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

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Jared T. Freiburg, PhD

Freiburg@Illinois.edu

Illinois State Geological Survey

University of Illinois at Urbana-Champaign

U.S. Department of Energy

National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
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Project Overview

- Funding Source
  - DOE: $1,499,987.00
  - Cost Share: $376,397.00
- Project Dates
  - Start: September 21, 2021
  - Finish: September 20, 2023

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

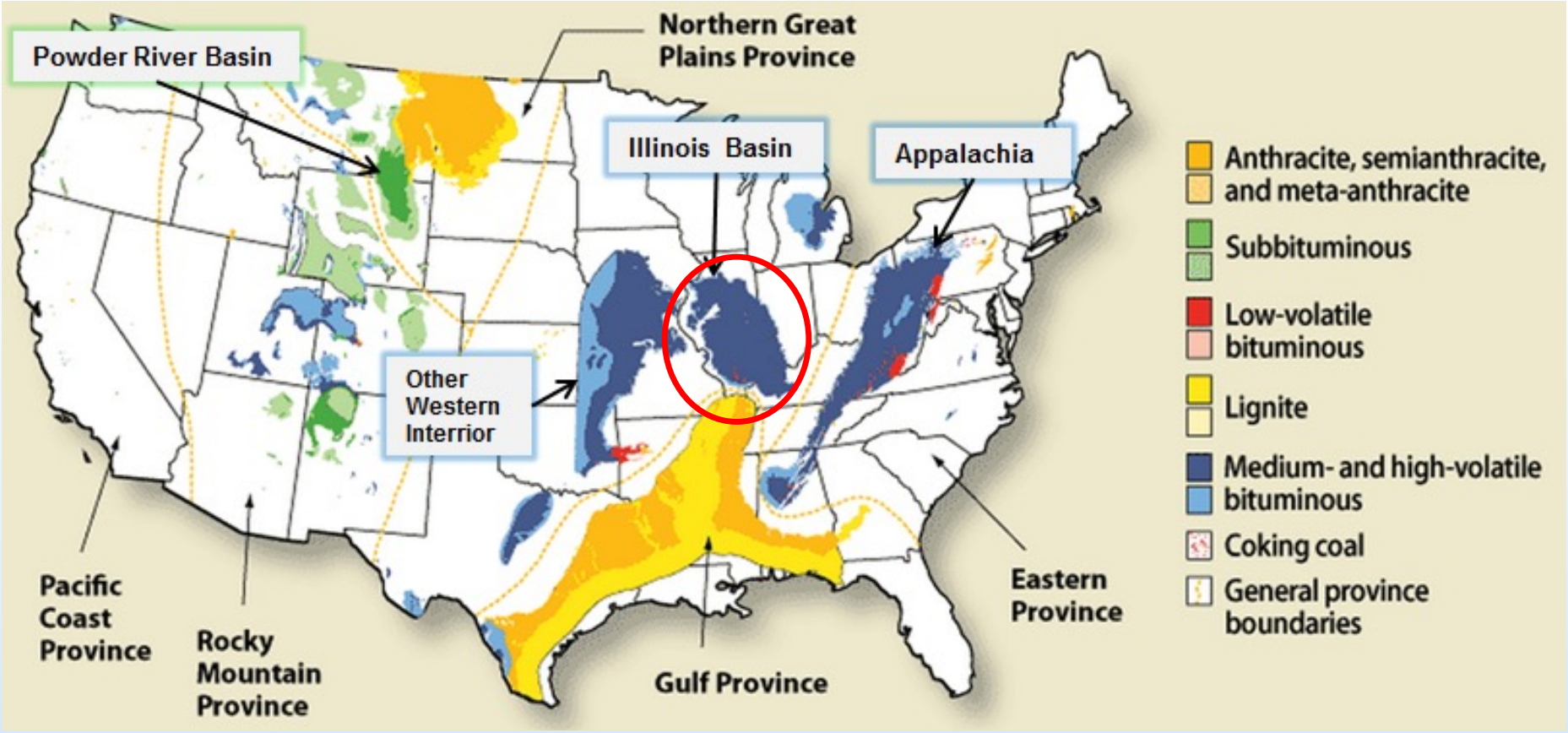
synTerra

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
  - **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

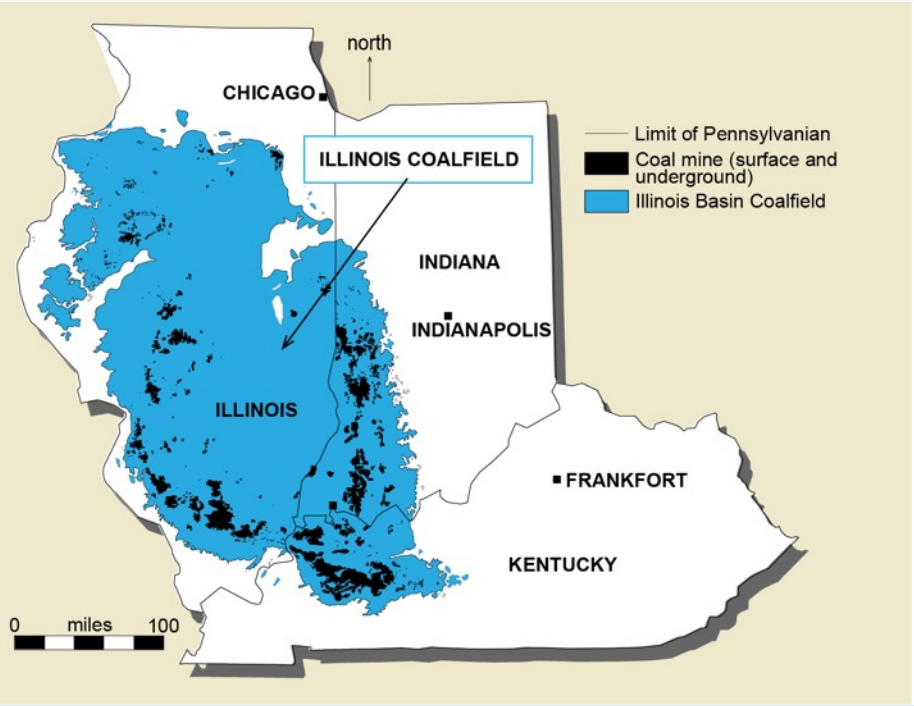
Illinois Basin CORE-CM



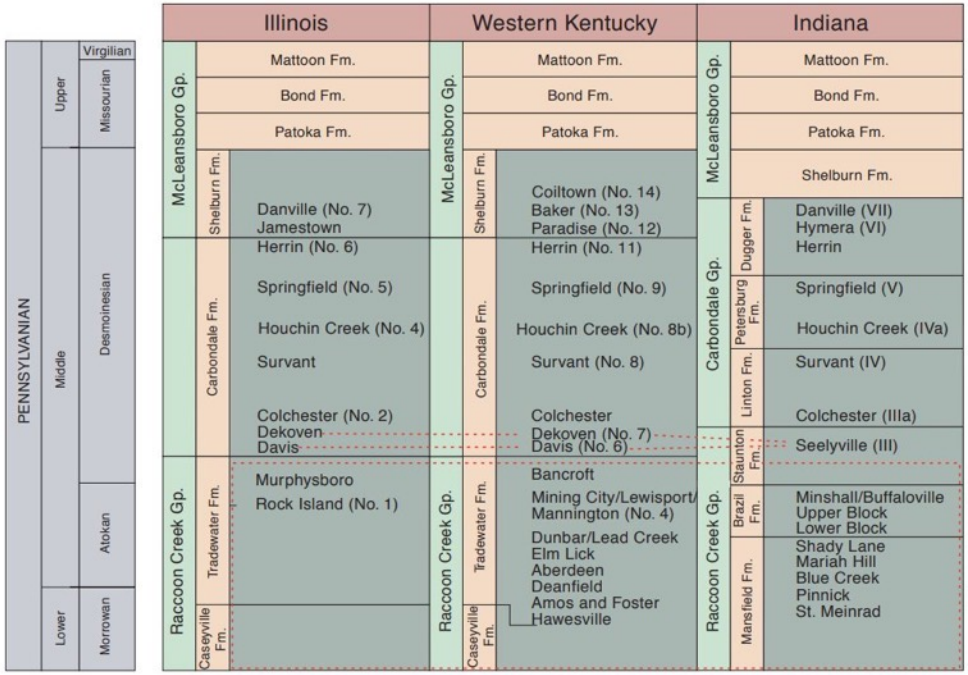
Source: U.S. Energy Information Administration

Project Background

Illinois Basin Coalfield



Modified from Korose and Elrick (2013)



Hatch and Affolter (2002)

- 150 billion short tons mined from Herrin and Springfield Coals
- 103 billion short tons of reserves

Environmental Justice (Task 1)

- CORE-CM extraction technology and use of resources such as coal, biomass, and/or low-carbon energy.
-
- Coal-waste vs. amount of product produced.
- The project's waste management strategy and the anticipated impacts of residual waste on residents and historically underserved communities.
- **How can CORE-CM related extraction technology utilize coal-waste/byproducts to make Illinois a cleaner, healthier, socially equitable and more prosperous of a state?**

PRN, Cap and Run Report

80% of coal ash dumps in Illinois are located within 3 miles of a minority or low-income community, whose population is relatively higher than the state average.

PRN, Cap and Run Report

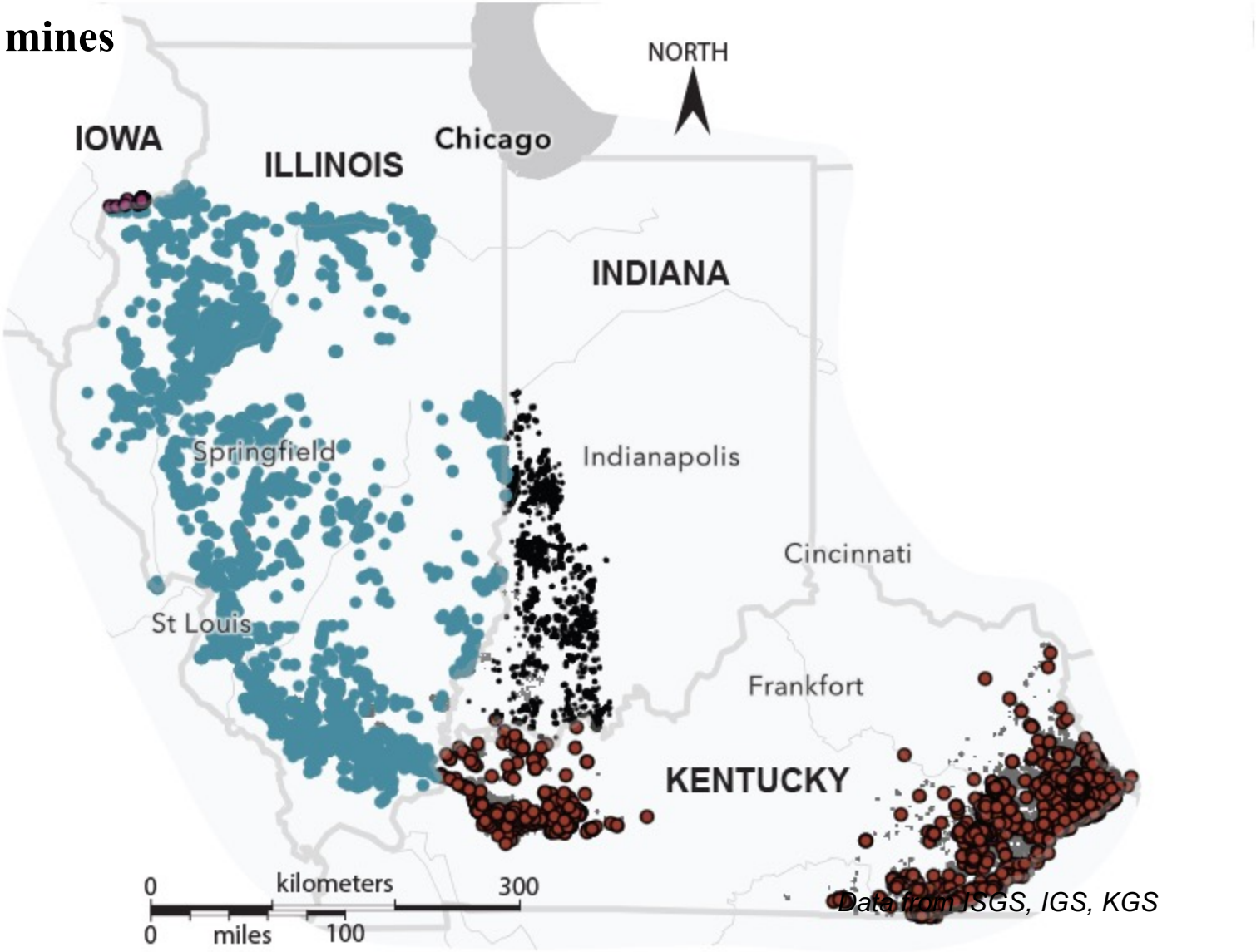
TABLE 25: DISPROPORTIONATE IMPACT WITHIN THREE MILES OF ILLINOIS COAL ASH DUMPS[60]

Estimate of Proportion of Population within 3 miles	Minority Population	Low Income Population
Baldwin	2%	**32%**
Coffeen	11%	**46%**
Crawford	**92%**	**59%**
Dallman	34%	**38%**
Duck Creek	2%	**34%**
Edwards	4%	**33%**
Havana	3%	**48%**
Hennepin	**54%**	**49%**
Hutsonville	2%	**31%**
Joliet 29	**53%**	**37%**
Joppa Steam	9%	**43%**
Kincaid	8%	**34%**
Joliet 9/Lincoln Stone Quarry	**59%**	**41%**
Marion	9%	20%
Meredosia	1%	**49%**
Newton	0%	16%
Pearl	1%	**46%**
Powerton	8%	**34%**
Prairie State	1%	9%
Waukegan	**79%**	**51%**
Will County	32%	21%
Woodriver	14%	**45%**
Venice	**82%**	**66%**
Vermilion	5%	24%
Illinois State Average	38%	31%

BOLDED TEXT PERCENTAGES INDICATE VALUES ABOVE THE STATE AVERAGE.

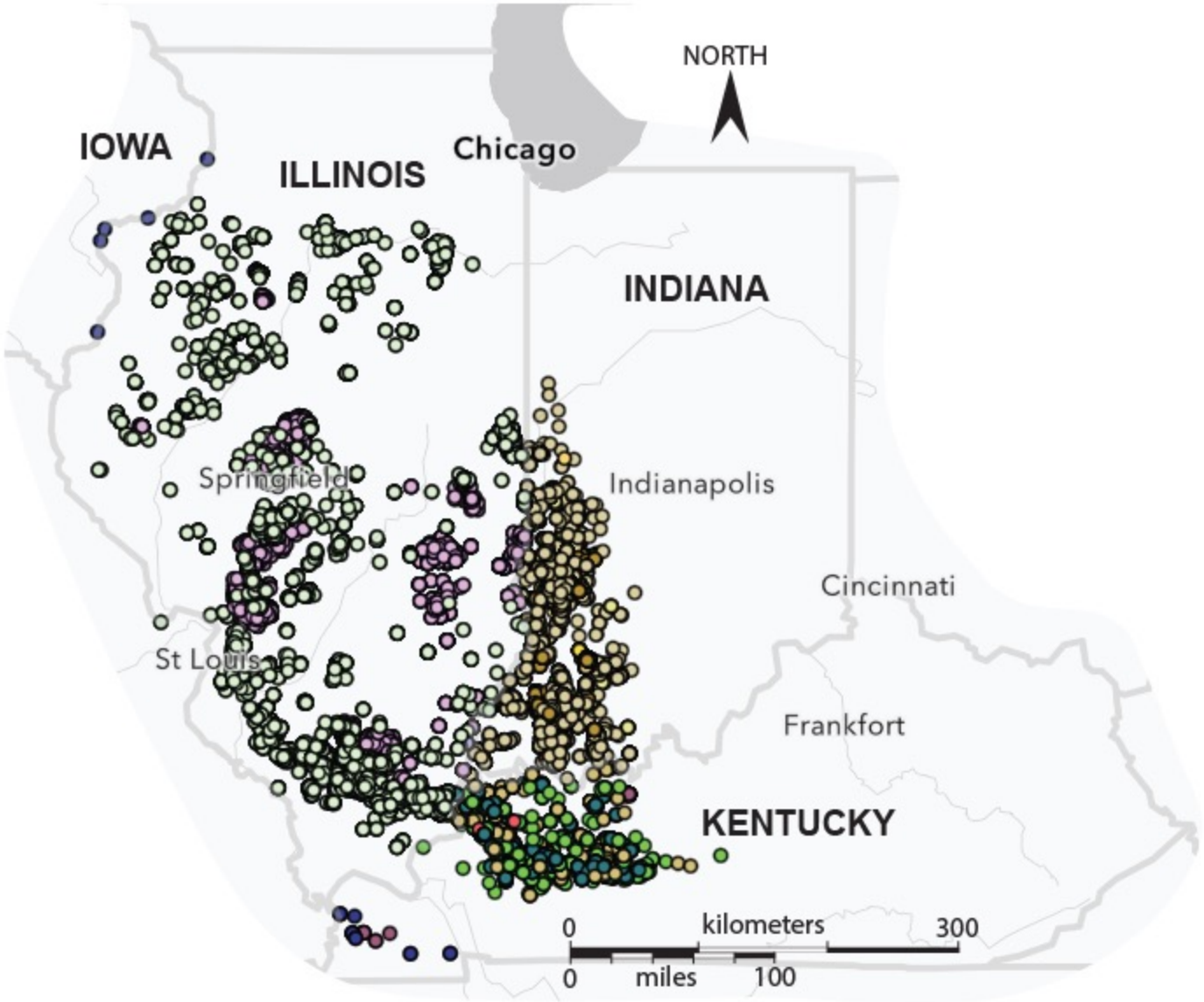
Characterization (Task 2)

Coal mines

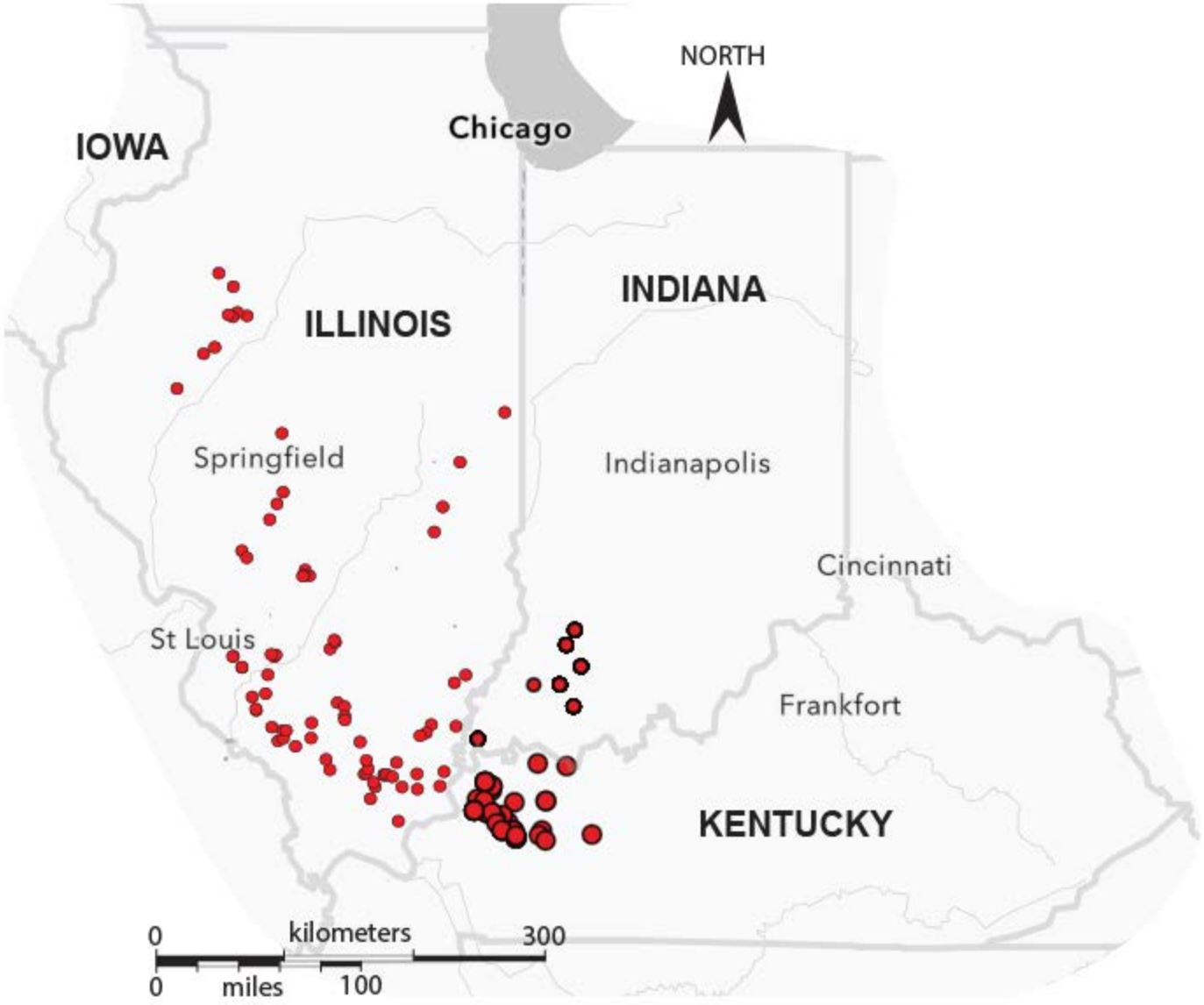


Data from ISGS, IGS, KGS

Coal quality data

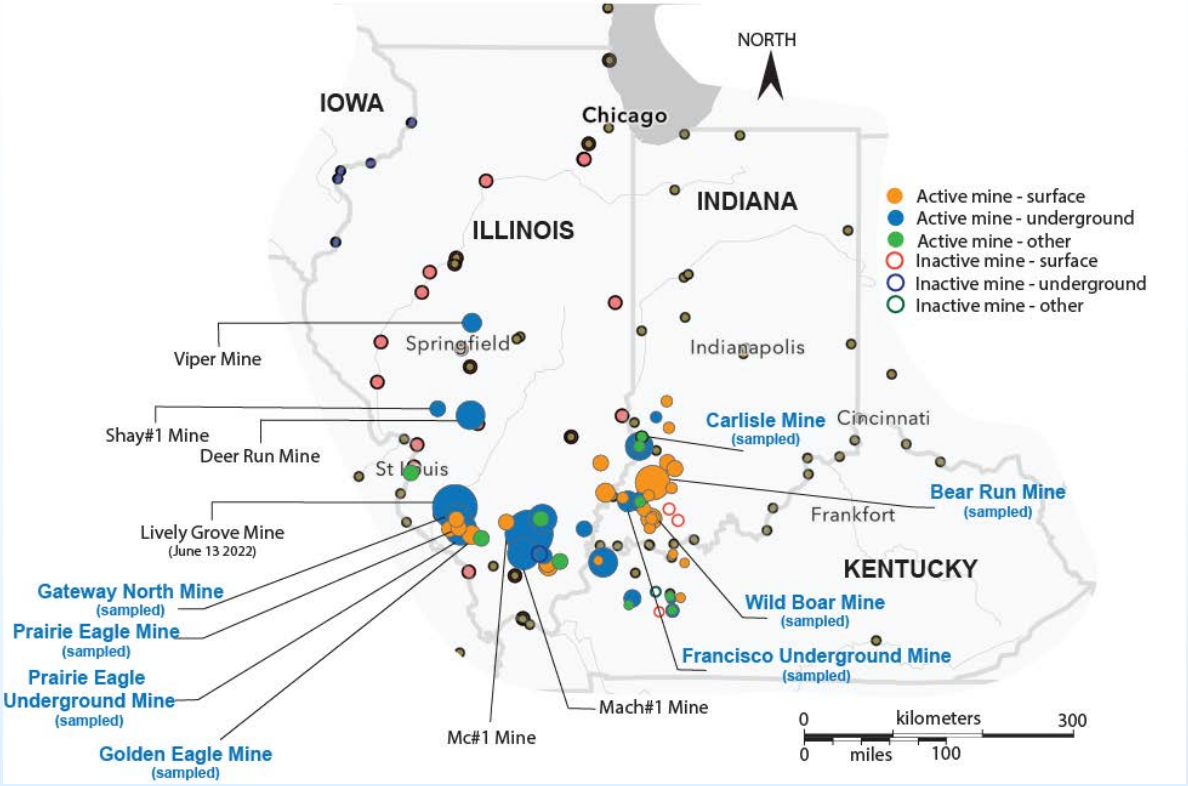


REE+Y geochemical data in coal materials



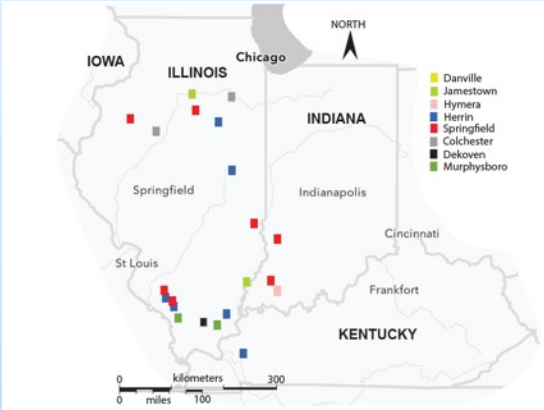
Data from ISGS, IGS, KGS, Kolker et al., 2021

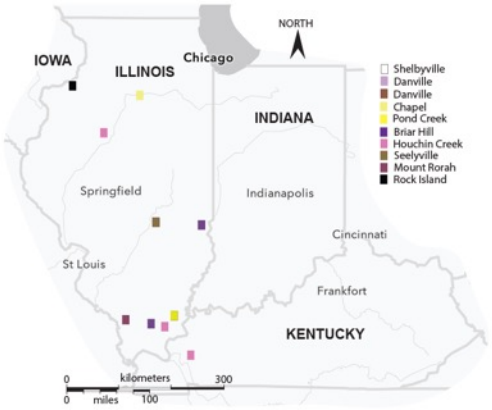
Characterization and Data Acquisition

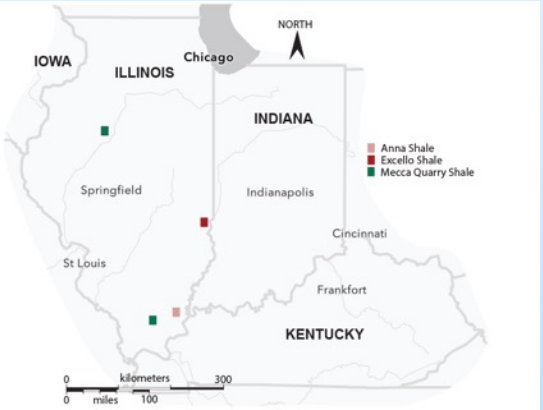


- Identification and planning
- Strategy of sampling
- Resource calculation and modeling

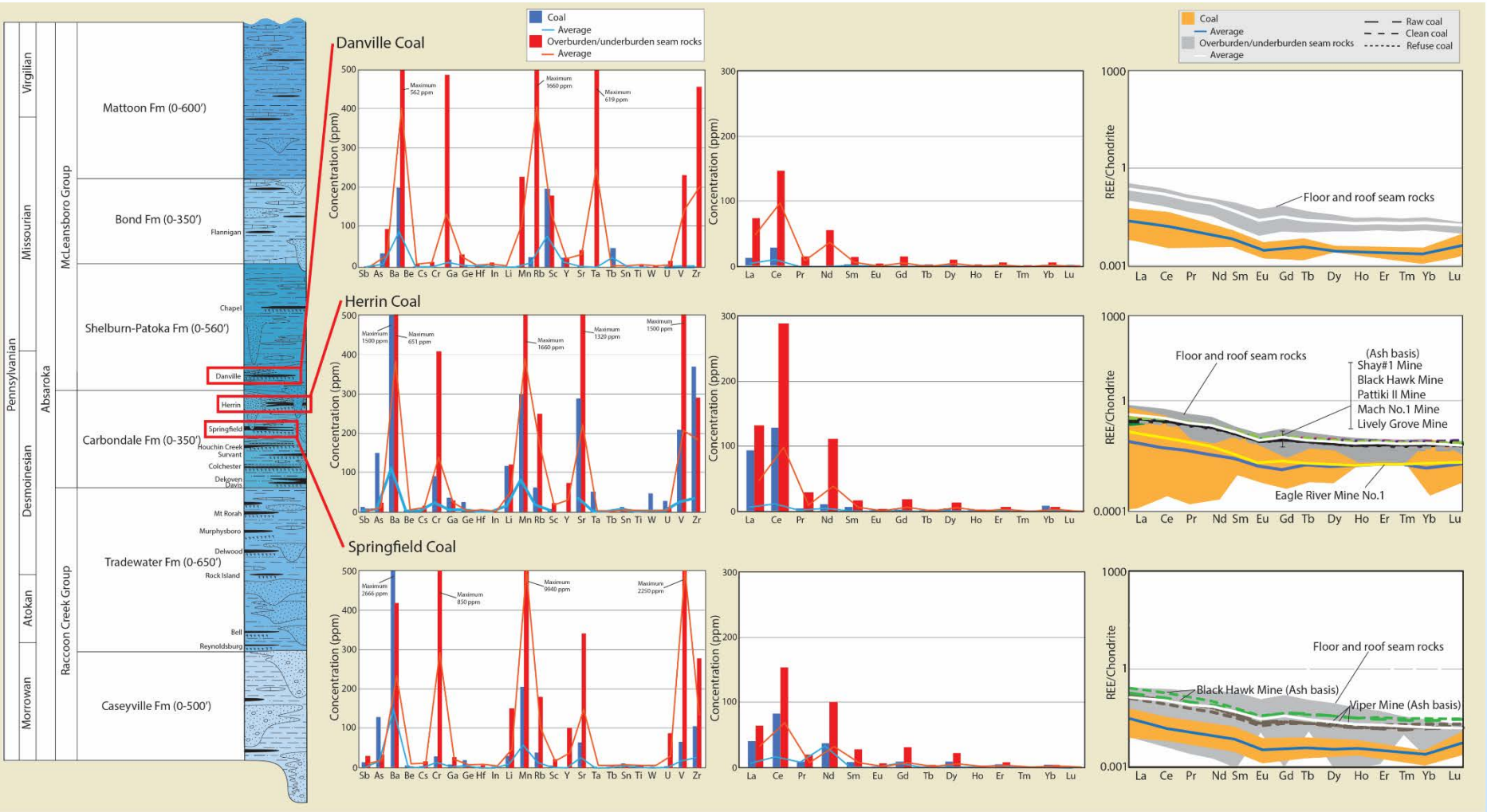
Sampling raw coal, coal floor seam, coal roof seam, shale (n = 286)



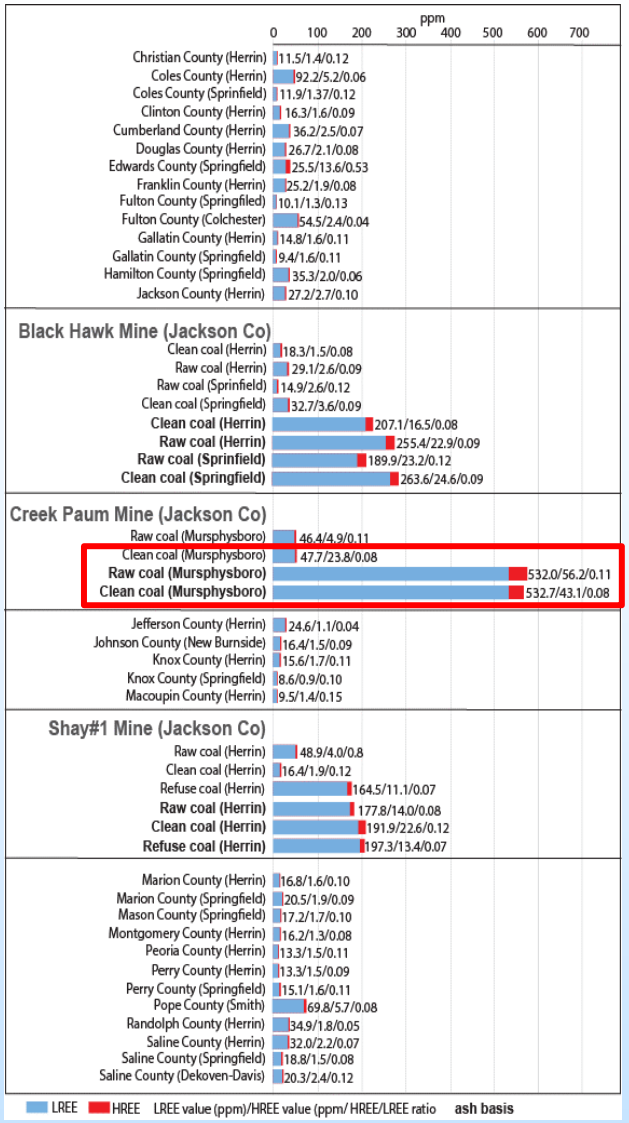


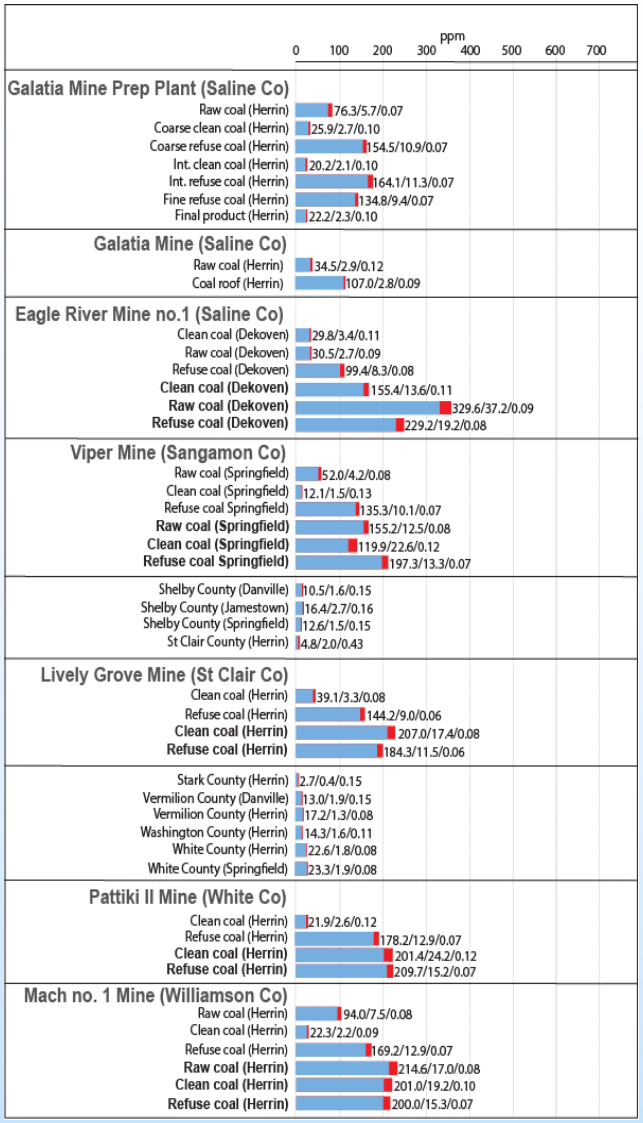


Preliminary Results

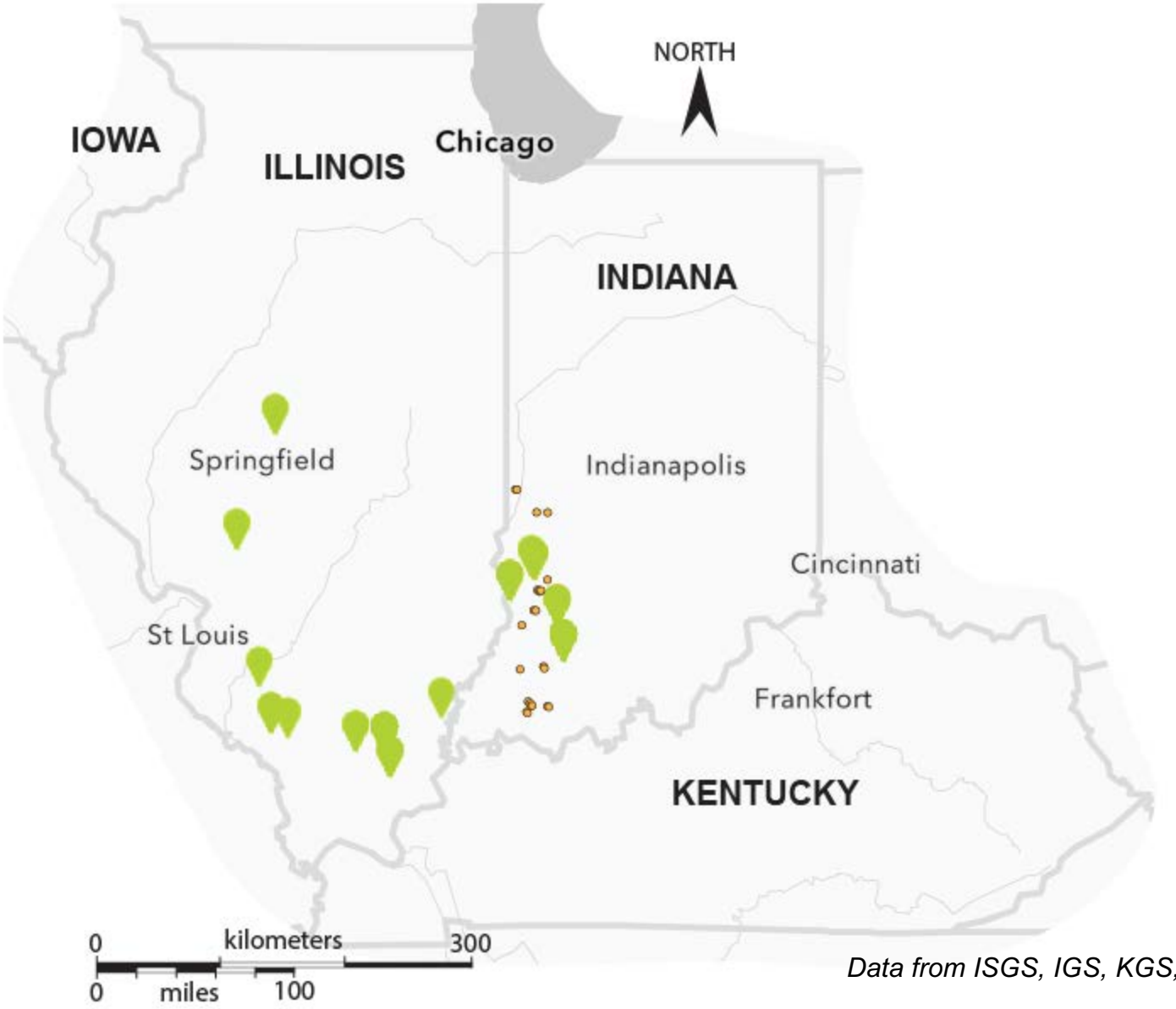


Variations in REEs in Illinois coals



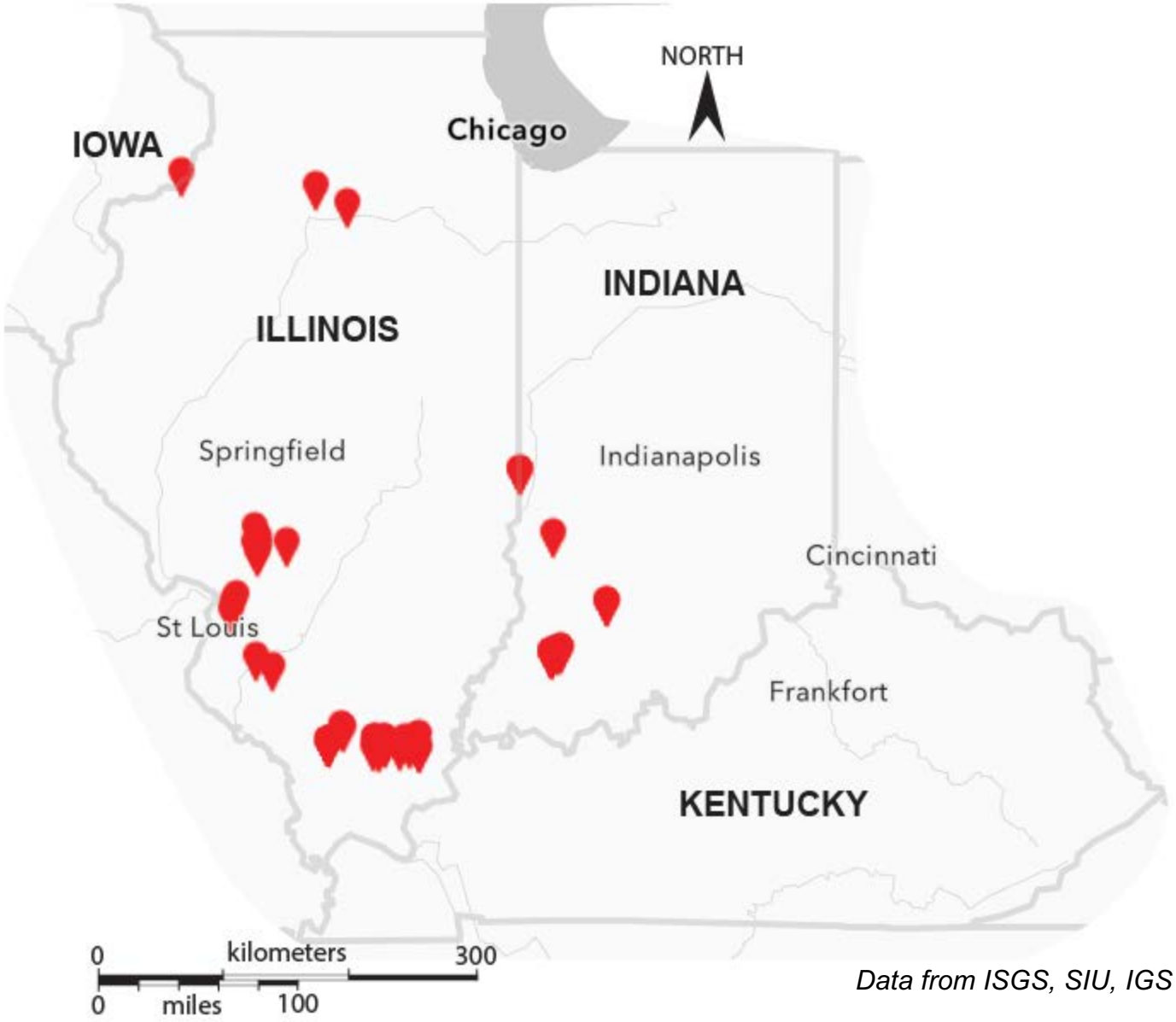


Coal wastes and slurries (Task 3 Coal Waste)



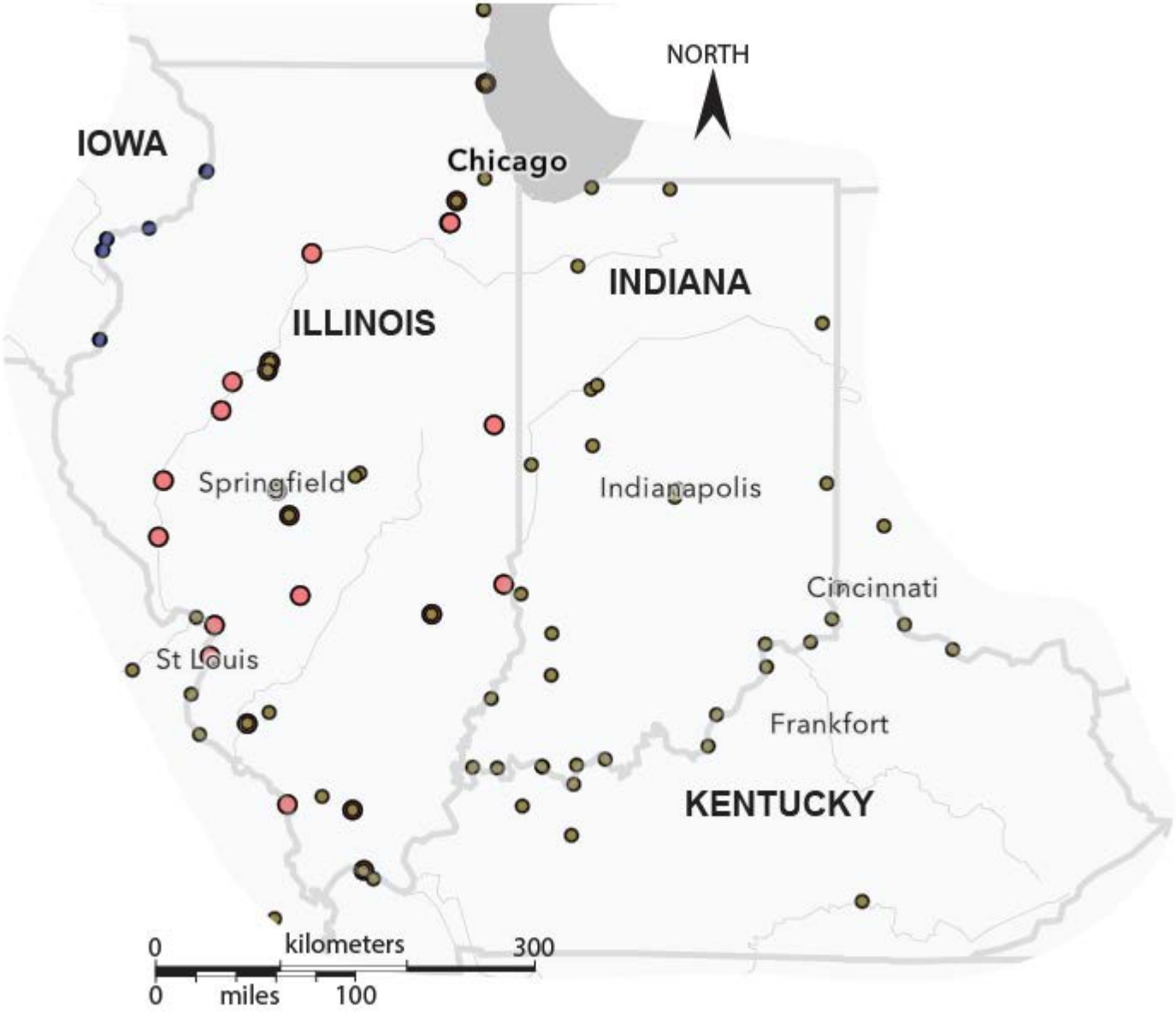
Data from ISGS, IGS, KGS, EPA

Acid mine drainage (AMD)



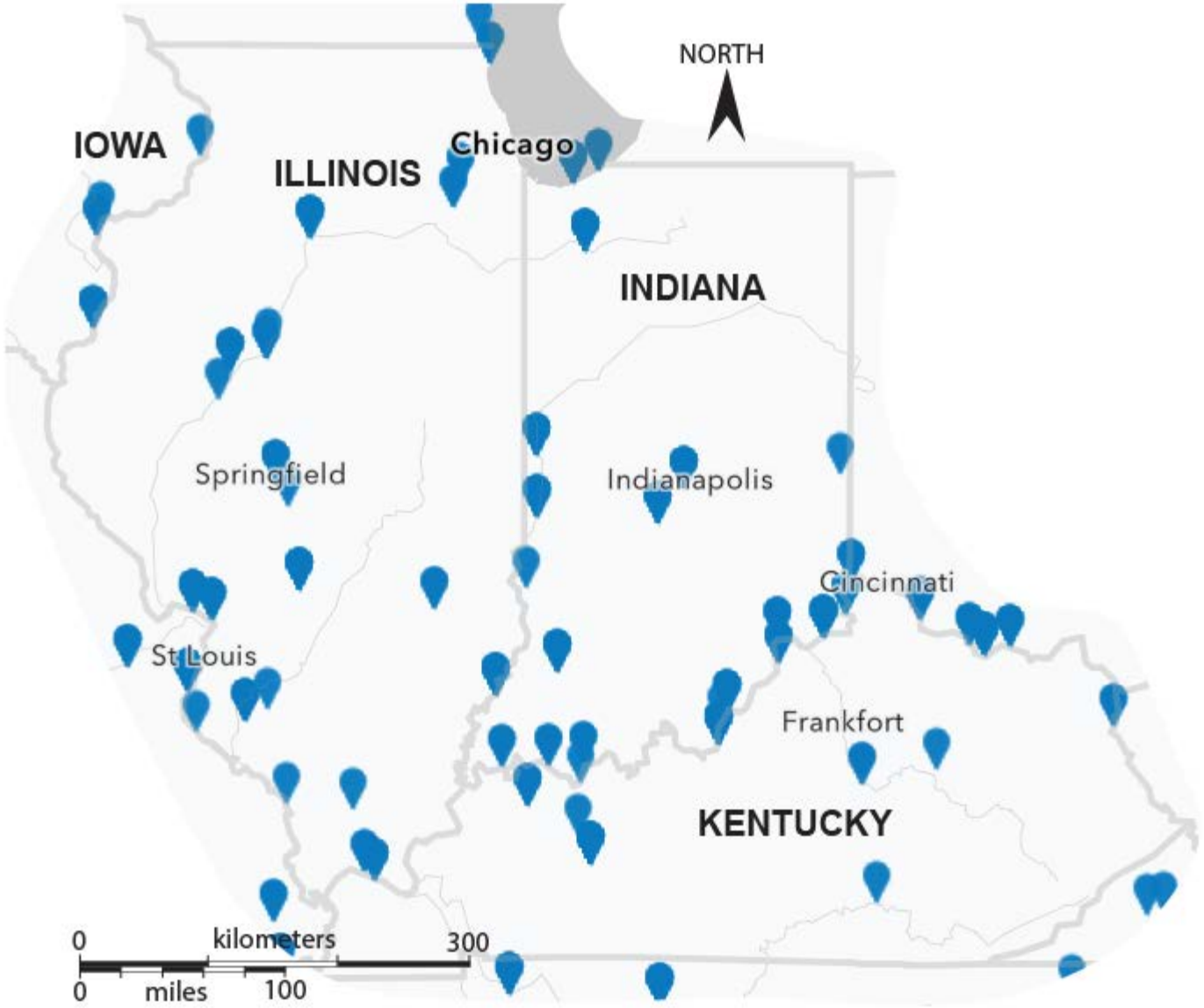
Data from ISGS, SIU, IGS

Coal fired power plants



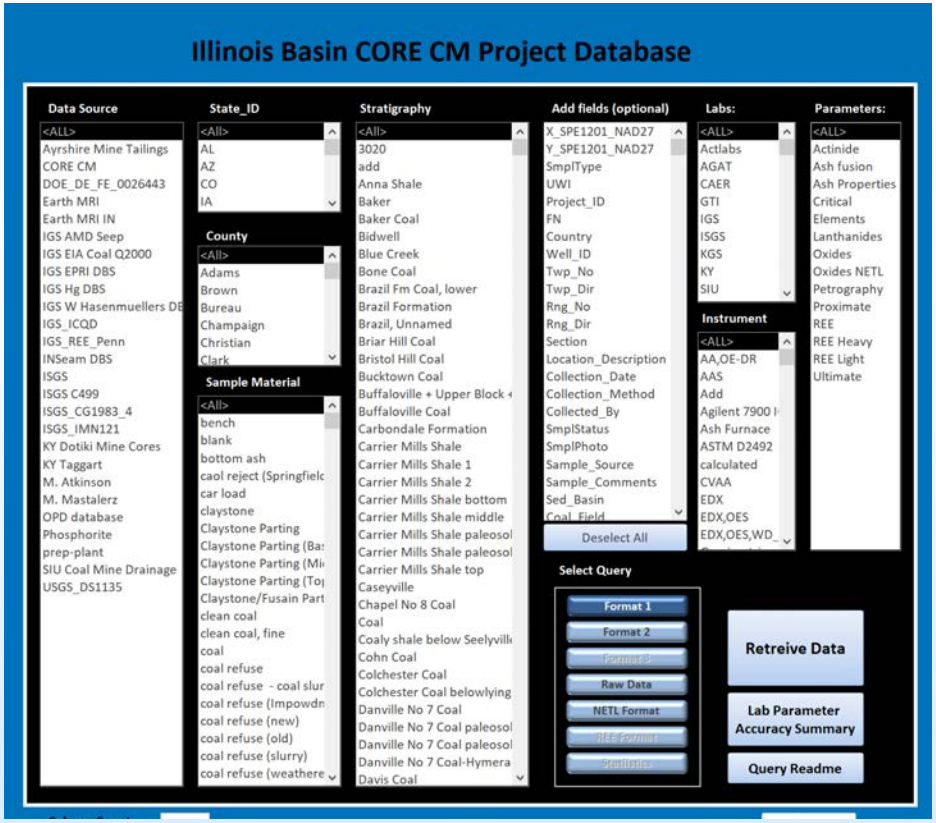
Data from ISGS, IGS, KGS, Iowa GS, EPA, Earthjustice

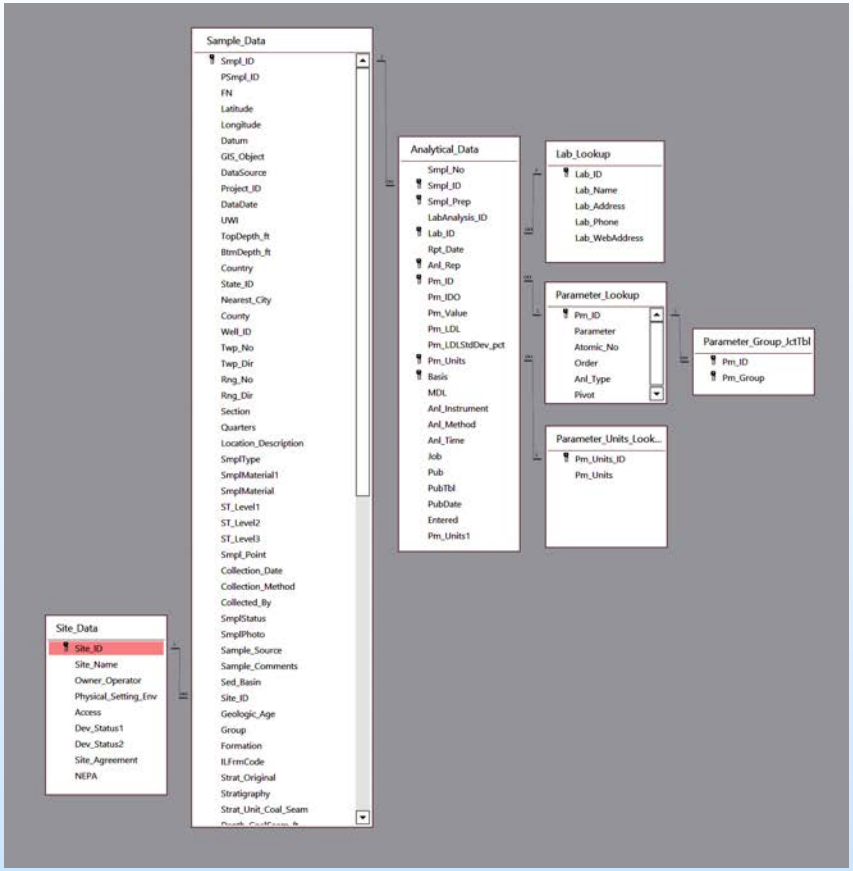
Ash ponds



Data from ISGS, IGS, KGS, EPA, Earthjustice

Illinois Basin CORE-CM Database





- 204,221 analyses to date

CORE-CM Resource Model

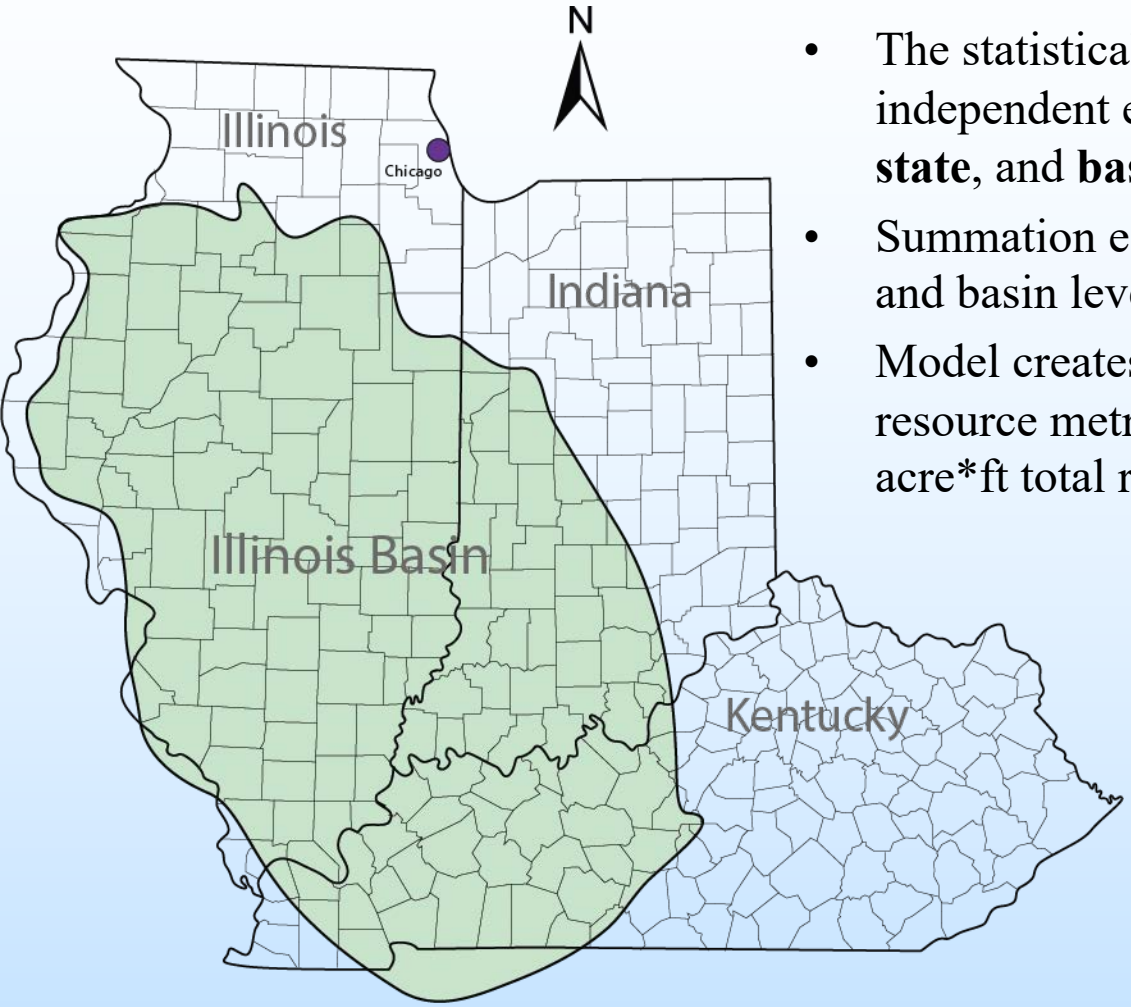
- Objectives

1. Provide basin-wide estimates and ranges of in-place resources
    1. Coal
    2. Critical Minerals (mainly REE)
2. Generate insight into what parameters have the largest impact on volume to guide future work
3. Provide ranges of expected coal quality where practical

- Tasks

- This is a volumetric model designed primarily to satisfy task 2
- **Current**: Task 2
  - Subtask 2.2 – analytical geologic resources models
  - Subtask 2.3 – Gap analysis
- **Planned**: Task 3
  - Subtask 3.2 – waste stream assessment

Model Dimension and Scale

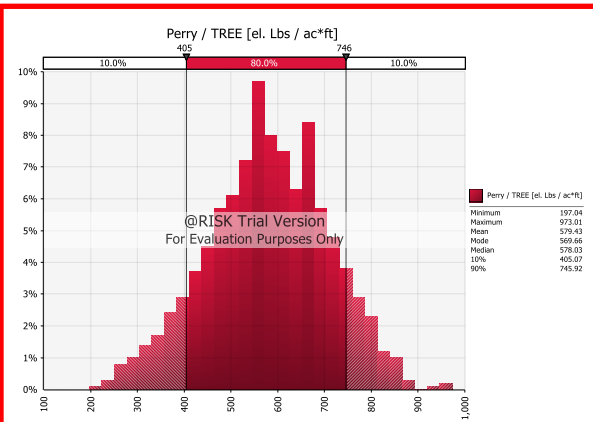


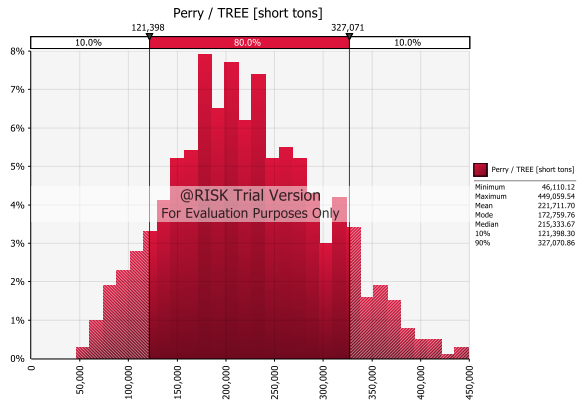
- The statistical model simultaneously solves for independent estimates of REE at the **county**, **state**, and **basin** scale
- Summation estimates are also made at the state and basin level from the county level
- Model creates both total mass REE and Coal resource metrics, as well as resources per acre*ft total rock extracted

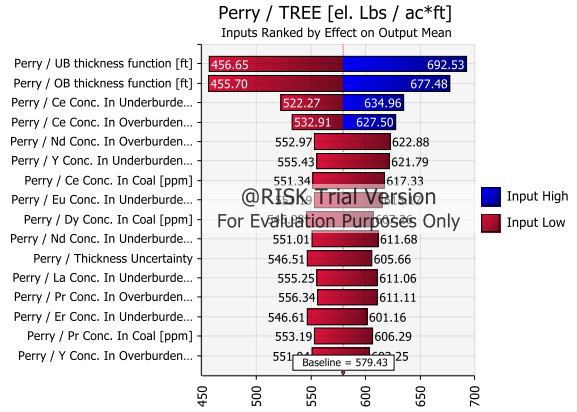
Sensitivity analysis is performed at every scale

- Includes all volumetric parameters
- Analysis reaches through intermediate scales to ultimate causes

County Results
Perry County, Illinois







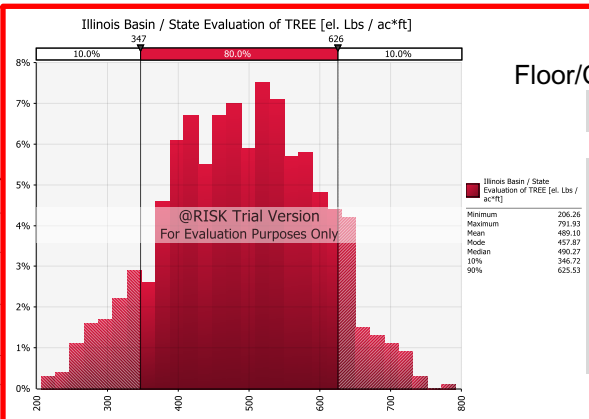
Total REE Estimate for Springfield Coal:

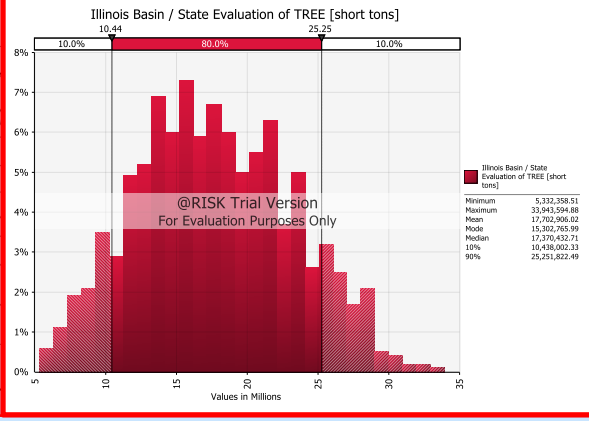
- 500-700lbs/acre*ft coal + floor & ceiling extracted
- For 150k-250k short tons TREE in place in Perry County

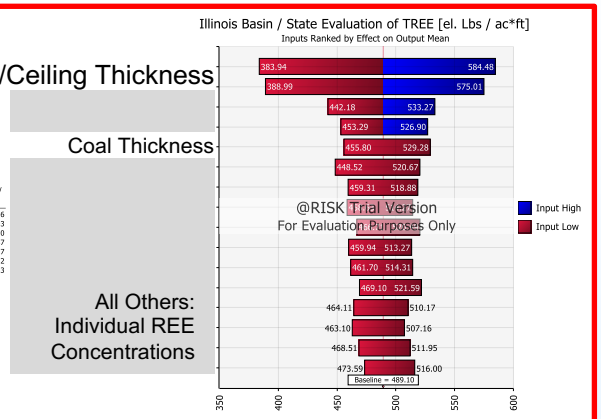
Main factor impacting total REE are thickness of REE-bearing floor and ceiling rock

- Coal thickness is comparatively unimportant
- Coal concentration of REE elements also of limited importance

Basin Scale Results







Total REE Estimate:

- 350-600lbs/acre*ft coal + floor & ceiling extracted
- For 12-24 million short tons TREE in place in the Illinois Basin

Main factor impacting total REE are thickness of REE-bearing floor and ceiling rock

For the Springfield Coal only, mean TREE in place in the Illinois Basin is 17 million tons.

- Note that there are 16 coal seams of interest in the basin

Infrastructure, industries, and businesses (Task 4)

Team is compiling industries and businesses in IB and surrounding regions that use carbon, REEs, or CMs in products (e.g. graphene, magnets, batteries, lasers) or integrate them into final products (e.g. gas and wind turbines, satellite communications)

EXAMPLES:

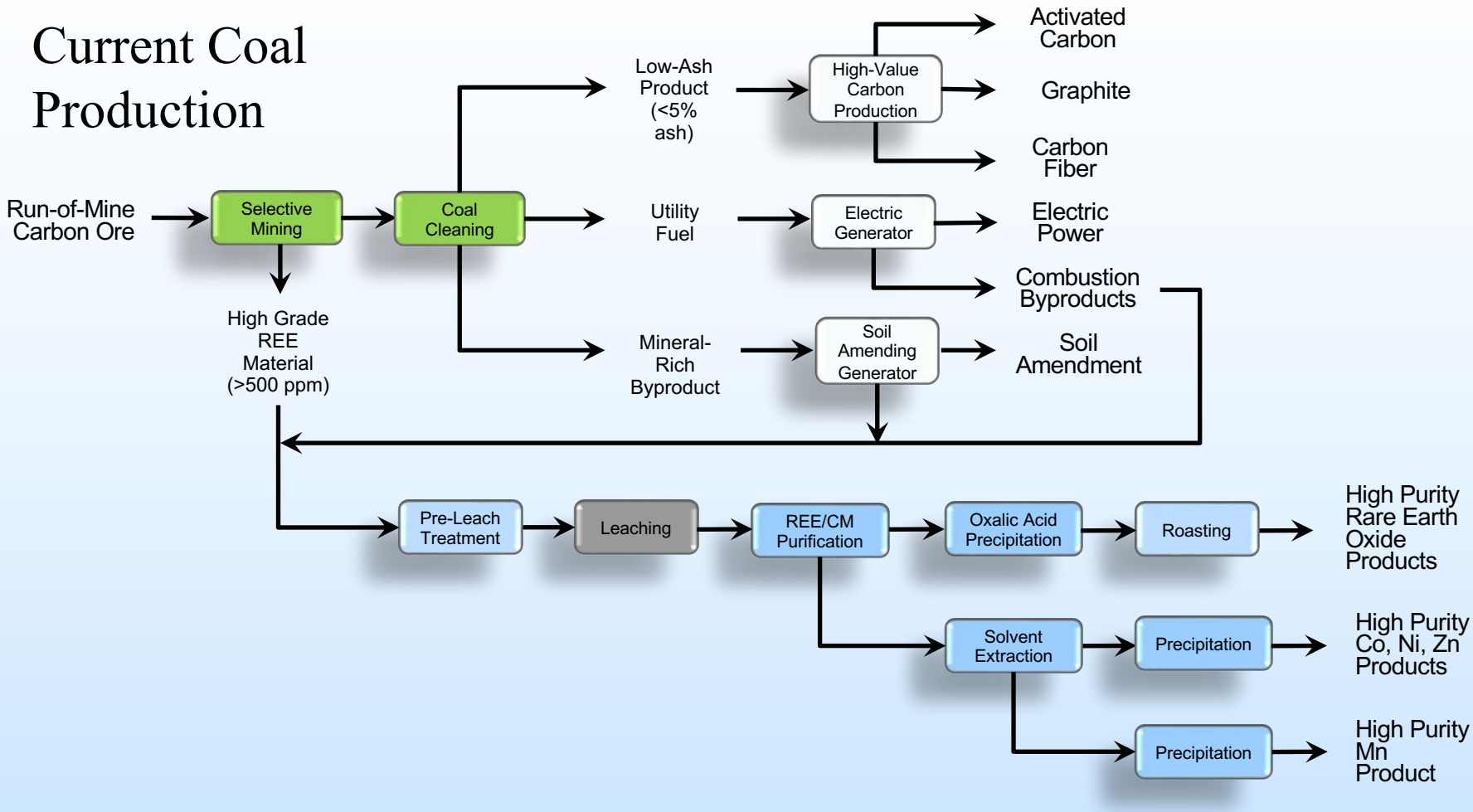
- ***October 19, 2022 – ICL $400 Million lithium iron phosphate cathode active material plant in St. Louis, Missouri***

- ***APRIL 13,2022 -$2 billion electric vehicle battery manufacturing plant coming to Kentucky***

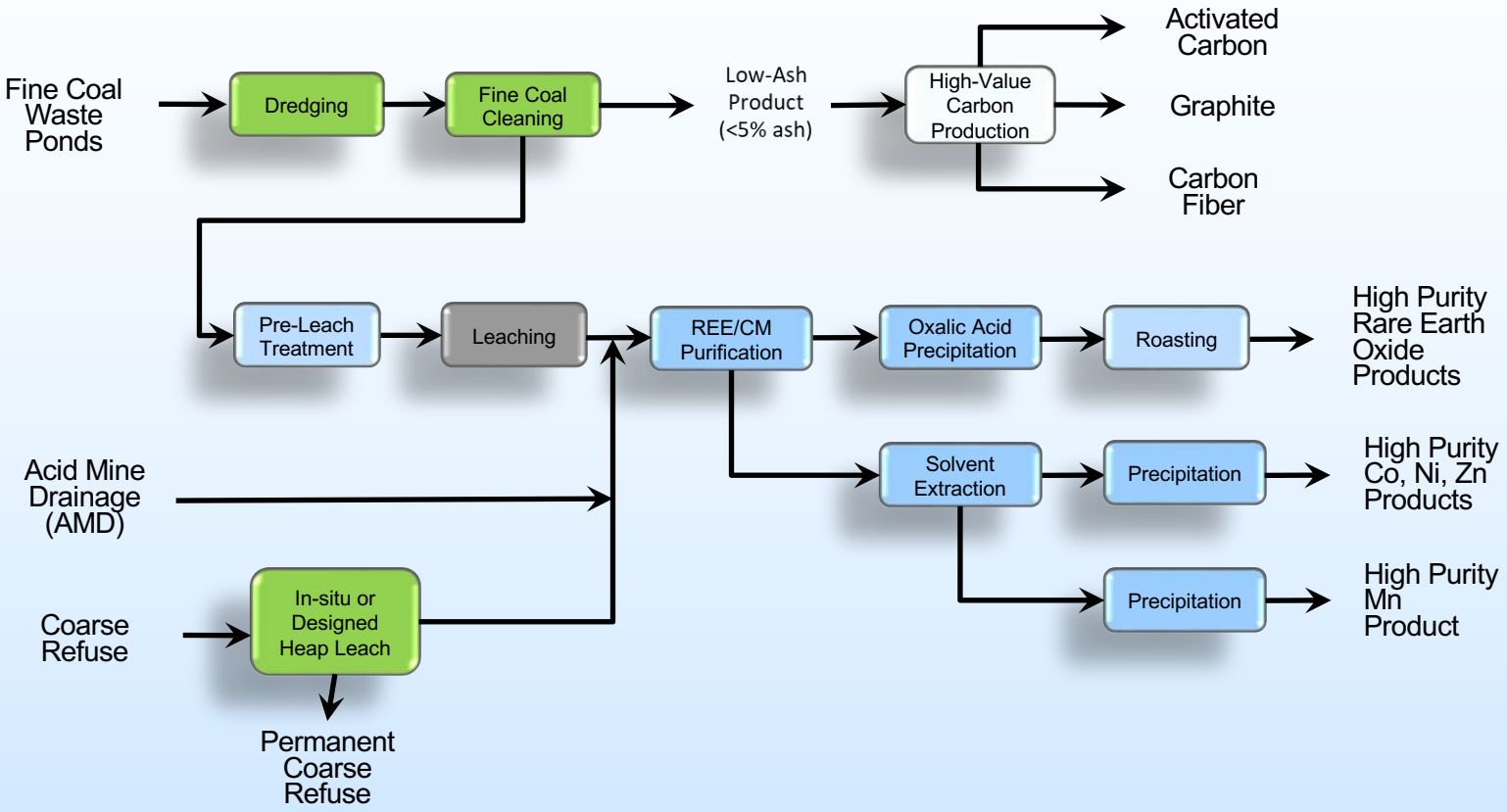
- ***JANUARY 28, 2022 - Quadrant to Add 200 Full-Time Jobs in Louisville with New $95 Million-Plus Magnet Manufacturing Facility***
  - ***Rare-earth magnets will be used in EV motors and other applications***

- ***SEPTEMBER, 2021 - Ford's $5.8B, 5,000-job battery park in Hardin County, Kentucky***

Technology Assessment, Development, and Field Testing (Task 5)



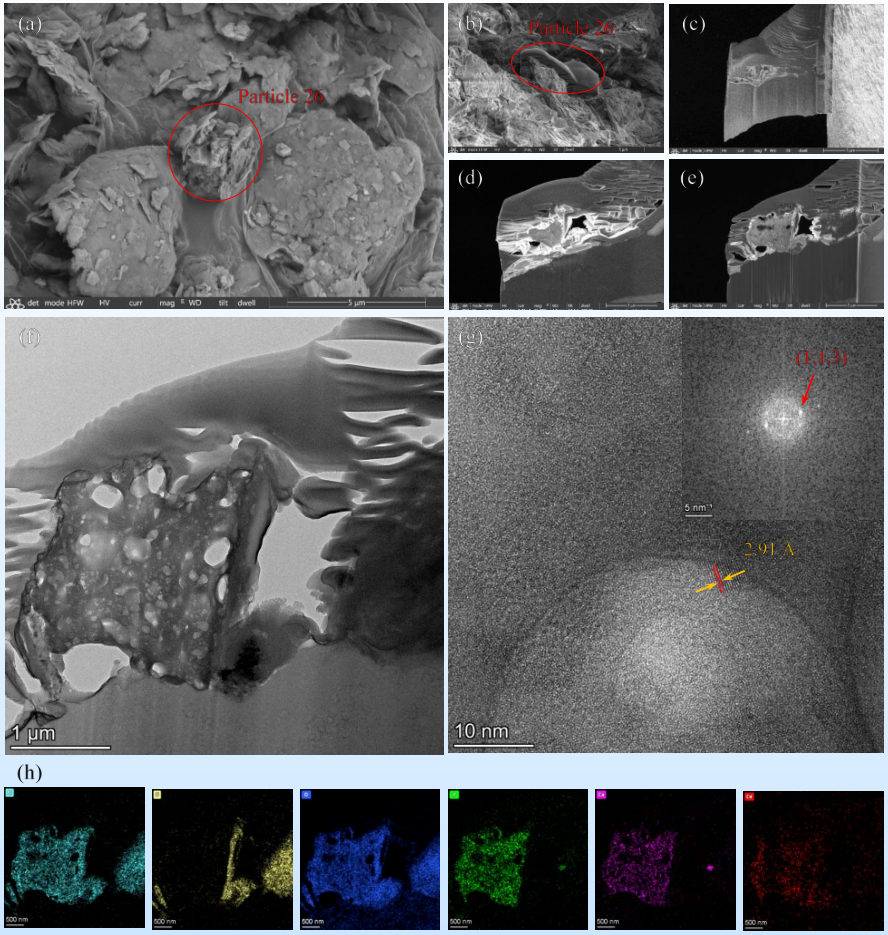
Old Mine Waste Sources



Separation and Purification of CORE-CM

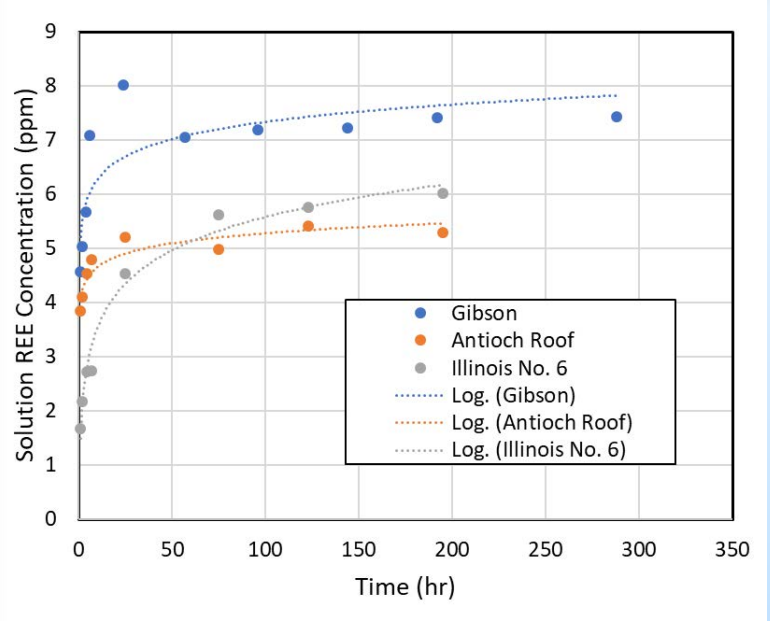
Challenges

- REE mineral grain size is less than 10 microns which limits the ability to pre-concentrate like other richer REE deposits.
- Requires direct hydrometallurgical processing which leads to high contamination in the pregnant leach solution.
- Low feed grade, poor leaching recovery, low PLS concentration, and waste disposal are other concerns of note.
- Prior analyses have shown that chemical costs (acid and base) are a major impediment to an economically viable process.



Separation and Purification of CORE-CM

- Heap leaching is the lowest cost extraction process and commonly used for low grade deposits.
- Samples of coarse refuse were collected at a number of coal operations in the Illinois Basin.
- Weathered and fresh refuse samples were collected to identify differences.
- Bottle role tests were performed to access the heap leach potential of each source.
- The results indicated that the leachable REEs are release within the first hour of the leaching process.



Separation and Purification of CORE-CM

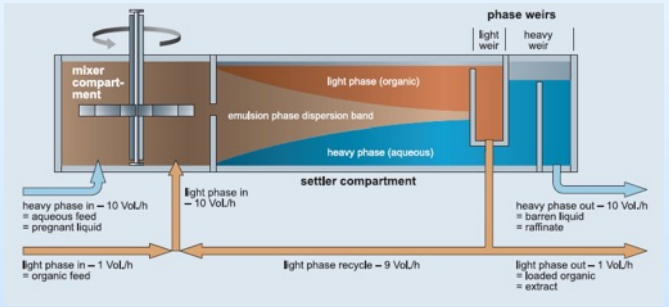
- Higher REE concentrations were generated from the fresh coarse refuse samples.
- REE recovery values of around 10%-12% were achieved on three sources.
- REE contents greater than 5 ppm in the pregnant leach solution (PLS) was achieved on three sources.
- Fe and Al contents in the PLS can be high thereby complicating downstream circuits and costs.

Course Refuse Source	REE Recovery (%)	Solution REE Content (ppm)	Solution Fe Content (ppm)	Solution Al Content (ppm)
Gibson S Fresh	12.0	7.0		
Gibson S Weathered	3.0	1.6	641	85
Hamilton Fresh	5.3	3.0	1237	306
Hamilton Weathered	5.0	2.6	1161	208
WK 13 Fresh	5.5	3.5	781	142
WK 13 Weathered	0.8	0.6		
Illinois No. 6	11.5	5.8	610	233
Antoich	2.0	1.1		
Antoich (roof)	10.0	5.2	5807	185
Antoich (floor)	7.0	2.9	6000	83

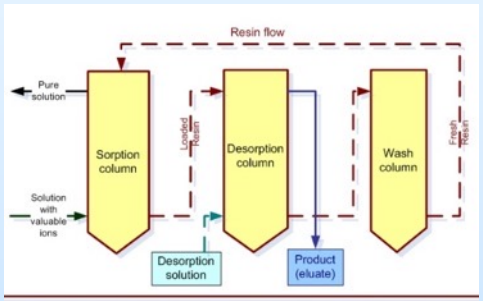
Rare Earth & Critical Material Purification Technologies

- SX is the most widely used technology
  - Requires 900 – 1000 mixer settlers to produce 16 individual REE products.
  - Environmental concerns
- Ion exchange is an alternative
- Emerging technologies:
  - Ion Chromatography
  - Membrane Separation
  - Molecular Recognition
  - Biofilm
  - Microbial Encapsulation

Solvent Extraction (SX)



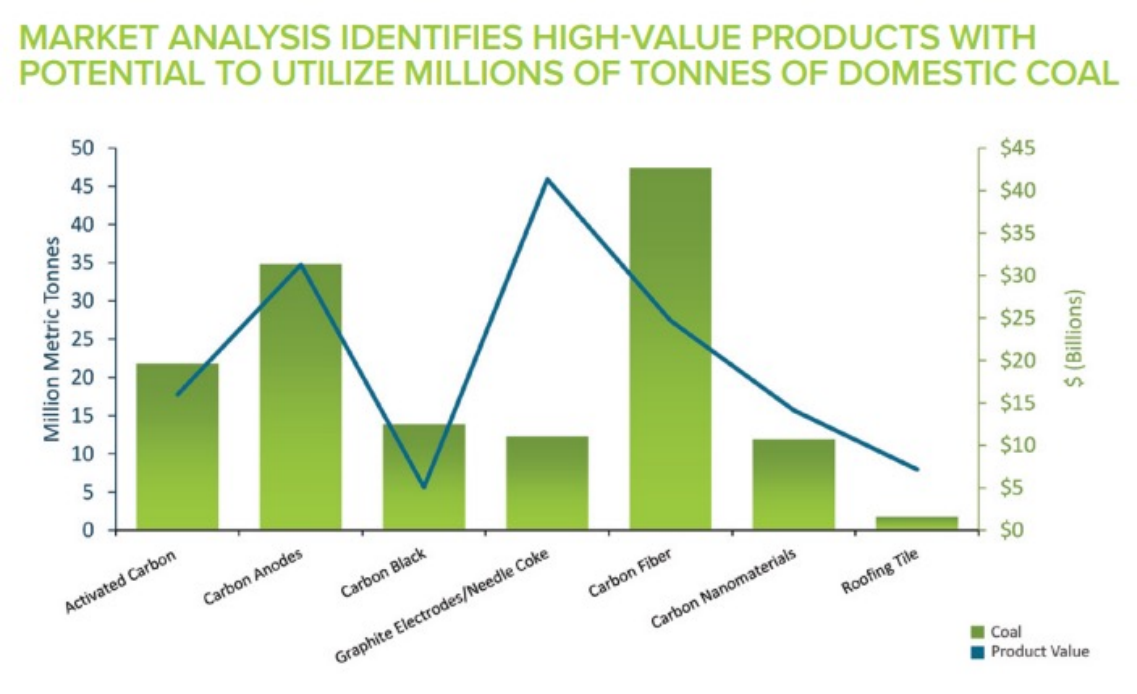
Ion Exchange (IX)



Incorporation of CORE-CM into Products

High-Value Carbon Products

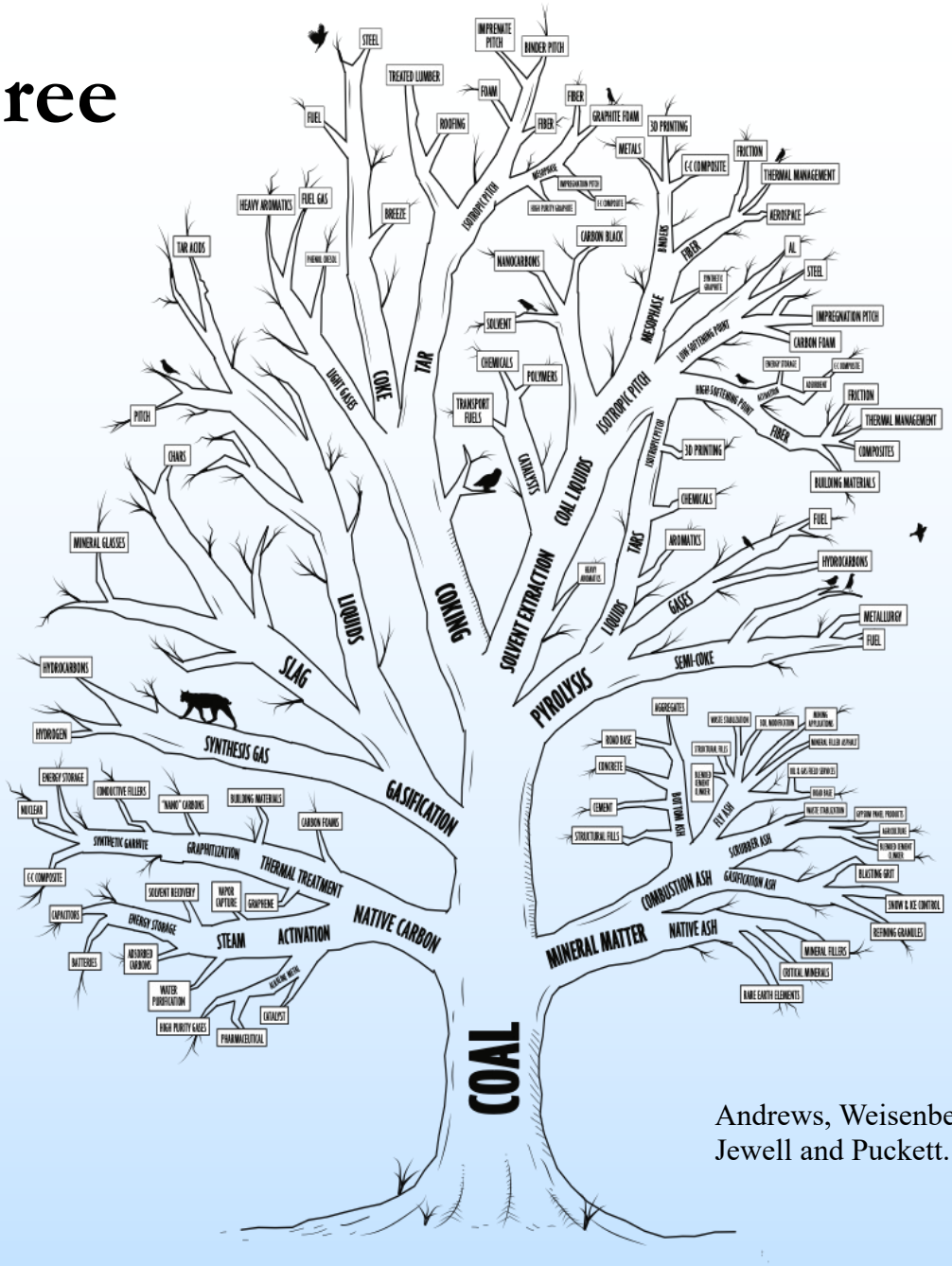
- Metallurgical Anodes (both carbon and graphite)
- Carbons for Energy Storage
- Carbon Fiber
- Activated Carbon
- Carbon Nanomaterials
- Construction Materials
- Carbon Black
- Others



From: NETL *S&T Accomplishments 2020*

A New Coal Tree

- Materials science advances and modern societal demand have fundamentally changed what opportunities coal offers in developing new economic activity and job creation in the nation's coal basins.



Andrews, Weisenberger, Jewell and Puckett. 2022.

IL Basin CORE-CM Technology Innovation Center

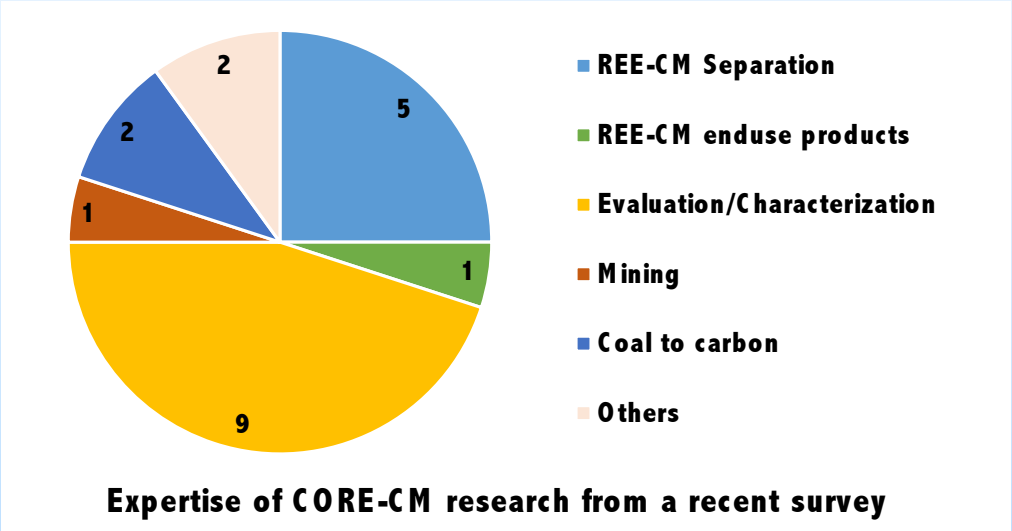
Structured as a hub setup based on 3 university campuses (UIUC, UK, and SIU) to represent a basin-wide geographic distribution of resources and research capabilities

- Provide a regional platform to accelerate **research** for advanced processing & manufacturing of CORE-CM products
- **Engagement** with industry and other private and public stakeholders
- Identify and plan for basin-specific **opportunities of education & training**

Technology Innovation Center with a hub structure based at 3 university campuses in IL Basin

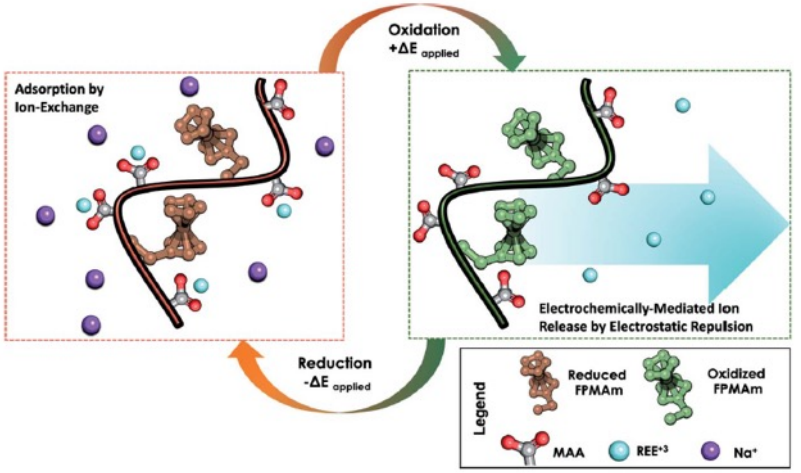
Survey on CORE-CM Research Capabilities & Resources at UIUC, UK and SIU

- A breadth of R&D expertise at 3 campuses, including REE-CM separation, end uses, characterization, mining, carbon materials, etc.
- Existing R&D capabilities available for characterizing and producing REE-CM and carbons such as 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

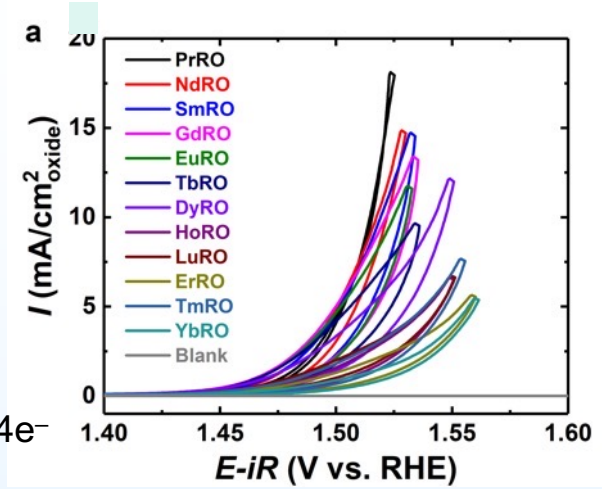
Selected Activities of CORE-CM R&D at UIUC



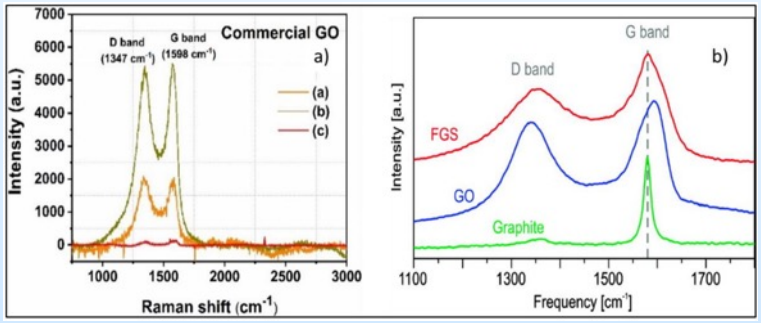
New redox copolymers for selective REE adsorption and electro-chemical regeneration (Vapnik, Elbert, Su. J. Mater. (2021) *Chem. A,* 9, 20068- 20077.)

Oxygen Evolution Reaction (OER)

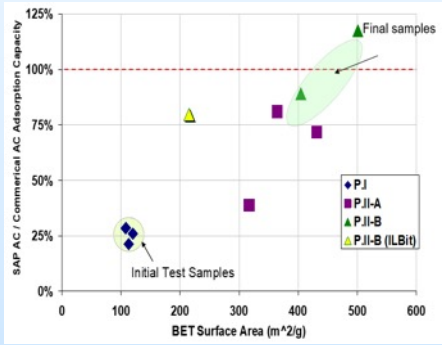
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$



REE for producing electrochemical catalysts such as for H_2 production, CO_2RR, metal-air battery, & artificial photosynthesis (Wang, Zhang, Yang. (2022) *J. of Energy Chemistry*, *70*, 623-629.)



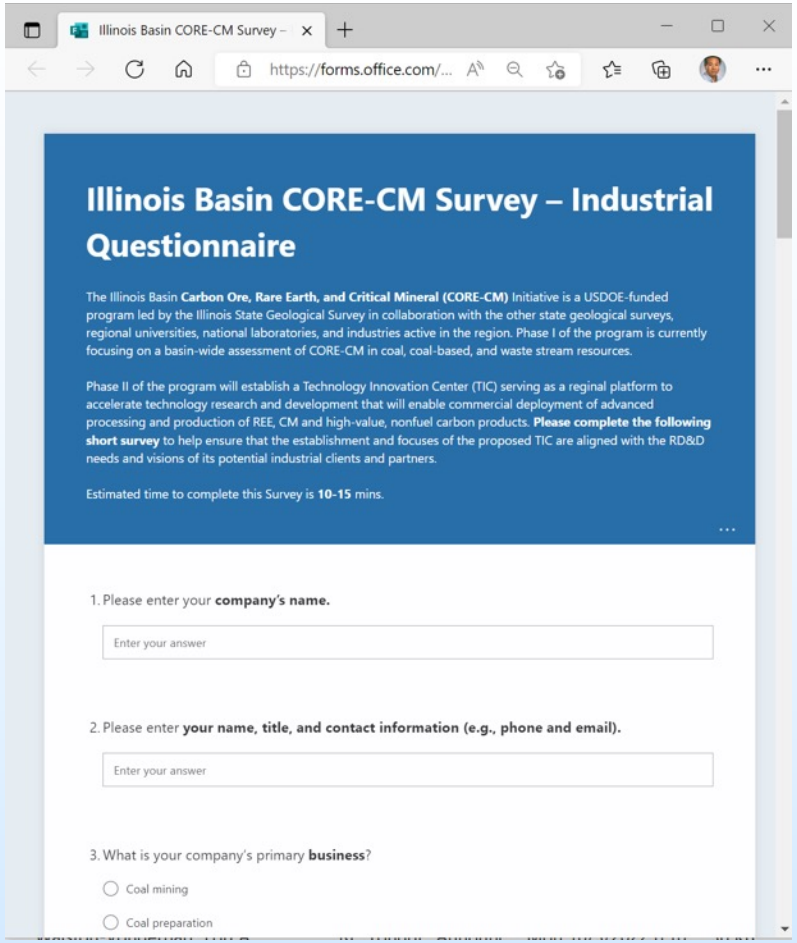
Coal-based and graphite-based graphene oxide (GO) samples showed similar Raman spectra (D and G bands) (Dastgheib. Produce GO, reduced GO (RGO) & functionalized activated carbon (FAC) from US coals. *Award# DE-FE0031798*. 2019-2023)



On-Site production of low-cost carbon sorbents for Hg and acid gas removal using IL and PRB coals (Chang, Lu, Rostam-Abadi. *US Patent No. 9,555,368,* 2017)

Industry Partnerships and Outreach

- Assess reginal industries over the CORE-CM supply chains and workforce needs:
  - Collecting industry information of each CORE-CM sector
  - mines, power plants, batteries, magnet, EV, emerging tech
  - A survey is currently in preparation to obtain inputs related to industrial needs, roles, engagement, workforce development opportunities, etc.



An Industrial Survey in Preparation to Collect Industrial Inputs for TIC Planning

Partnerships

- Technical Advisory Board
- Prairie State Generating Company
- Community Colleges

Prairie State Generating Company

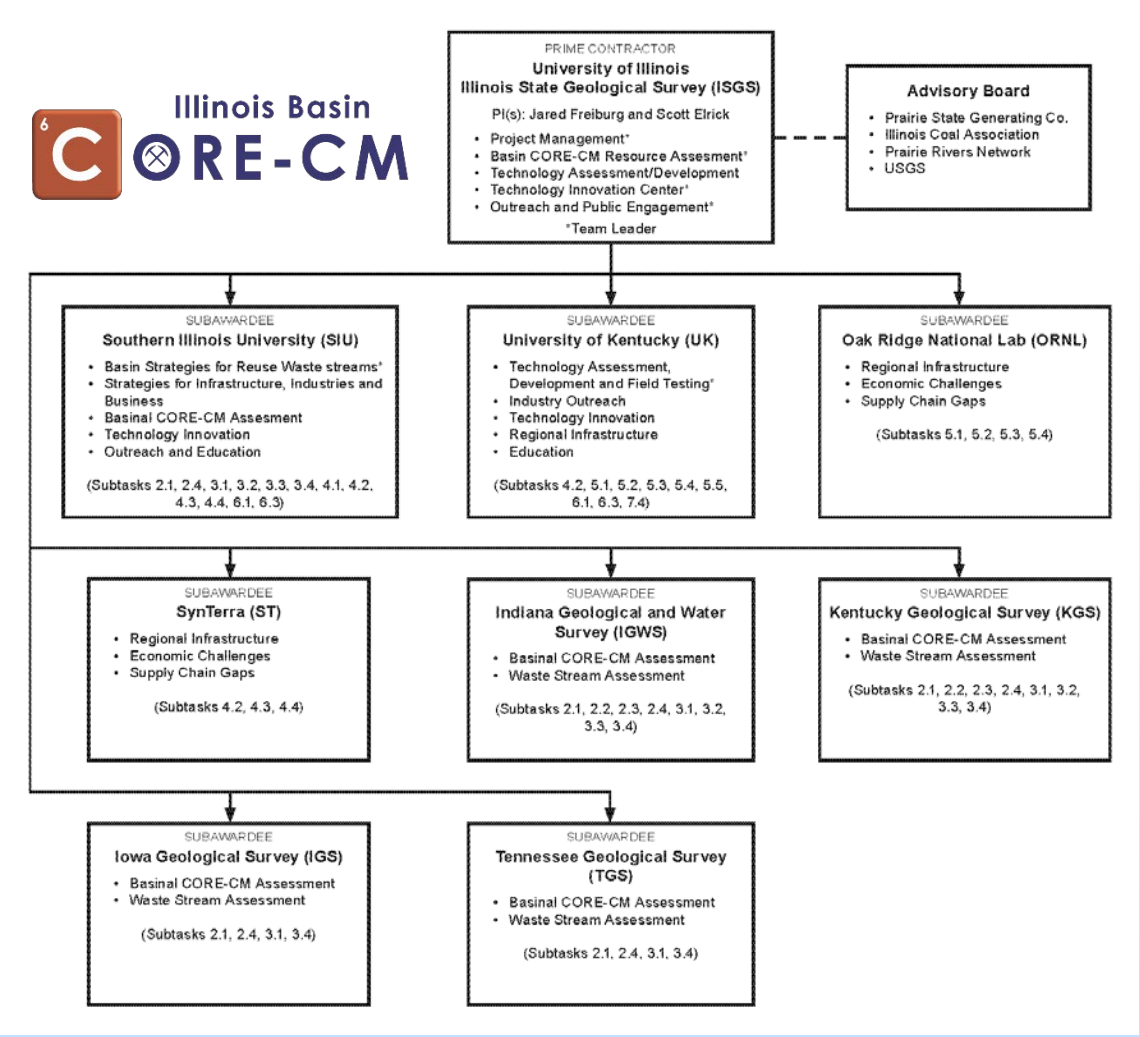
"together we can do great things"

Summary

The Illinois Basin provides a major opportunity to develop a new industry using coal-waste

- Extensive Characterization and Resource Model
- Business and partnership opportunities
- Development of new CM separation and carbon technologies
  - Field testing
- The Illinois Basin Technology Innovation, Research, and Education Center
- Outreach, partnership, and collaboration!

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								

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	10/21/21			
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	09/20/23		75%	
1.0/1.2	E	Input for NET REE-SED Sample data Needs	09/20/23		50%	
1.0	F	Phase 1 Final Report	09/20/23			
2.0	G	Basinal Resource Assessment	06/20/23		50%	
2.0/2.3	H	Resource Assessment Gap Analysis	12/20/22		90%	
2.0/2.4	I	Characterization and Data Acquisition Plan	12/20/22		90%	
2.0/3.0	J	Resource Samples for Mineral Characterization and Analysis	5/20/23		75%	
3.0	K	Initial Waste Stream Reuse Plan	06/20/23		20%	
4.0	L	Results of Basinal Strategies for Infrastructure, Industries and Business Assessment	06/20/23		10%	
4.0/4.4	M	Supply Chain Gap Analysis	12/20/22		20%	
5.0	N	Initial Technology Assessment and Field Development Plan	06/20/23		75%	
5.0/5.1	O	Technology Gap Analysis	12/20/22		90%	
5.0/5.2	P	SIPOC Analysis	12/20/22		75%	
6.0	Q	Initial Technology Innovation Center Plan	06/20/23		20%	
7.0	R	Initial Stakeholder Outreach and Education Plan	06/20/23		10%	