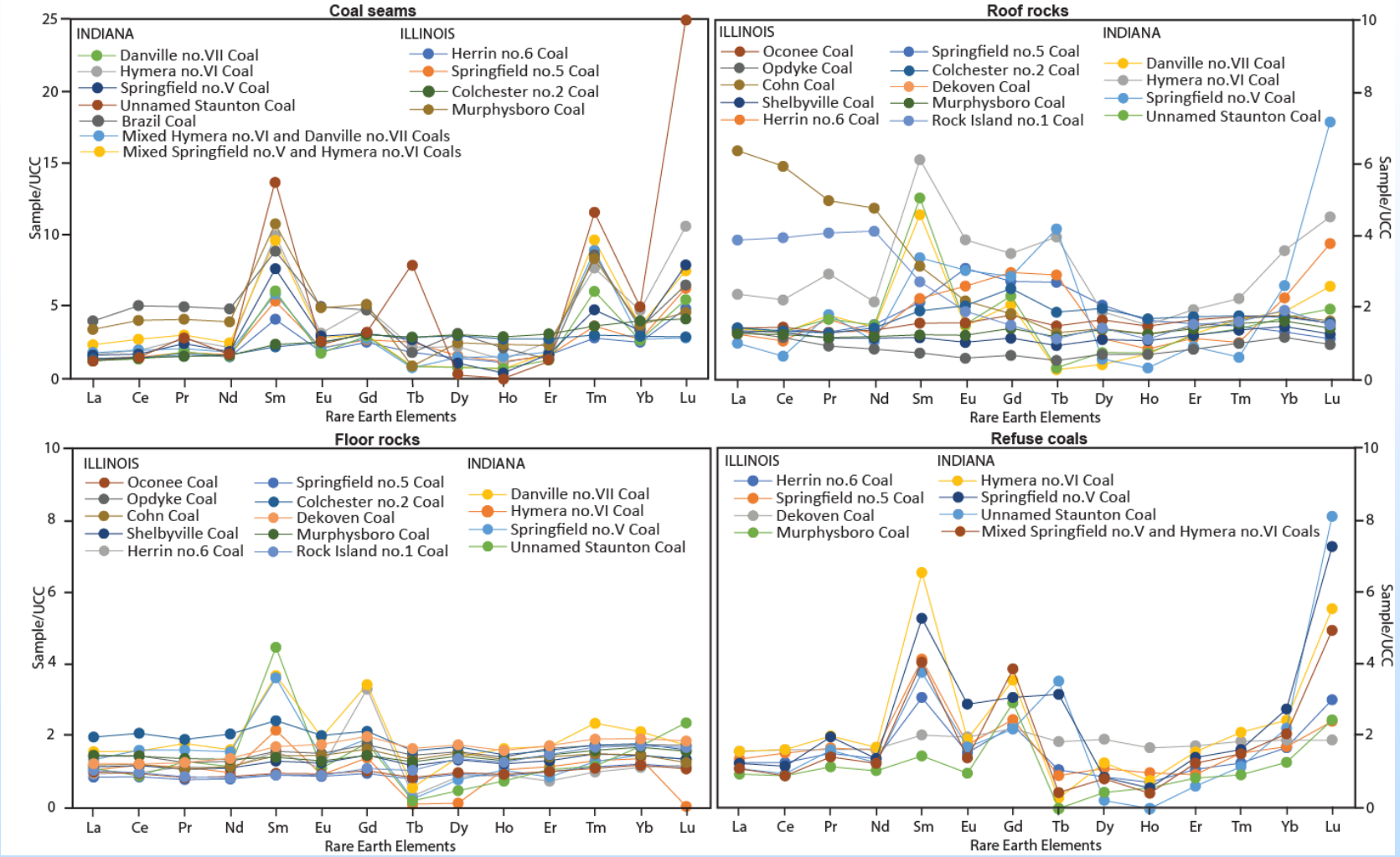
OAK RIDGE National Laboratory

IOWA GEOLOGICAL SURVEY

U.S. DEPARTMENT OF ENERGY

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Appendix



Plots showing the rare earth elements in the major coal seams, roof and floor rocks, and refuse coals in Illinois and Indiana.

Raw Coal

- All coal samples have concentration values slightly enriched than UCC.
- Sm and Tm show systematically an enrichment in concentration values than UCC, while Dy and Ho are slightly depleted in the Springfield no.V and unnamed Staunton Coals in Indiana.
- Most of LREEs have concentration values less than 50 ppm, and a few ppm in HREEs.
- All coal samples generally have total REE concentration values below 300 ppm.
- Murphysboro Coal from the Creek Paum Mine in Illinois and the unnamed Staunton Coal from the Antioch and Shamrock mines in Indiana show total REE concentration values of 599.4 ppm, 1,205.7 ppm, and 1302.9 ppm respectively.
- Brazil Formation Coal from the Shamrock Mine contains a total REE concentration of 703.1 ppm.
- Cohn and Friendsville Coals from the Friendsville Mine in Illinois have a high total REE concentration values on ash basis of 598.8 and 409.3 ppm respectively.
- These coals have individual elements that have particularly high LREE concentration values. These elements include La that is slightly above 100 ppm, Ce that varies between 250 and 350 ppm, and Nd that is up to 100 ppm.

Floor

- Concentration values for the floor rocks are slightly enriched than UCC for the Cohn, Danville no.7, Colchester no.2, Dekoven, and Murphysboro Coals in Illinois, and the Danville no.VII, Hymera no.VI, Springfield no.V, unnamed Staunton in Indiana.
- The Herrin no.6 and Springfield no.5 coals in Illinois are slightly depleted than UCC, while the same coal seams in Indiana are slightly enriched than UCC.
- Most floor rocks show a depletion in Tb, Dy, and locally in Er and Ho. Samarium and Gadolinium are enriched for the Danville no.VII, Hymera no.VI, Springfield no.V, and unnamed Staunton coals.
- The Colchester no.2 coal in Illinois has the highest LREE/UCC concentration values.

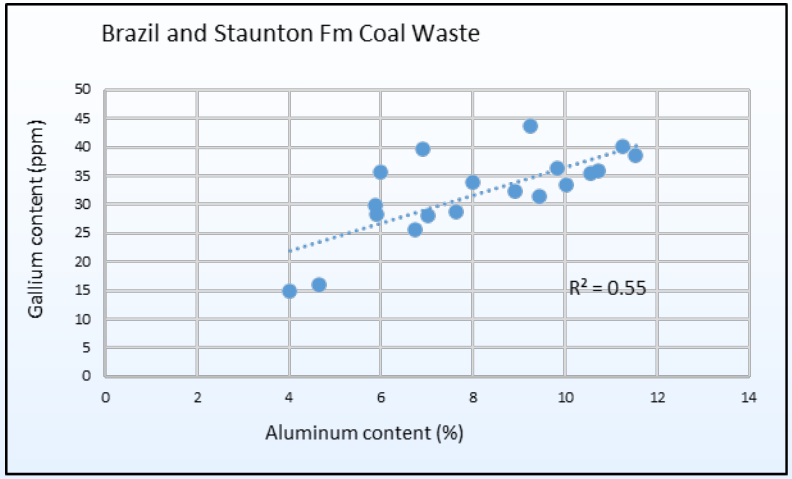
Roof Rock

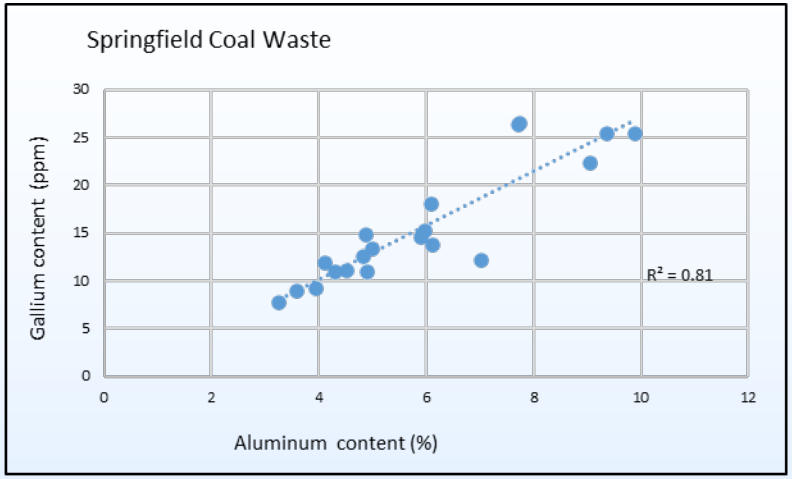
- The highest REE concentration values are encountered in the roof rocks overlying the Cohn, Friendsville, and Rock Island no.1 Coals in Illinois, and Hymera no.VI Coal in Indiana.
- The average total REE concentration values on whole rock are respectively 350.9 ppm (max: 2,258.7 ppm in Clarke County, Illinois) for the Cohn Coal roof rocks, 424.4 ppm for the Friendsville roof rocks, 549.0 ppm for the Rock Island no.1 Coal roof rocks, and 412.9 ppm for the Hymera no.VI Coal roof rocks.
- The Cohn and Rock Island no.1 Coals roof rocks show an enrichment in LREE and a depletion in HREE, while the Hymera no.VI Coal roof rock shows a flat pattern with an enrichment in middle REE (MREE; Sm, Eu, and Gd).
- The roof rocks overlying the Herrin no.6 and Springfield no.V Coals contain a slight MREE enrichment.
- In Clark County, Illinois, a roof rock sample overlying the Cohn Coal contains REE concentration values: 588 ppm in La, 1,110.0 ppm in Ce, and 37 ppm in Nd.

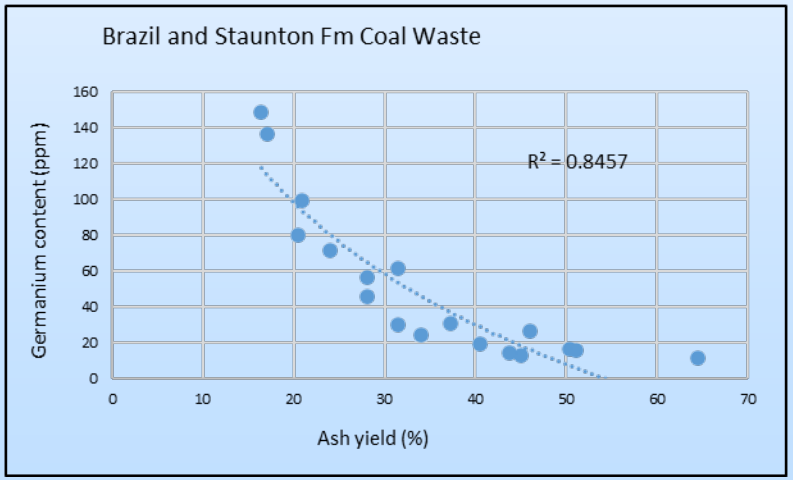
Coal Waste

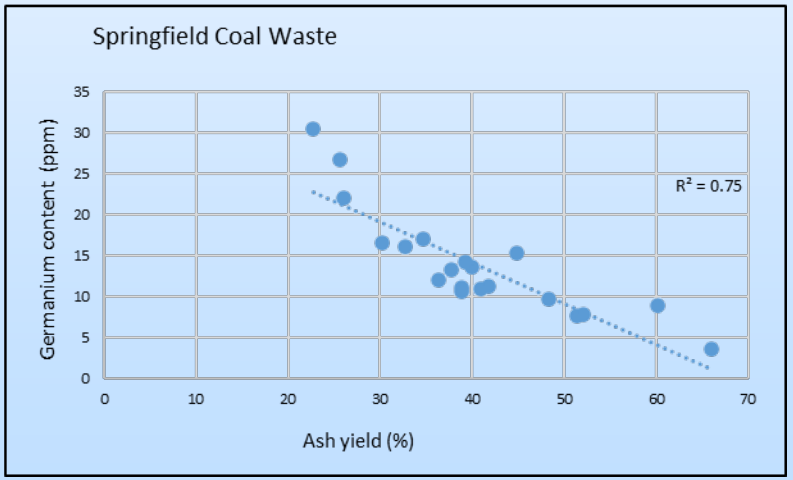
- REE concentrations in the refuse materials are only slightly enriched above UCC and are much below the REE patterns in coal seams.
- The REE patterns show mainly a slight enrichment in LREE and a depletion in LREE.
- The MREE concentration values show a few enrichments in Sm and Gd.
- Tb is enriched in the refuses from Springfield no.V and unnamed Staunton coals in Illinois, and is depleted in all refuses from the Illinois Basin coal seams.

Coal tailings as the source of critical minerals – Ga and Ge



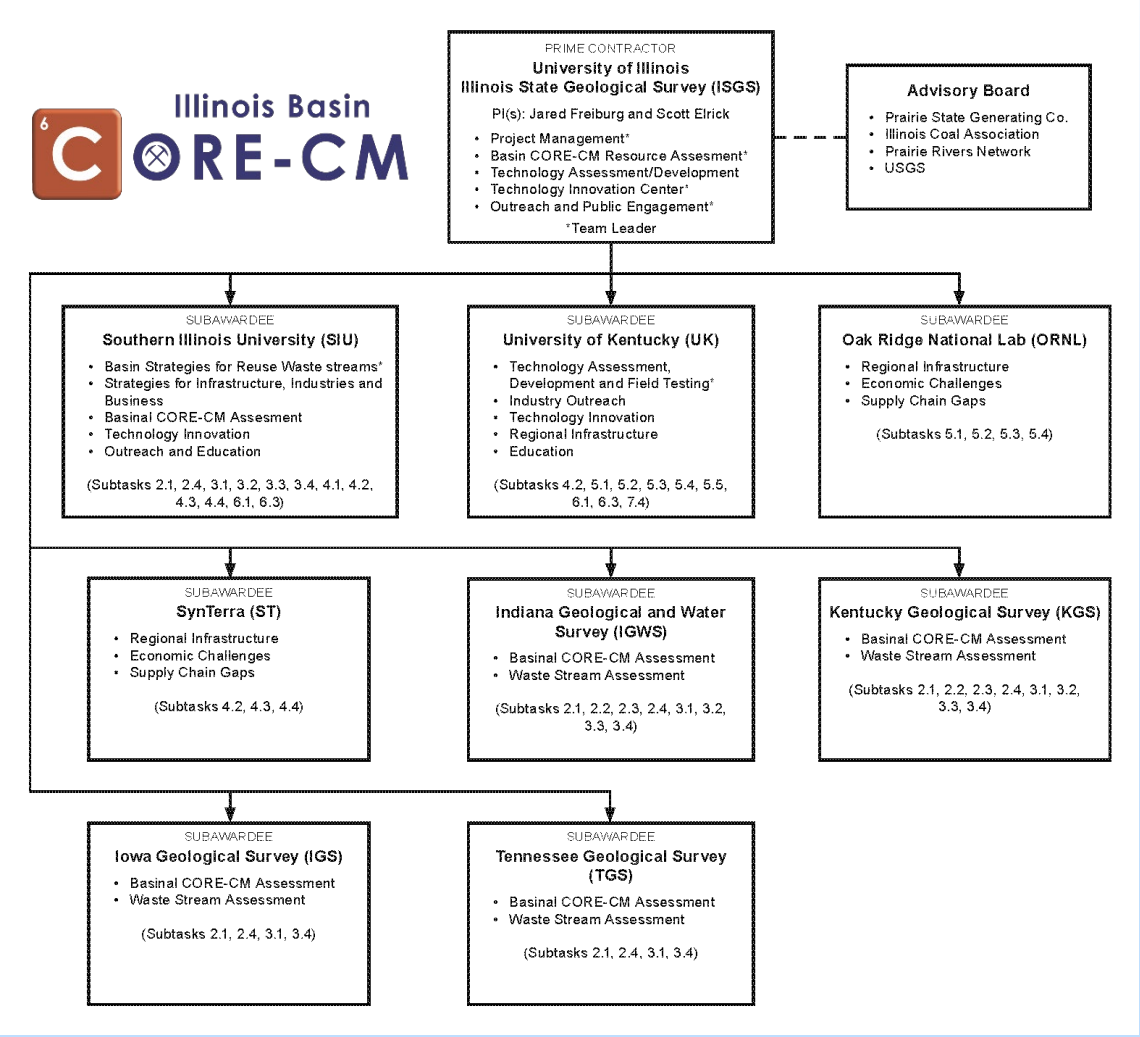






Organic fraction of coal tailings is a promising source of Ge, as suggested by a negative correlation of Ge with ash yield.

Organization Chart



Gantt Chart

#	Task Name	Start	End	Budget Period 1									ISGS	Subawardees							
				2021		2022					2023										
				Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3		SIU	UK	IGWS	KGS	IGS	TGS	ORNL	ST
1.0	**Project Management and Planning**											F									
1.1	Summary of Environmental Justice Considerations	09/21/2021	09/21/2023		A							B	X								
1.2	Summary of Economic Revitalization and Job Creation Outcomes	09/21/2021	09/21/2023		C							D,E	X								
1.3	Environmental, Safety, and Health (ES&H) Analysis for Products Proposed to be Manufactured From CORE-CM Resources	09/21/2021	09/21/2023										X								
2.0	**Basinal CORE-CM Resources Assessment**										G, J										
2.1	Collect, assemble, and evaluate existing data	09/21/2021	6/21/2023										X	X		X	X	X	X		
2.2	Develop analytical geologic resource models and maps	03/21/2022	6/21/2023										X	X		X	X				
2.3	Gap analysis	03/21/2022	6/21/2023					H					X	X		X	X				
2.4	Characterization and Data Acquisition Plan	03/21/2022	6/21/2023					I					X	X		X	X	X	X	X	
3.0	**Basinal Strategies for Reuse of Waste Streams**										J,K										
3.1	Review existing data and identify gaps	09/21/2021	6/21/2023											X		X	X	X	X		
3.2	Waste Stream assessment for CORE-CM	03/21/2022	6/21/2023											X		X	X	X	X		
3.3	Research and Development (R&D) plans for project development	03/21/2022	6/21/2023											X		X	X				
4.0	**Basinal Strategies for Infrastructure, Industries and Businesses**										L										
4.1	Identify CORE-CM infrastructure, industries, and businesses	09/21/2021	6/21/2023																		X
4.2	Regional infrastructure needs	03/21/2022	6/21/2023												X						X
4.3	Economic Challenges	03/21/2022	6/21/2023																	X	X
4.4	Supply Chain Gaps	03/21/2022	6/21/2023								M										X
5.0	**Technology Assessment, Development and Field Testing**										N										
5.1	Conventional and innovative mining techniques	09/21/2021	6/21/2023						O						X						X
5.2	Separation and purification of CORE-CM	09/21/2021	6/21/2023							P					X						
5.3	Incorporation of CORE-CM into products	09/21/2021	6/21/2023										X		X					X	
5.4	Strategies to fulfill gaps and field test technologies	03/21/2022	6/21/2023												X					X	
6.0	**Technology Innovation Center**										Q										
6.1	Technology Innovation Center Plan of Development	09/21/2021	6/21/2023										X	X	X						
6.2	Private-public partnerships	09/21/2021	6/21/2023										X								
6.3	Education and training opportunities	09/21/2021	6/21/2023										X	X	X						
7.0	**Stakeholder Outreach and Education**										R										
7.1	Conduct Stakeholder Analysis	09/21/2021	6/21/2023										X								
7.2	Develop Stakeholder Engagement, Outreach, and Education Plan	03/21/2022	6/21/2023										X								
7.3	Develop Outreach Materials	03/21/2022	6/21/2023										X	X	X	X	X				
7.4	Collaborations	03/21/2022	6/21/2023										X								

*No-cost extension to 5/31/2024

Milestones

Milestone Log						
Task/ Subtask	Letter	Milestone Title	Planned Completion Date	Actual Completion Date	Percentage Completion	Status
1.0/1.1	A	Project Kickoff Meeting	10/21/21	10/07/21	100%	Completed 10/21
1.0/1.1	B	Site Access Agreement	03/20/24			
1.0/1.2	C	Revised Project Management Plan	10/21/21	10/13/21	100%	Submitted 10/13/
1.0/1.2	D	EDX FOA-2364 REE Researcher Database	03/20/24		75%	Submitted 1/2/24
1.0/1.2	E	Input for NET REE-SED Sample data Needs	03/20/24		75%	
1.0	F	Phase 1 Final Report	03/20/24	02/22/24	100%	Submitted 02/22/
2.0	G	Basinal Resource Assessment	09/30/23	09/08/23	100%	Submitted 09/08/
2.0/2.3	H	Resource Assessment Gap Analysis	02/20/23	03/21/23	100%	Submitted 03/21/
2.0/2.4	I	Characterization and Data Acquisition Plan	02/20/23	03/21/23	100%	Submitted 03/21/
2.0/3.0	J	Resource Samples for Mineral Characterization and Analysis	09/30/23	09/25/23	100%	Submitted 09/25/
3.0	K	Initial Waste Stream Reuse Plan	02/16/24		90%	In prep
4.0	L	Results of Basinal Strategies for Infrastructure, Industries and Business Assessment	12/08/23	03/24/24	100%	Submitted 03/24/
4.0/4.4	M	Supply Chain Gap Analysis	12/08/23		99%	In review
5.0	N	Initial Technology Assessment and Field Development Plan	07/20/23	08/14/23	100%	Submitted 08/14/
5.0/5.1	O	Technology Gap Analysis	02/20/23	04/04/23	100%	Submitted 04/04/
5.0/5.2	P	SIPOC Analysis	07/20/23	07/20/23	100%	Submitted
6.0	Q	Initial Technology Innovation Center Plan	01/22/24		99%	In review
7.0	R	Initial Stakeholder Outreach and Education Plan	07/20/23	07/28/23	100%	Submitted 07/28/