NETL REE/CM-SED Assessment Method

Developing a Geo-data Science Driven Approach to Assess UCR REE/CMs in Carbon Ore and Related Systems

NATIONAL ENERGY TECHNOLOGY LABORATORY

Geo-Data Science Team:

- ***Geology*** **- Kelly Rose[1], Andrew Bean[2], Gabe Creason[2], MacKenzie Mark-Moser[2]**
- ***Geochemistry*** **- Burt Thomas[2] & Scott Montross[2]**
- ***Geostatistics, GIS*** **- Devin Justman[2], Kelly Rose[1], LRST pending staff[2]**
- ***Database & Computing Scientists*** **– Mike Sabbatino[2], Patrick Wingo[2], LRST pending staff[2], ITSS comp scientists[3]**

1 NETL, 2 LRST Contractor to NETL, 3 ITSS Contractor to NETL

U.S. DEPARTMENT OF ENERGY

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Warranty Disclaimer:

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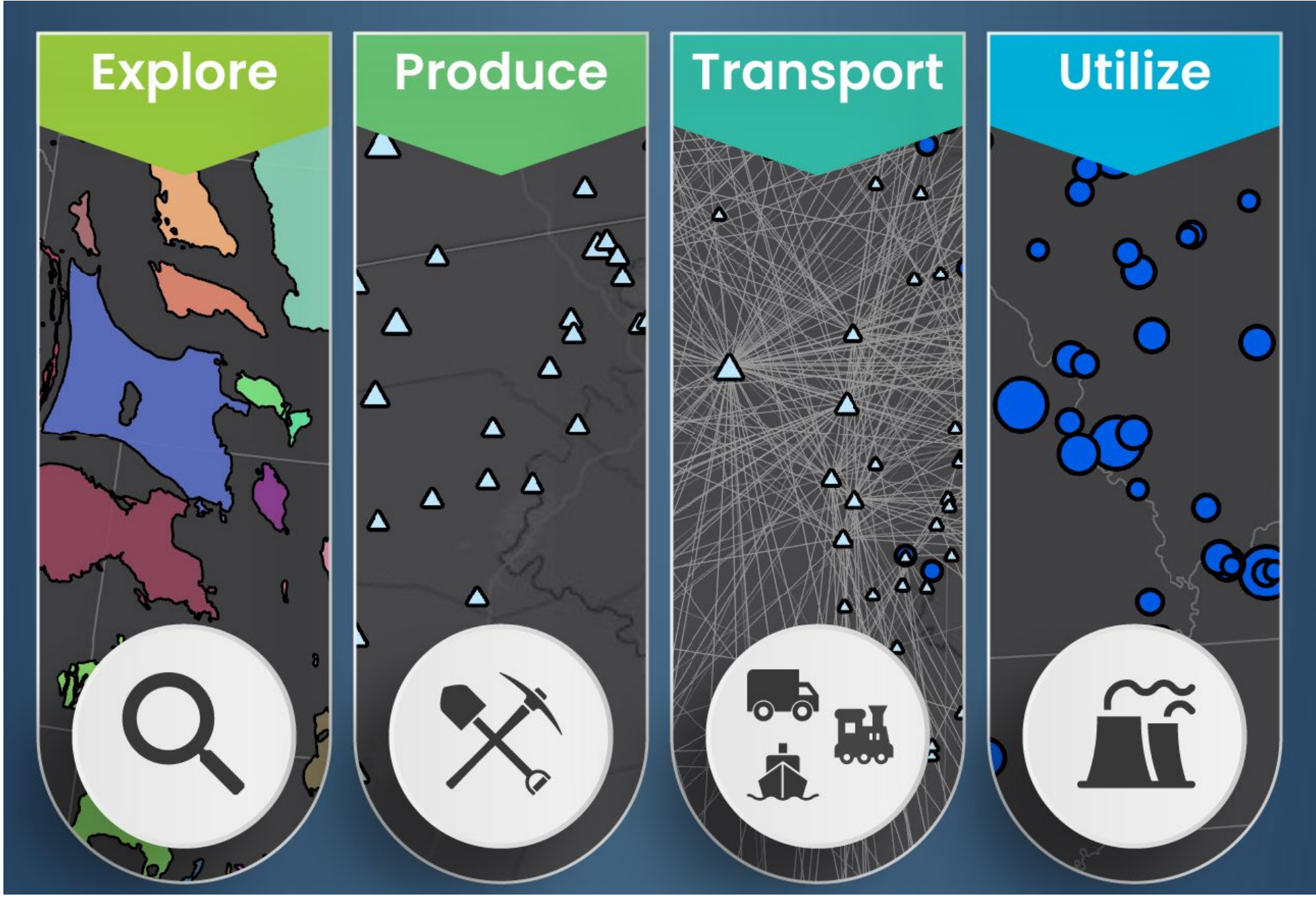
Developing data, models & tools to predict occurrence of unconventional REE/CM resources



Accelerating access to domestic UCR REE/CM resources from sedimentary/carbon ore systems, including waste materials

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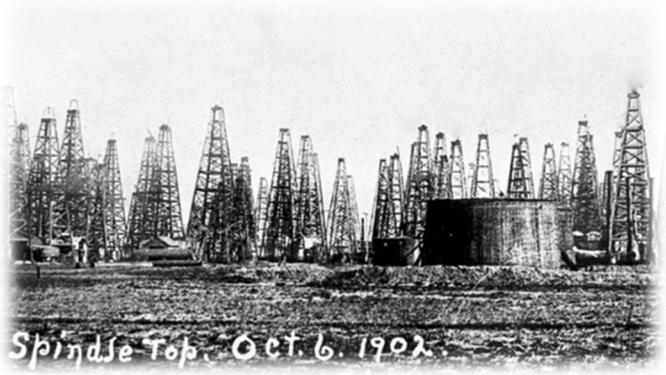
Mineral resources come from geologic media…



Economic deposits are <u>not</u> random…

Systematic, geologic-driven methods <u>improve predictability</u>…

To unlock domestic unconventional REE/CM-SED potential, requires data & knowledge informed predictions

Finding REE *"needles"* in the proverbial geological *"haystack"*

NETL is developing the REE-SED method to identify domestic deposits and unlock the domestic, economic REE supply from carbon ore and sedimentary systems

For prediction and ID of high concentration deposits

1st approach for assessing REEs in carbon-ore systems

Using a big-data, ML enabled geoscience approach

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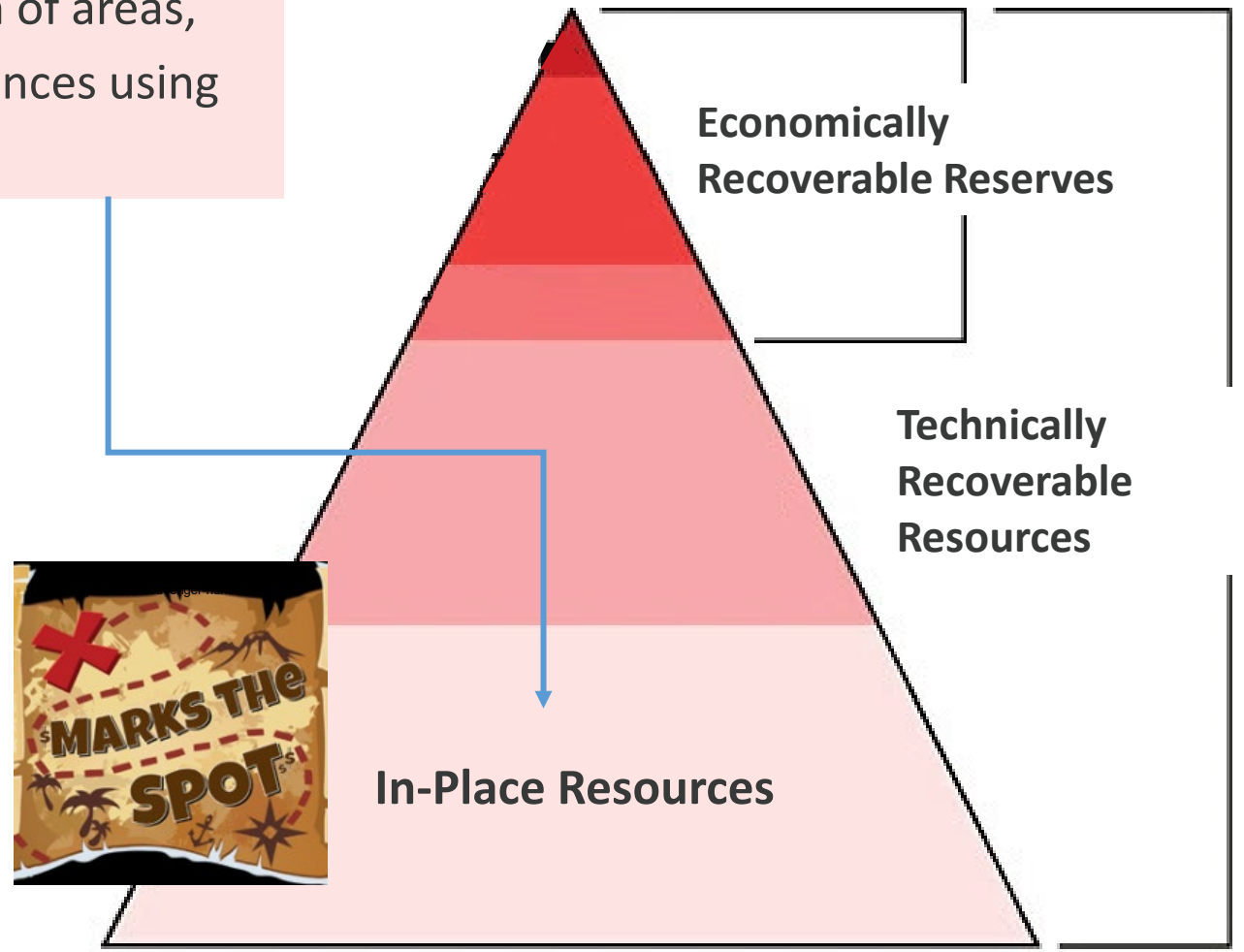
Research Success Metric

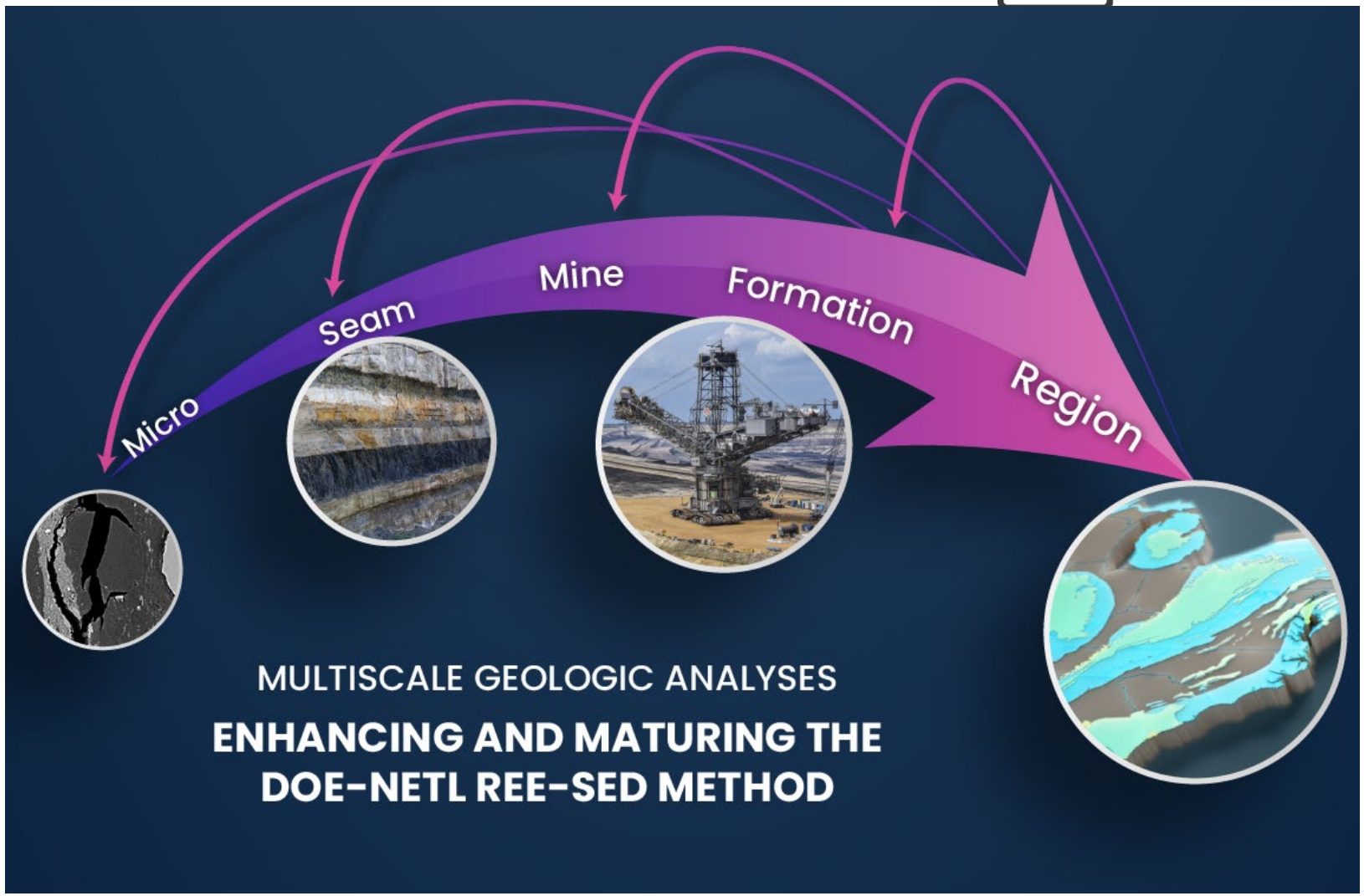
Success = ability to validate, verify prediction of areas, regions with higher potential for REE occurrences using the NETL REE/CM-SED assessment method

- **A specific grade or cutoff is <u>not</u> our goal**
  - Like other resources (e.g. hydrates, oil/gas, gold, coal etc) resource grade is tied to economic and technology factors
  - Economic "cutoffs" vary as commercial and technological factors evolve
- **Establishing the in-place potential benefits the rest of DOE's UCR REE/CM program**
  - As separation and extraction technologies improve, economic reserves and technically recoverable resources shift up from in-place
  - From there other NETL projects and industry will drive how the upper tiers of the resource metrics evolve



REE/CM-SED Is Multi-Scale, Data Dependent

- Success = ability to strategically predict and estimate the volume of total REE/CM-SED resource at **better than random** odds
  - From 1960 to 2010 the “dry hole” metric for oil/gas wells dropped from a level of over 40% in the 1960s to about 10% in 2010 – EIA
- With more knowledge & data, the accuracy of the REE/CM-SED approach will improve

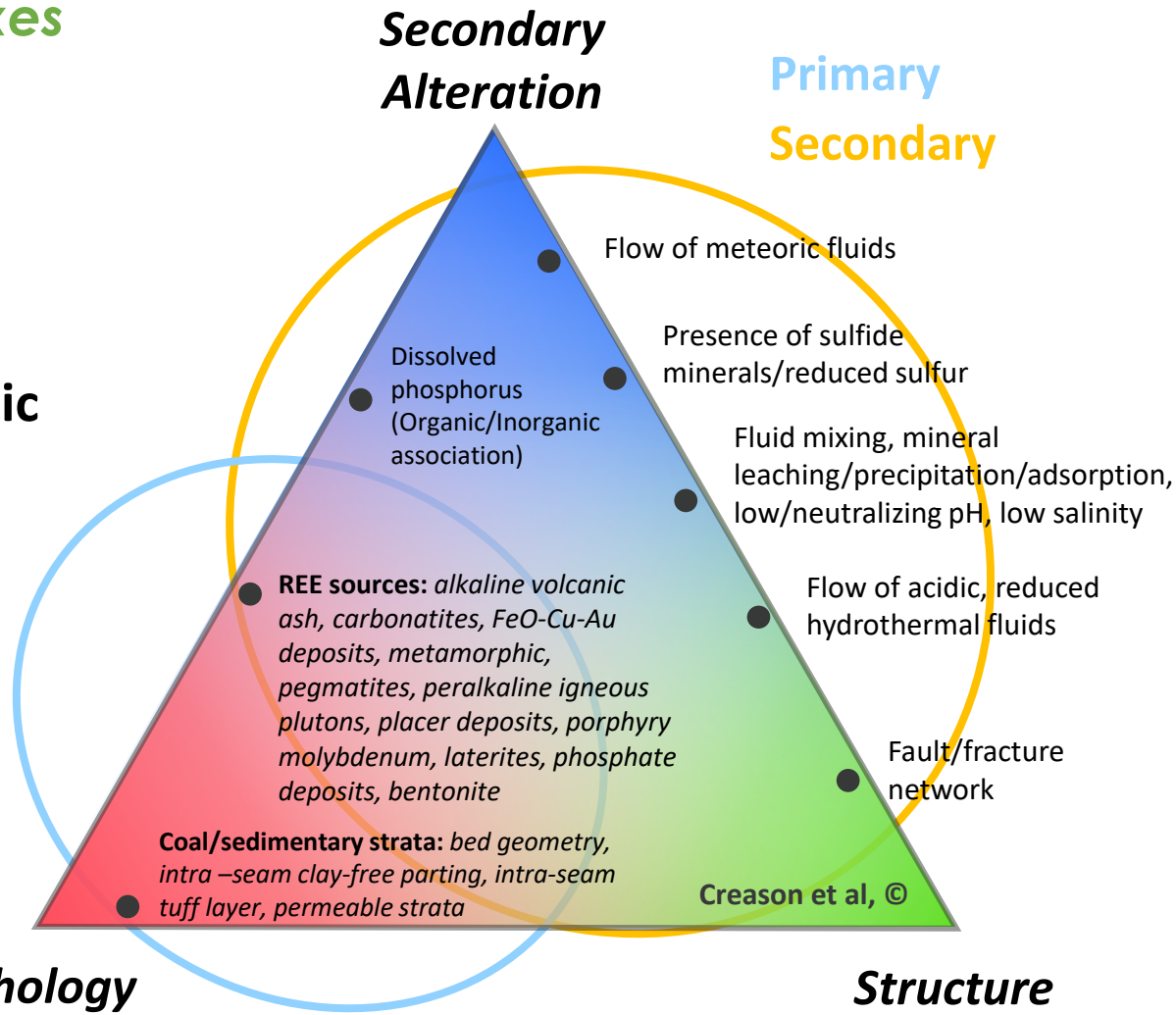


REE Task 9: A systematic, holistic approach

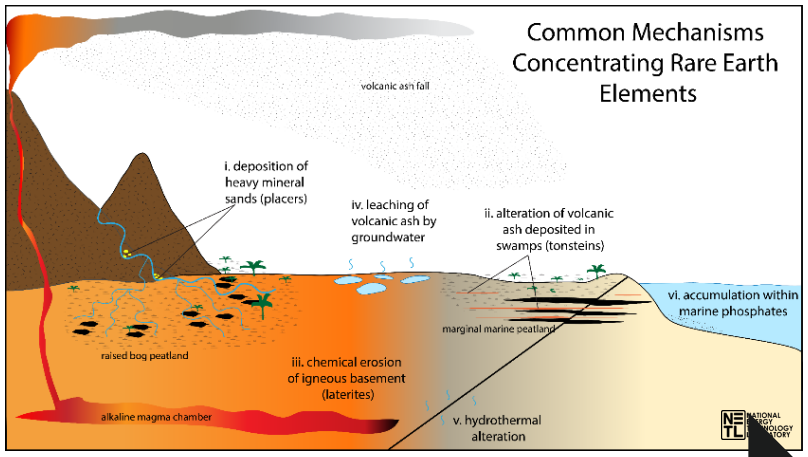
REE/CM-SED enrichment mechanisms vs STA axes

REE SOURCES + ACCUMULATION PROCESSES = REE SED DEPOSITS

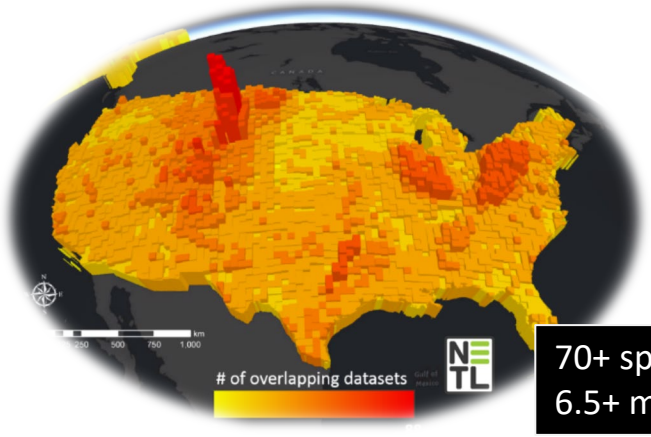
- The occurrence of natural resources are **not random**, they are a product of geologic processes
- **Most REE-SED deposits involve secondary geologic mechanisms**. Tonstein deposits are only documented primary REE-SED deposit type.
- In combination with data science methods we are further **reducing uncertainty** and **improving accuracy** of predictions to drive techno-economic efficiency in REE-SED discovery and extraction
- Uncovering REE enrichment processes
  - Primary
  - Secondary



Geologic processes + Data underpin REE/CM-SED Method



Distilled knowledge from 100's of geologic studies of REE SED systems combined with millions of data records to the method

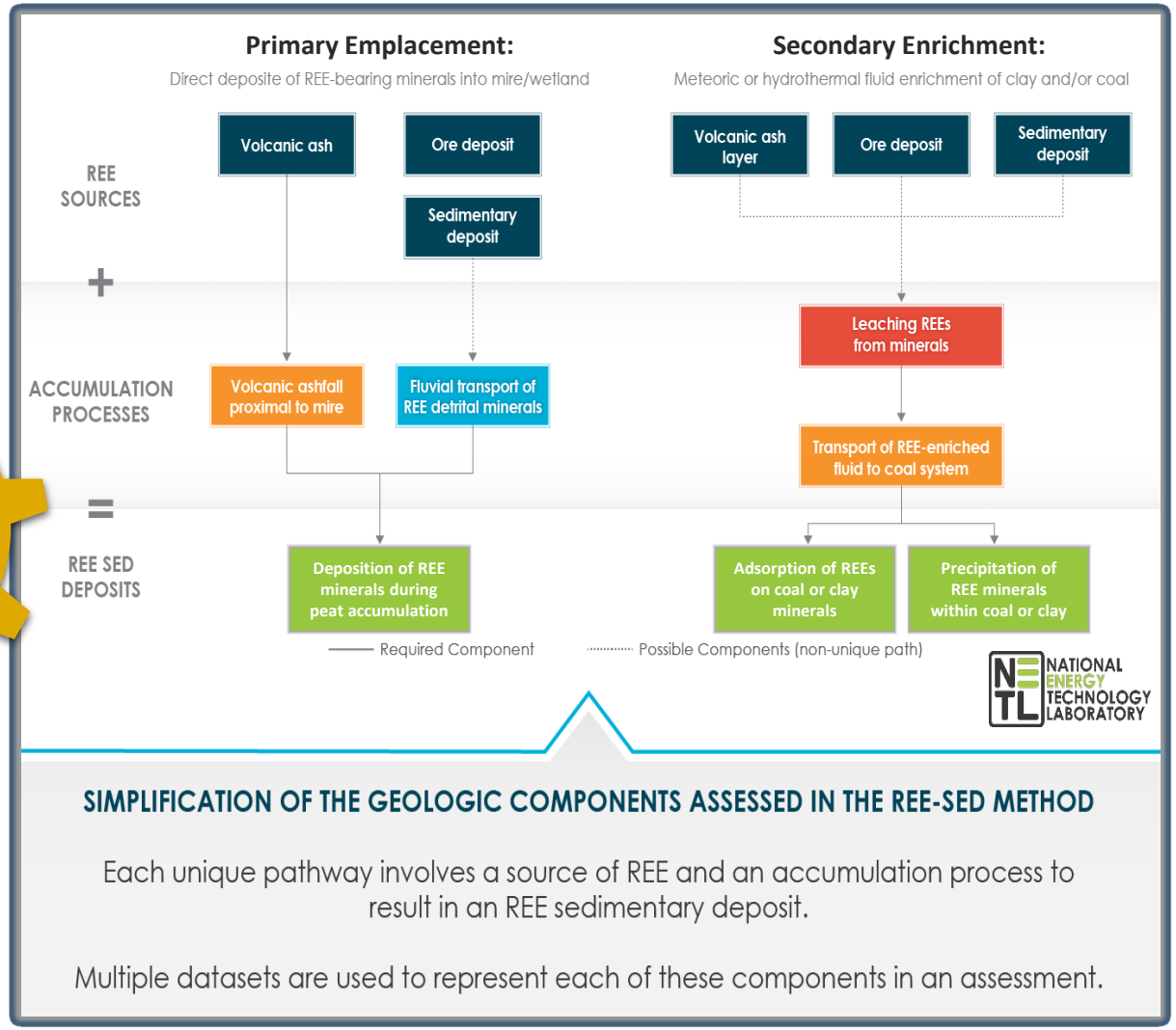


70+ spatial datasets
6.5+ million records

Geologic Processes

REE Sedimentary Assessment

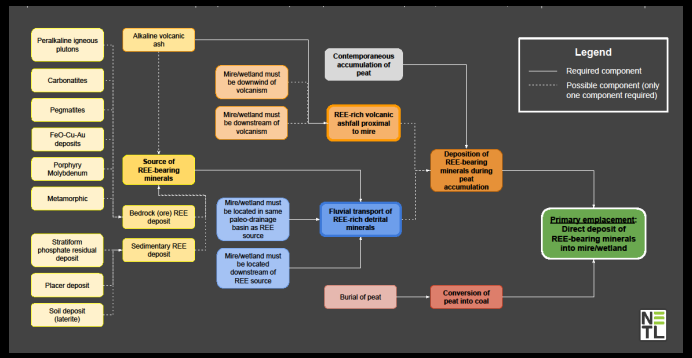
Data



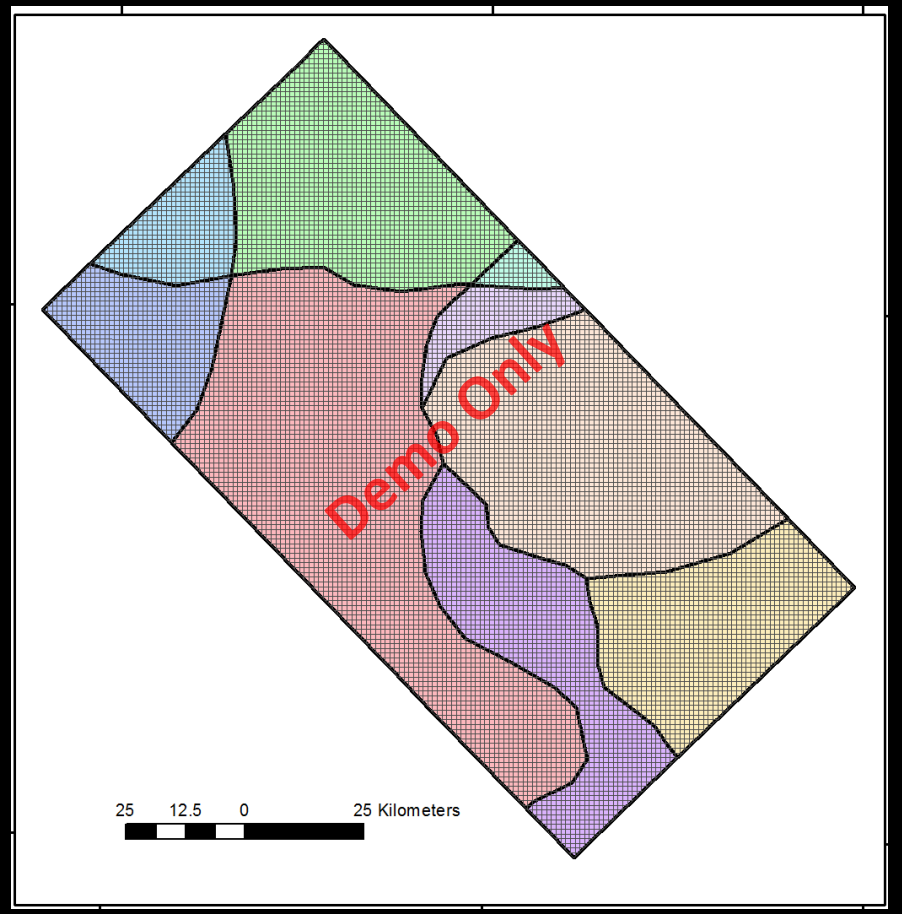
Creason, C. G., Bean, A., Rose, K., Justman, D., Thomas, R., Montross, S., Wingo, P., Mark-Moser, M., Ruppert, L., A Geo-Data Science Method for Assessing Rare Earth Element Occurrences in Coal and Other Sedimentary Systems, in prep, *Coal Geology*

Implementing the REE/CM-SED Assessment Method

Calculate the Potential for Emplacement (PE) metrics for each mechanism



Creason et al, ©



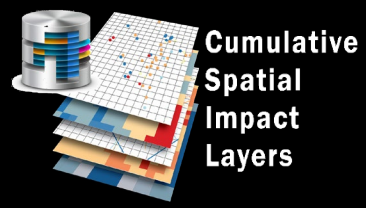
Assess possible types of REE/CM emplacement mechanisms

For each grid cell:

$$\text{PE Score} = \frac{\sum Ds_n}{Dr}$$

PE metrics:

- % data available
- % data supporting
- Net support



Romeo et al., 2019

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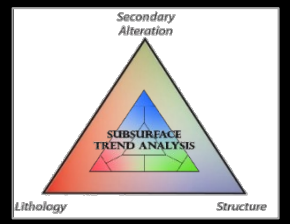


Rose et al., 2020

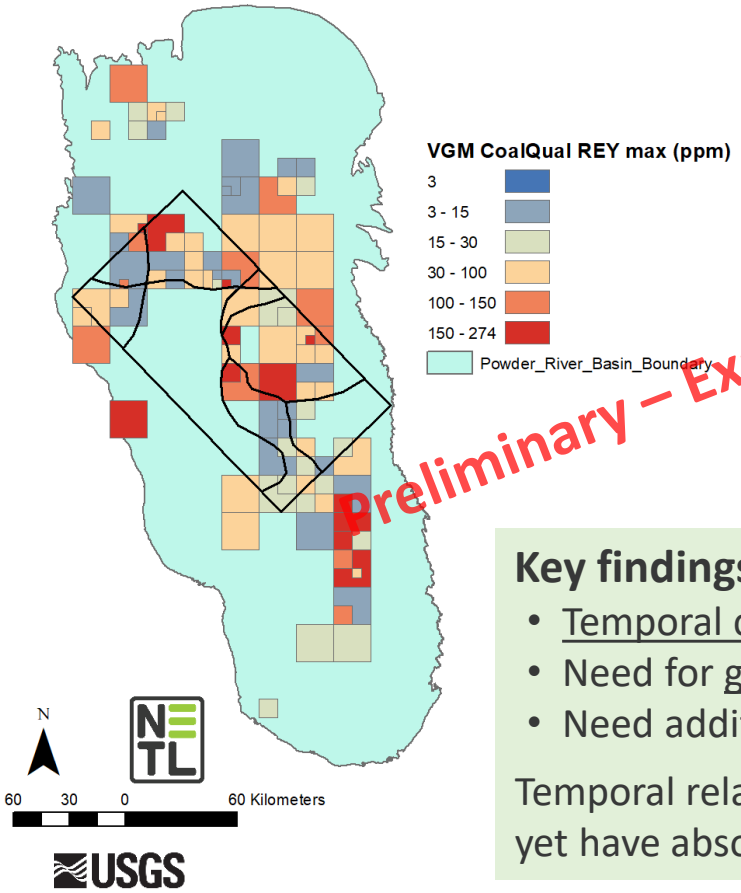
Creason, C. G., et al., A Geo-Data Science Method for Assessing Rare Earth Element Occurrences in Coal and Other Sedimentary Systems, in prep, *Coal Geology*

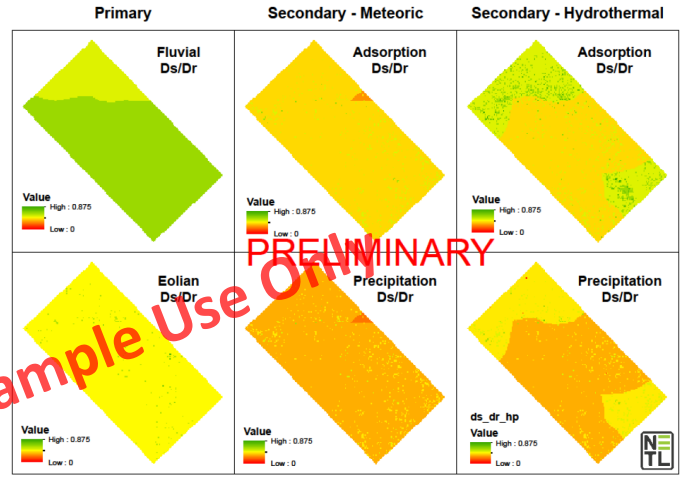
REE subtask 9.1.1

Current Status

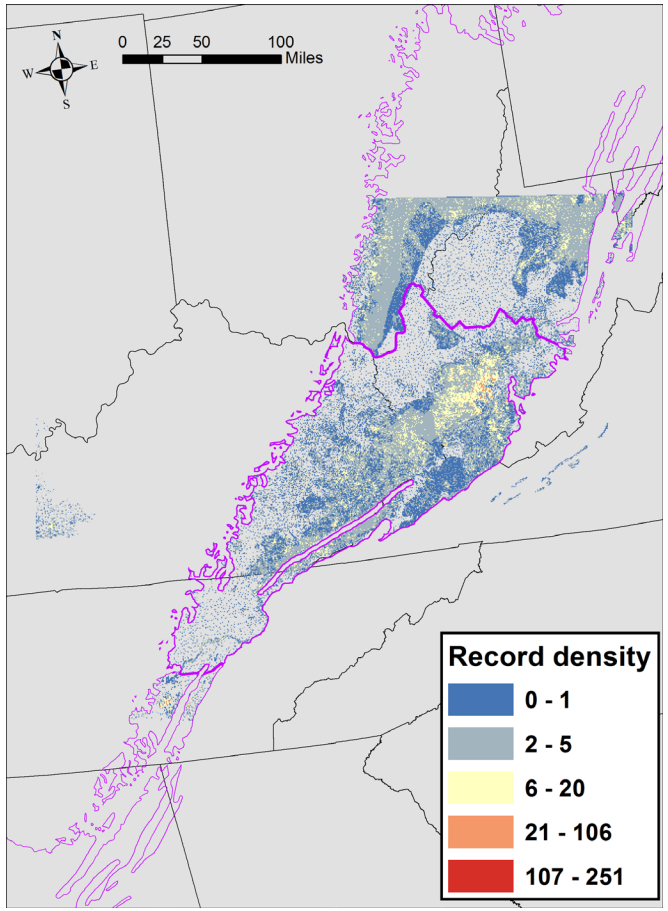
Validation of pilot test at basin scale

Tested in Powder River Basin, validation is ongoing





Performing test in Central Appalachian Basin, a more complex geologic environment



Key findings:

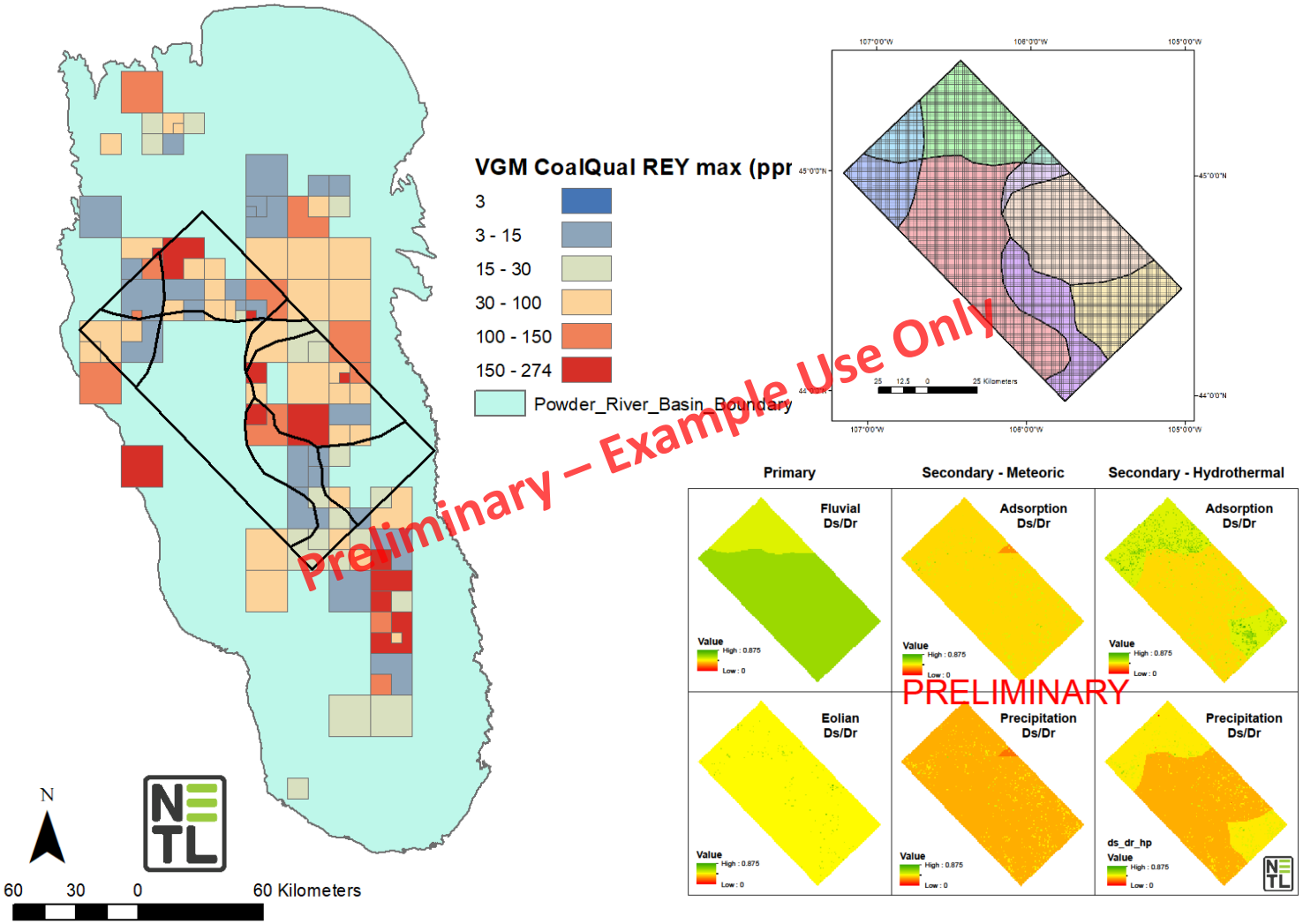
- Temporal constraints critically important to successful assessment
- Need for geologically constrained validation data
- Need additional data and information for key enrichment processes

Temporal relative relationships are codified in the method, but do not yet have absolute spatially explicit temporal relationships delineated

Creason, C. G., Bean, A., Rose, K., Justman, D., Thomas, R., Montross, S., Wingo, P., Mark-Moser, M., Ruppert, L., A Geo-Data Science Method for Assessing Rare Earth Element Occurrences in Coal and Other Sedimentary Systems, in prep, *Coal Geology*

9.1 Recent & Next Steps

Creason, C. G., Bean, A., Rose, K., Justman, D., Thomas, R., Montross, S., Wingo, P., Mark-Moser, M., Ruppert, L., A Geo-Data Science Method for Assessing Rare Earth Element Occurrences in Coal and Other Sedimentary Systems, in prep, *Coal Geology*



- **Calibrating method based on CoalQual data, REE coal core data (UWyo)**
- **Incorporating fuzzy logic into workflow using SIMPA tool**
  - Reduce effects of ‘hard’ domain boundaries
- **Using the Variable Grid Method to communicate uncertainty, quantify and visualize PE scores**
- **Integrating temporal components**
  - Consider order of operations, time-varying components
- **Developing an additional metric to represent “inferred” potential for enrichment**
  - More appropriate representation of PE score
- **Coordinating with USGS, OSMRE, others**
  - Access to additional data for Central App (esp. supplementary CoalQual data)
  - More data from WVGES, Kentucky Geo Survey

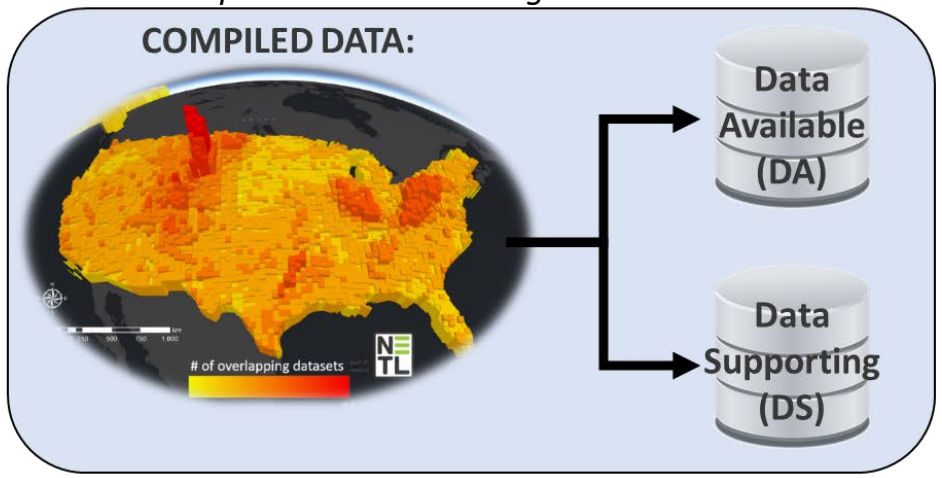
GUI Assessment Tool in Development

Ongoing work to guide end-user implementation of REE/CM-SED Method

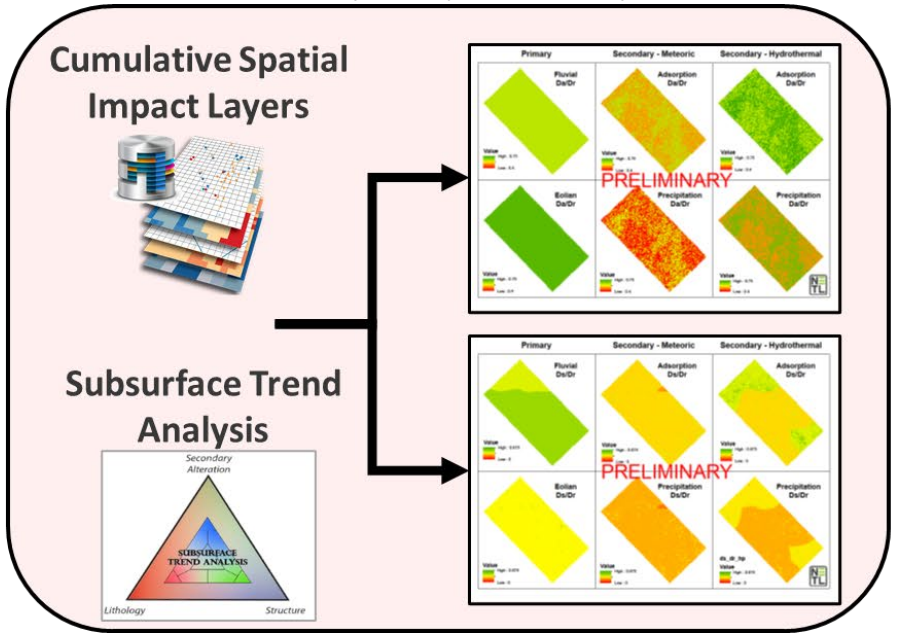
Leverage NETL big data, geo-data science tools, to facilitate REE/CM-SED Assessment Tool Development:

1. **Semi-automated data compilation into REE/CM-SED database using custom-developed tools (ongoing dev)**
2. **NETL's STA tool for REE/CM-SED inputs; results visualized spatially using NETL's CSIL tool**
3. **NETL's VGM to understand distribution of validation data, uncertainty quantification**

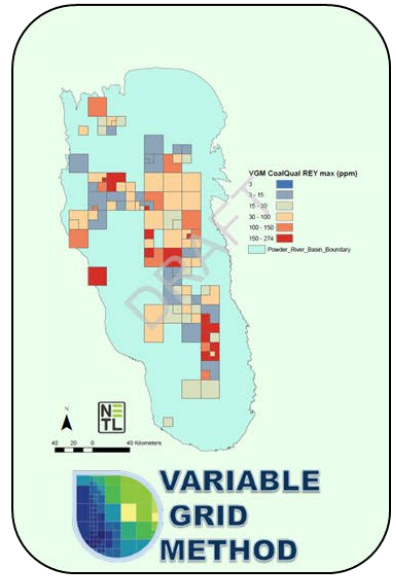
Compiled & collated using internal tools



Romeo et al., 2019; Rose et al., 2020



Bauer & Rose, 2015



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Ongoing work to guide end-user implementation of REE/CM-SED Method

- **Data collector module**
  - Combines raw, disparate spatial resources and compiles into databases **based on codified REE enrichment components**
- **Grid constructor module**
  - Divides region into grid cells **based on STA domains (lithologic, structural, secondary alteration)**
- **PE Score calculator module**
  - Leverages database outputs and grid from previous modules to **calculate PE score for all 3 categories: Primary, Secondary (meteoric & hydrothermal)**

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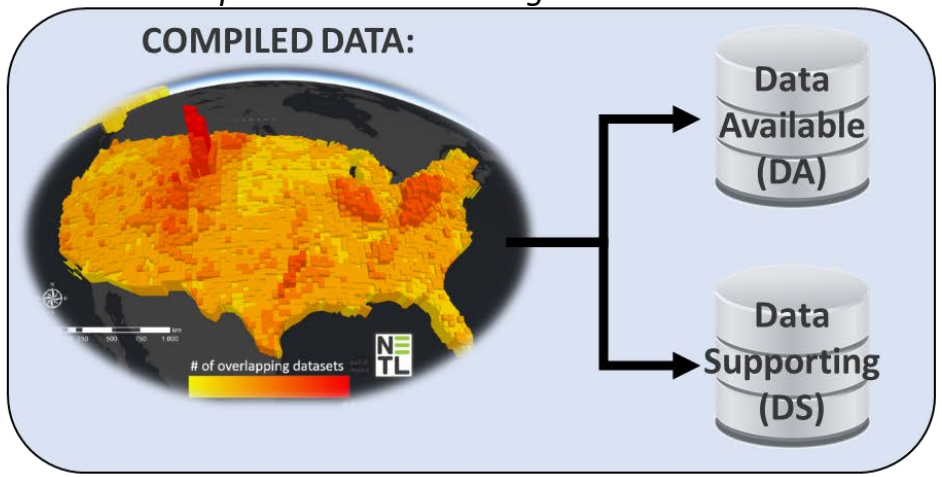

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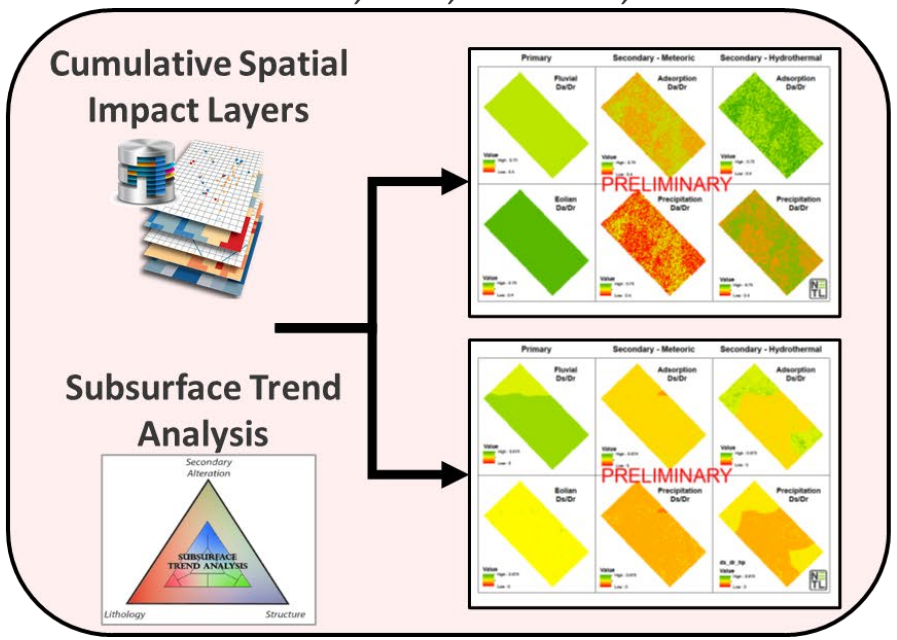

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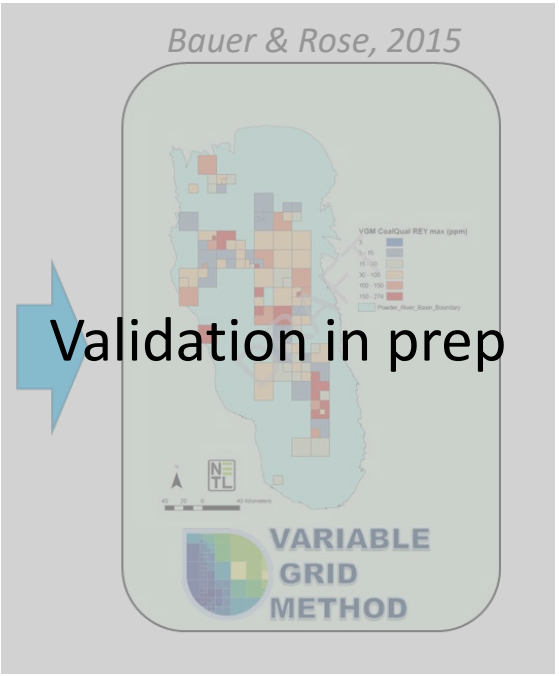

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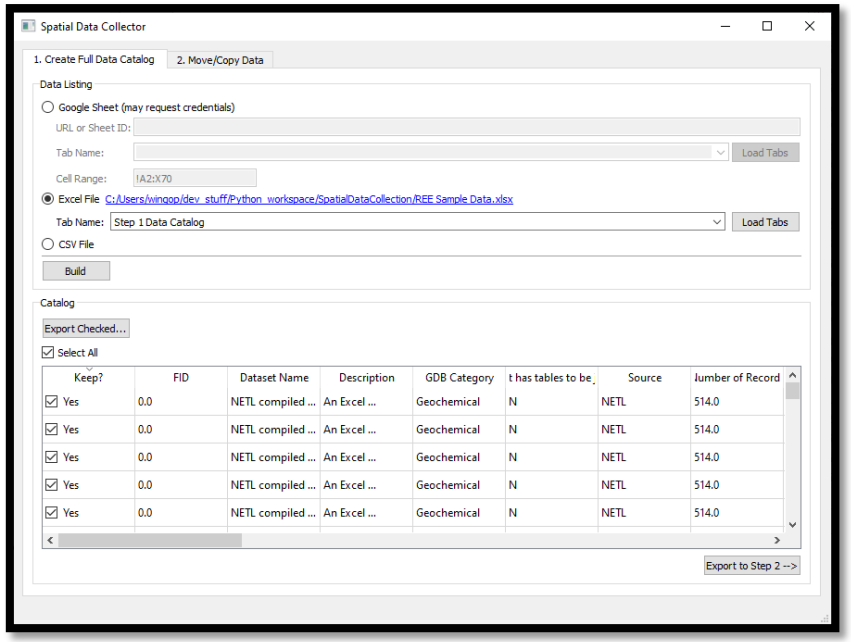

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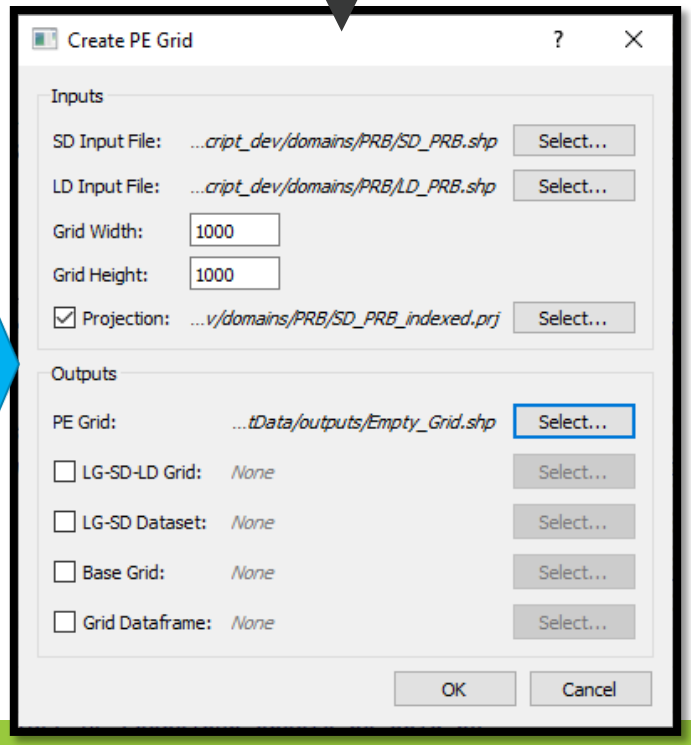

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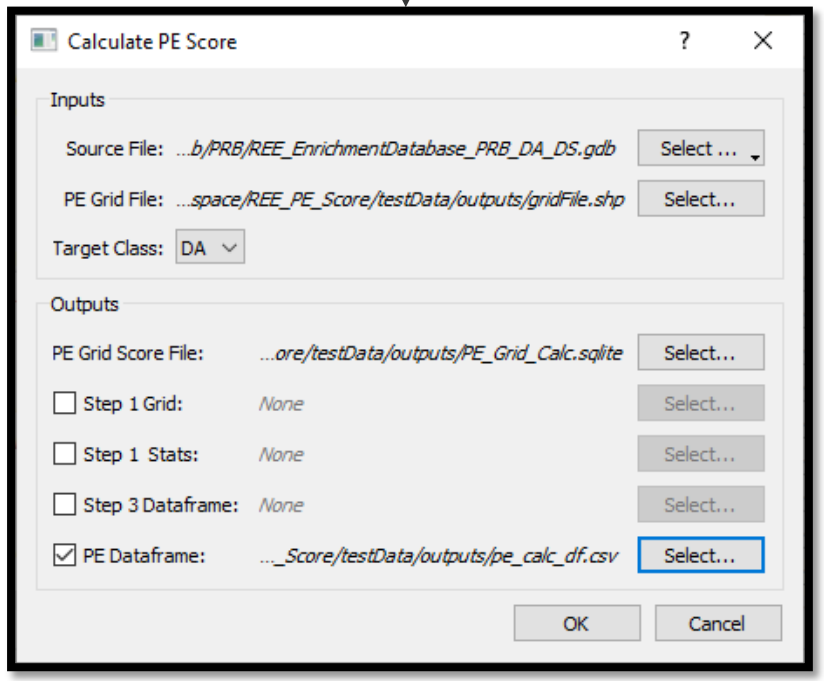

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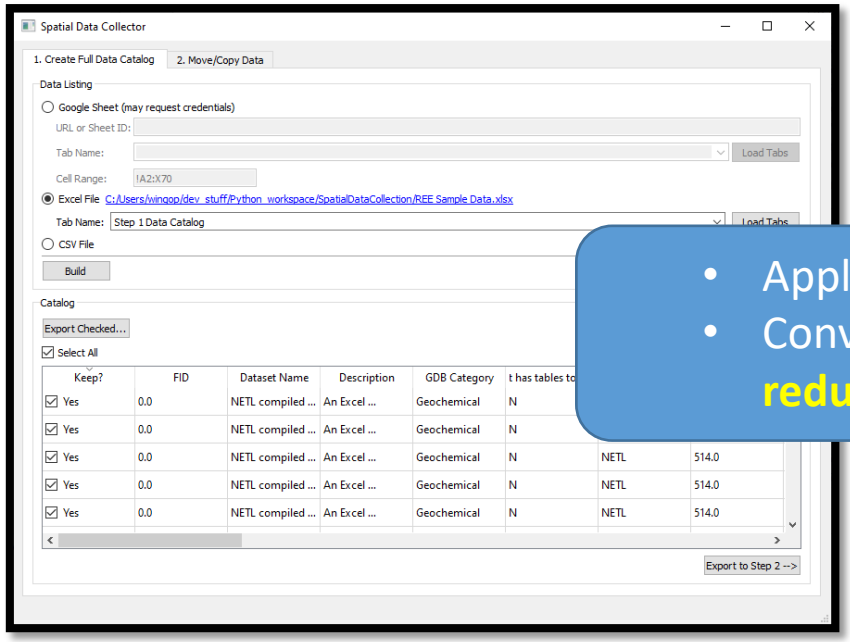

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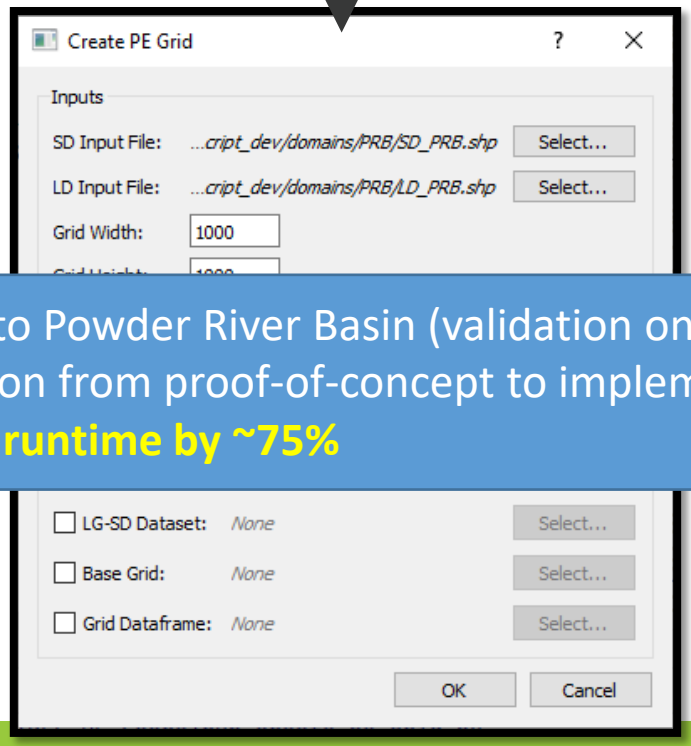

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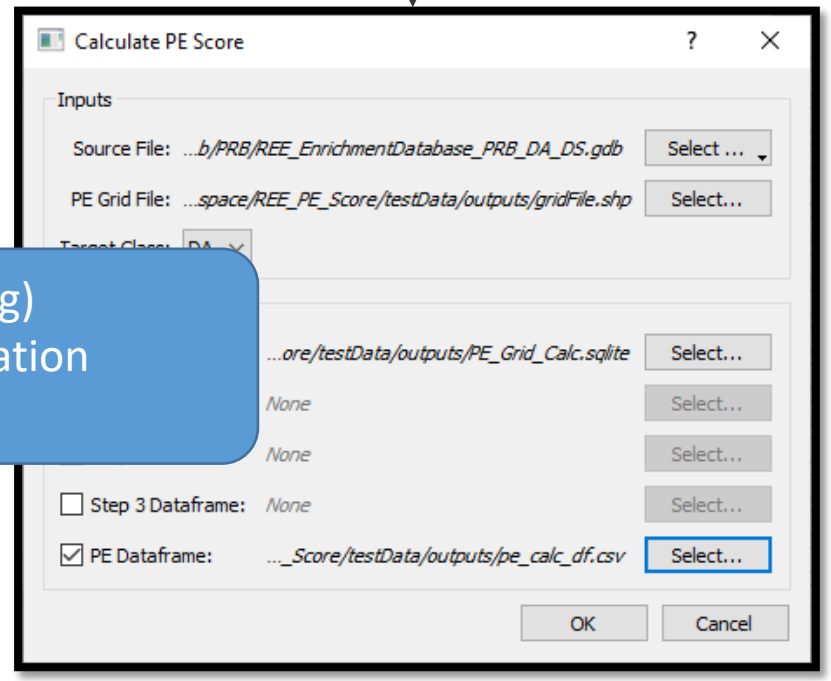

- Applied to Powder River Basin (validation ongoing)
- Conversion from proof-of-concept to implementation **reduced runtime by ~75%**

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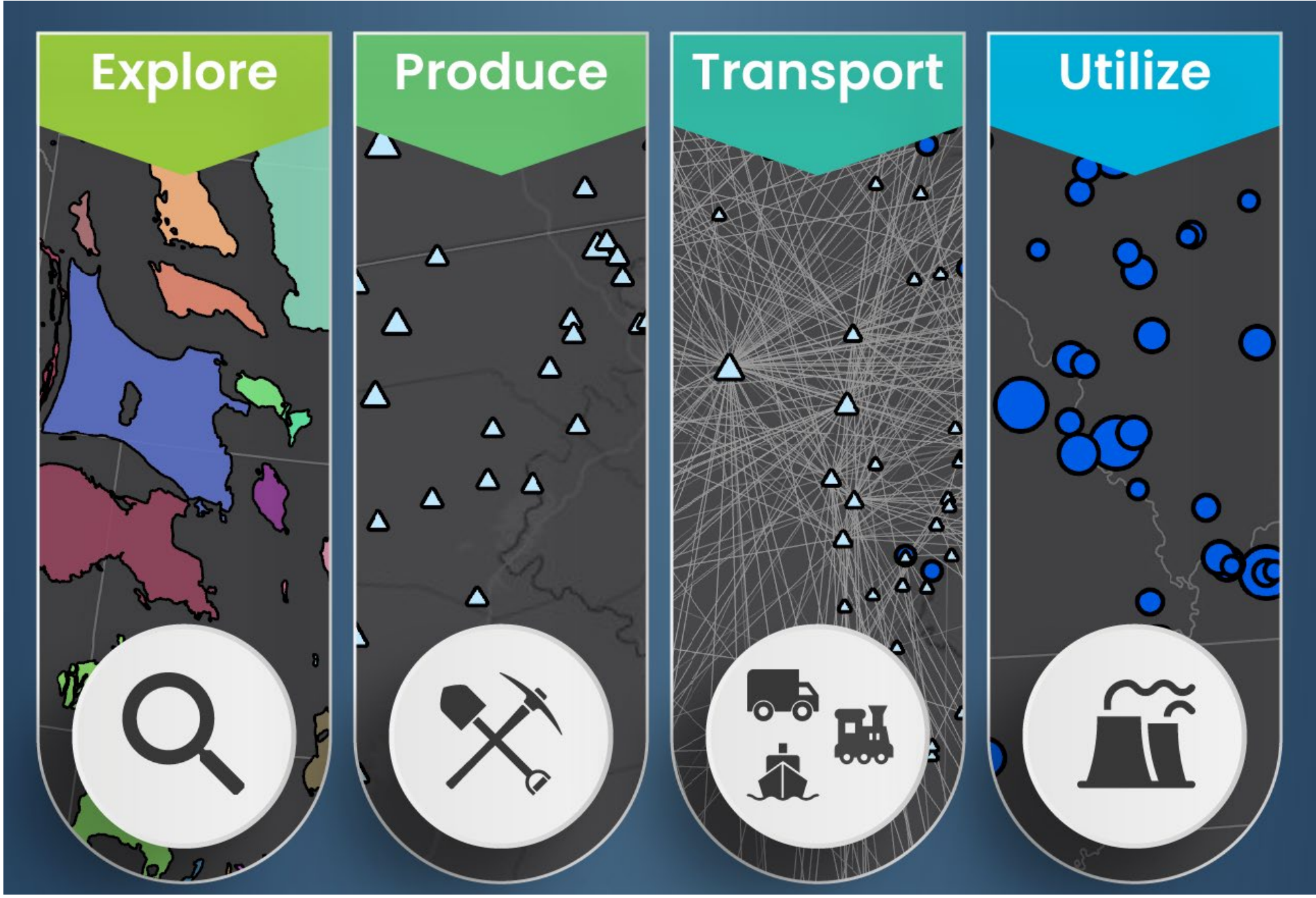
Beyond the Basin

Predicting REE-SED resources from geologic media and byproducts



Carbon Ore, Rare Earth - Critical Minerals Database & virtual platform (CORE-CM Data formerly the ACD)

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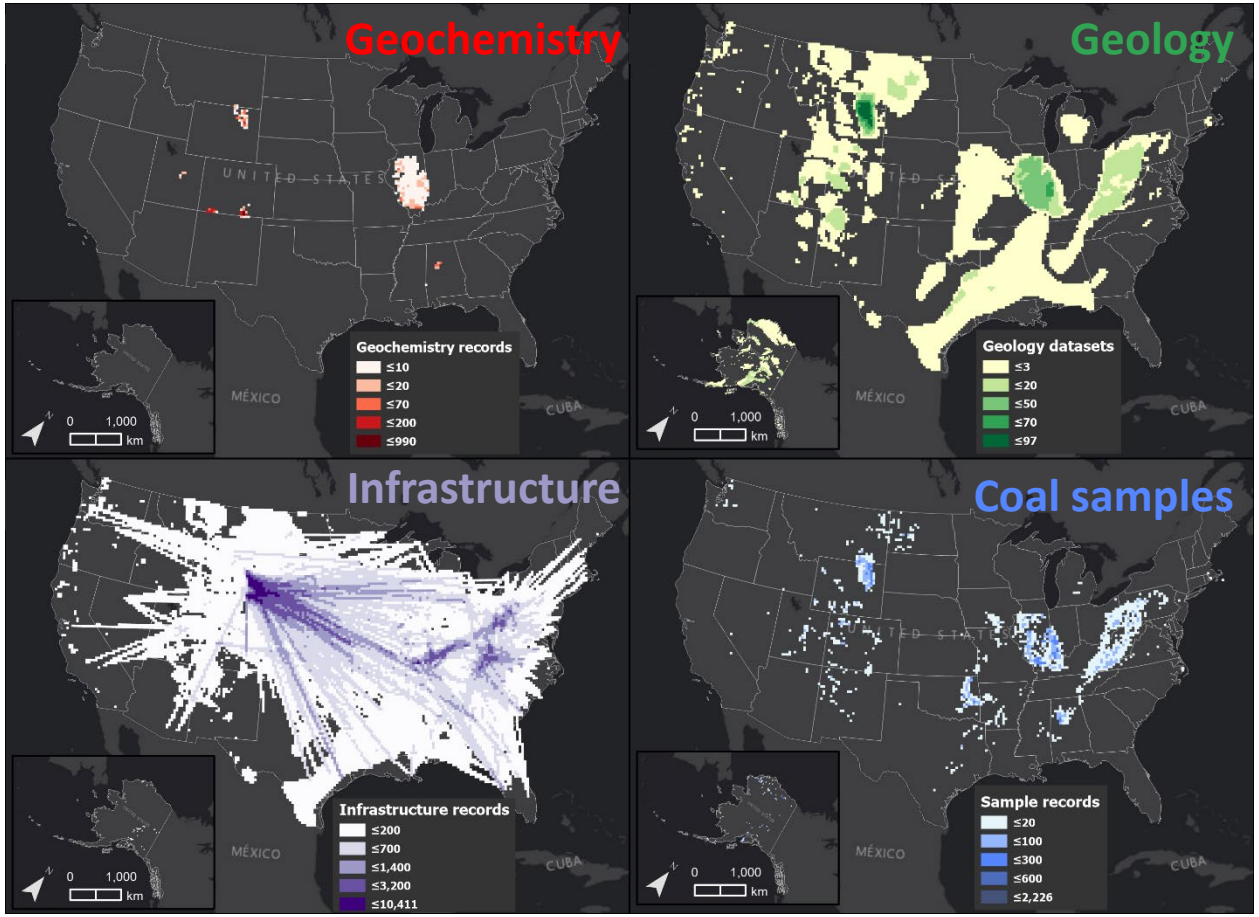
CORE-CM Data is now under development via the Coal Beneficiation FWP but crosscuts with this effort

- **Designed to optimize coal sources with producer and consumer needs**
  - Increased usage in carbon-based products
  - Mitigate impacts of coal ash disposal
  - Better pairing of coals to boilers
- **Provides coal property, geochemical, and infrastructure data**
  - Integrated from disparate sources
- **Opportunity to use for identifying inefficiencies, vulnerabilities and threats along supply chains**
  - Natural disasters, economic, environmental, etc.

Currently contains over 1.3 million records related to 398 datasets

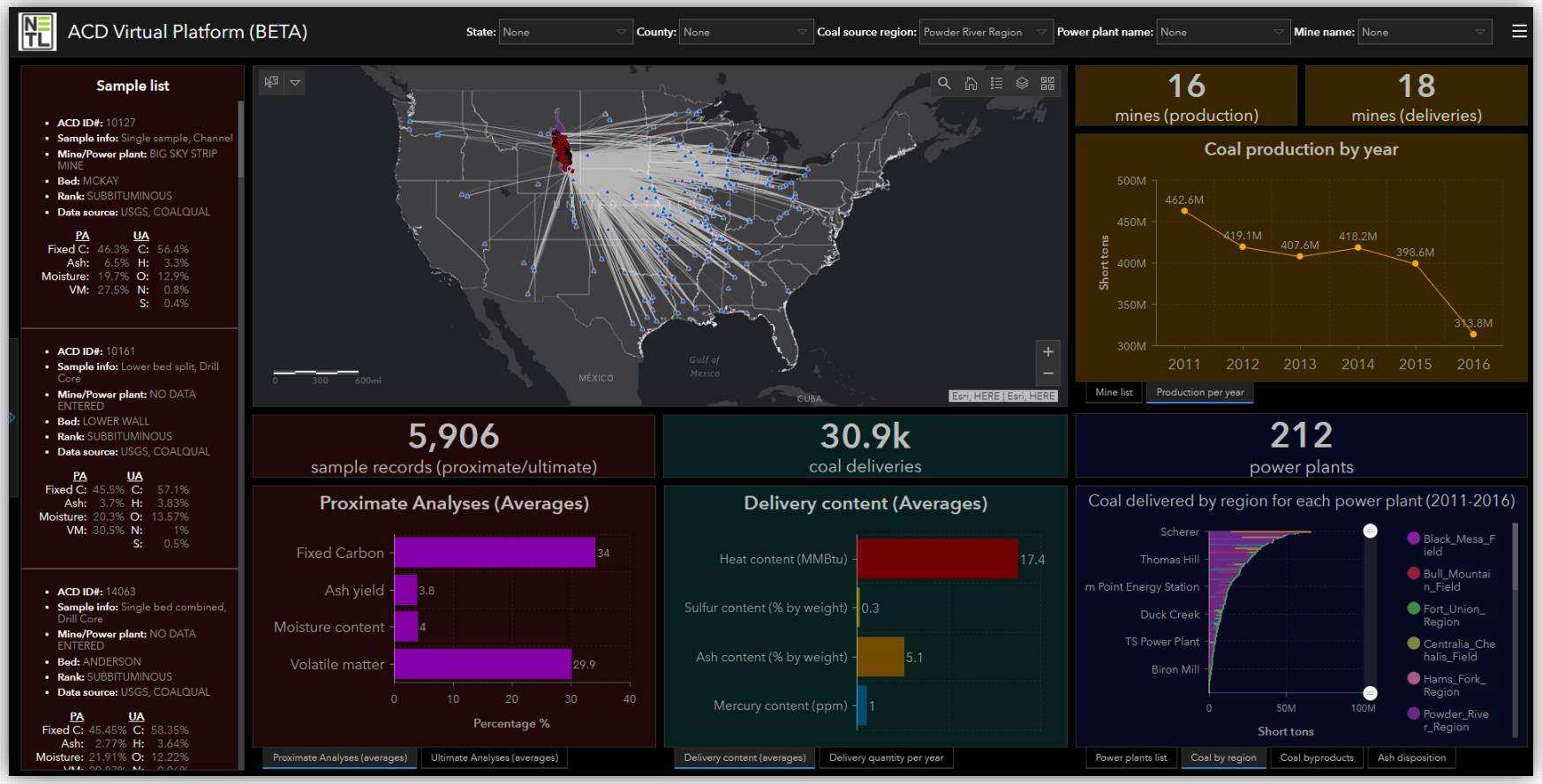


Justman, D., Rose, K., Thomas, B. (2021). A database and framework associated with US coal resources and supply chains. Data in Brief. In Prep.

CORE-CM Data and virtual platform

CORE-CM Data is under development via the Coal Beneficiation FWP but crosscuts with this effort

- **Virtual platform enables users to efficiently explore and query coal datasets within a spatial supply chain framework**
  - Coal mine/seam -> Post-combustion waste streams
- **CORE-CM is hosted on NETL's ArcGIS Online organization account via web application**
- **Data can be interacted with and queried to obtain key insights on specific regions or features**



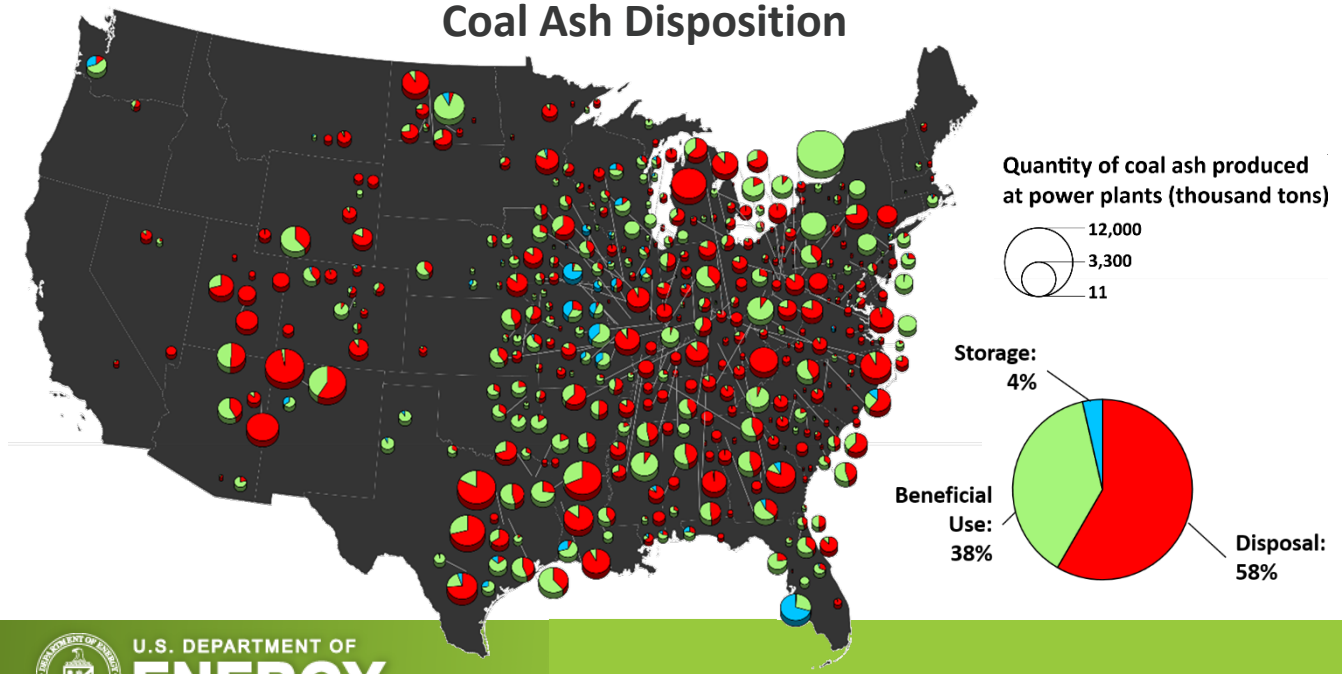
Screenshot displays coal supply chain data associated with the Powder River Basin.

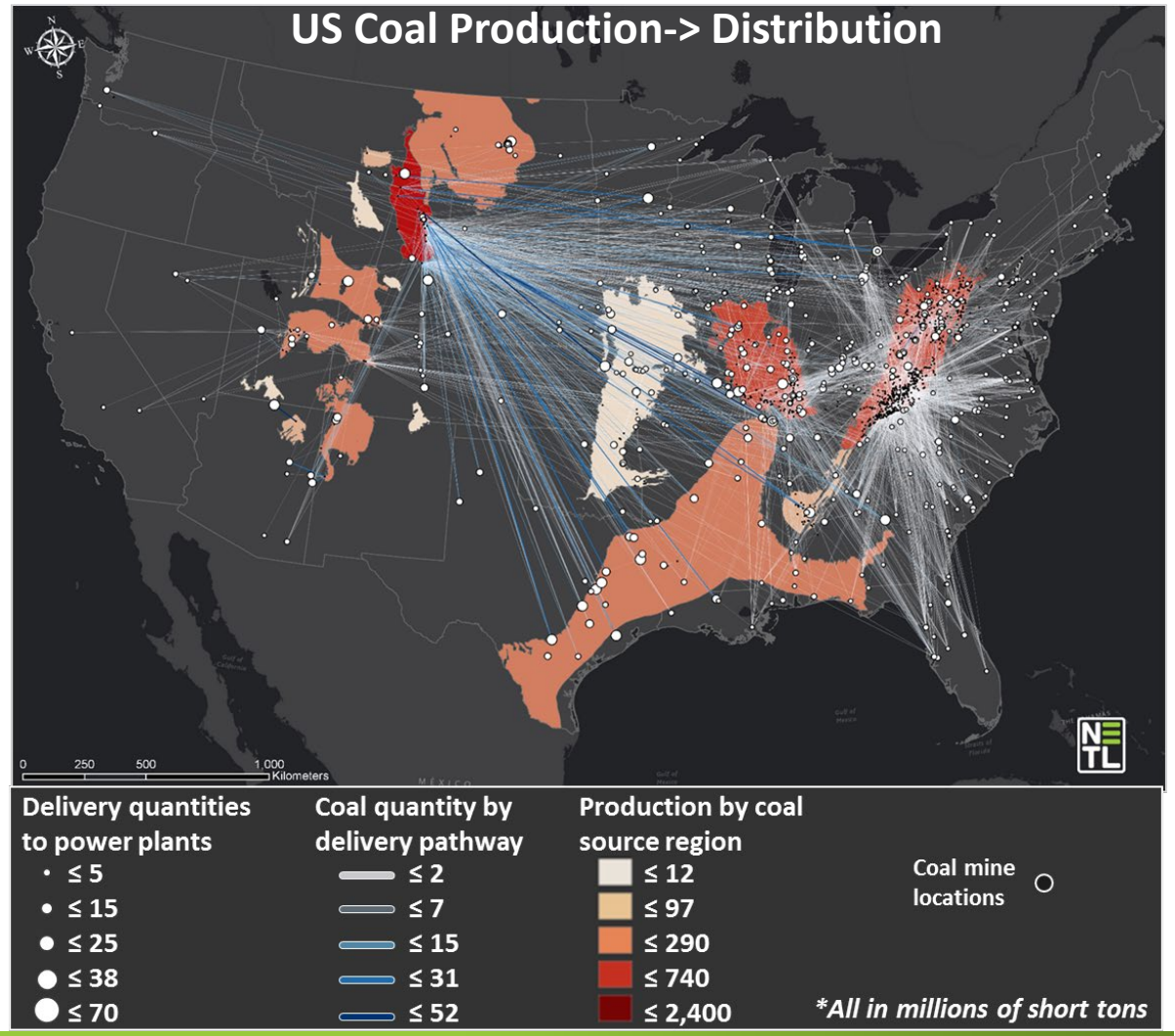
Justman, D., Rose, K., Thomas, B. (2021). A database and framework associated with US coal resources and supply chains. *Data in Brief*. In Prep.

Task 9.1.2 Key infrastructure datasets

Infrastructure network datasets containing over 90,000 records spanning:

- 2,168 mines
- 636 power plants
- 85,072 domestic coal deliveries (2011-2016)





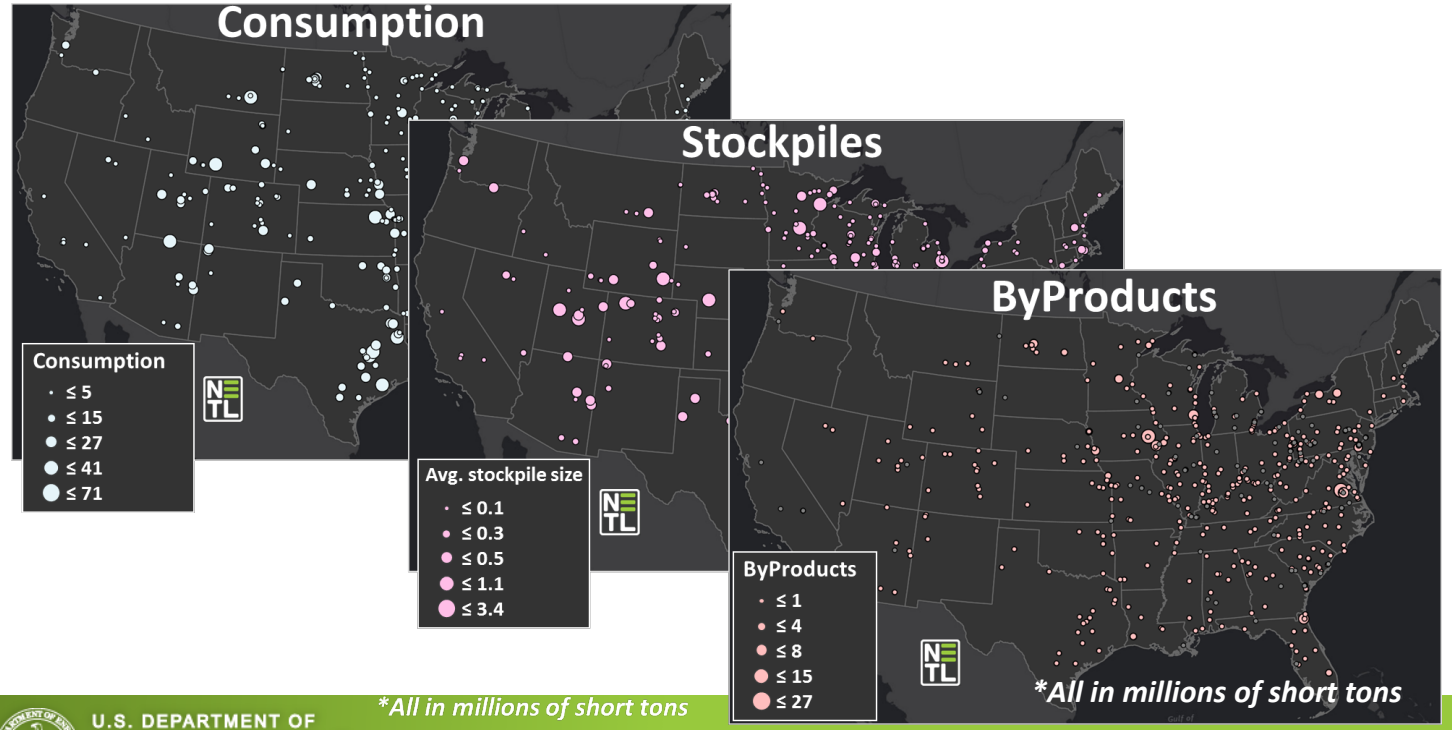
Task 9.1.2 Predicting REE-resources from coal related sources to byproducts

Characterize domestic coal throughout its lifecycle to optimize as a resource:

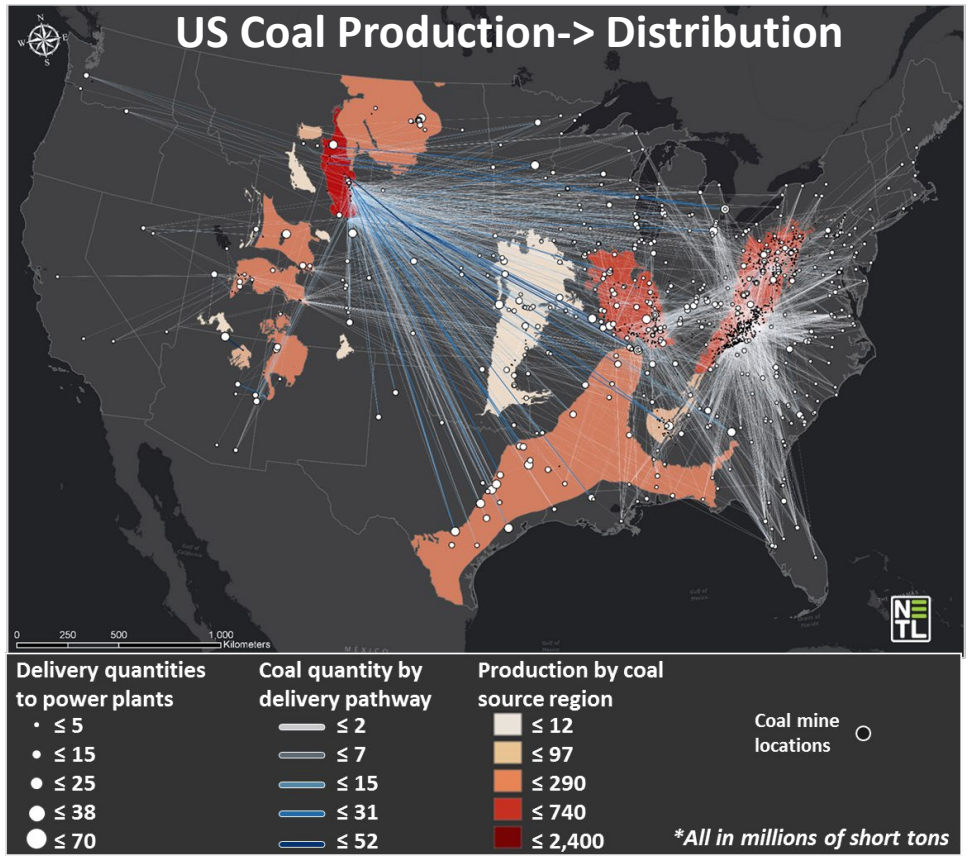
- Reduce cost of coal ash disposal/recycling
- Increase usage in materials (concrete, drywall, etc.)
- Reduce carbon footprint

Opportunity to use for identifying inefficiencies, vulnerabilities and threats along supply chains

- Natural disasters, economic, environmental, etc.



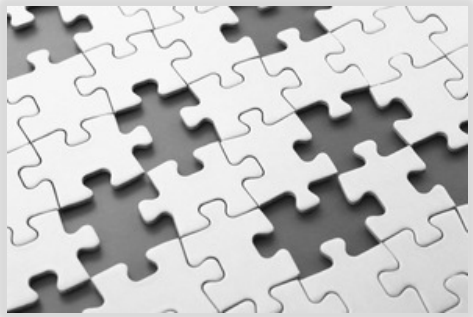
*All in millions of short tons



Geodatabase containing over 90,000 records spanning:

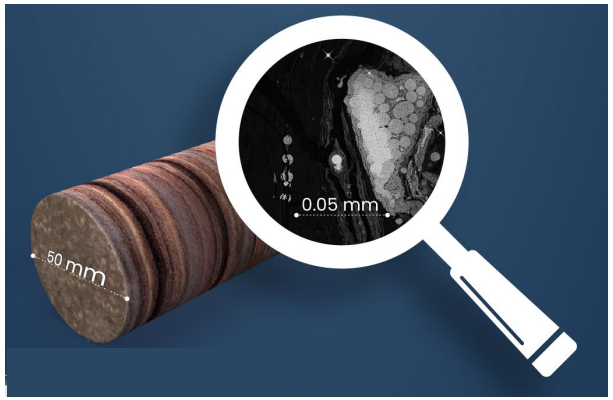
- **2168 mines**
- **636 power plants**
- **85,072 domestic coal deliveries**

Task 9.2 Spatial scale matters – Data collection to improve predictions

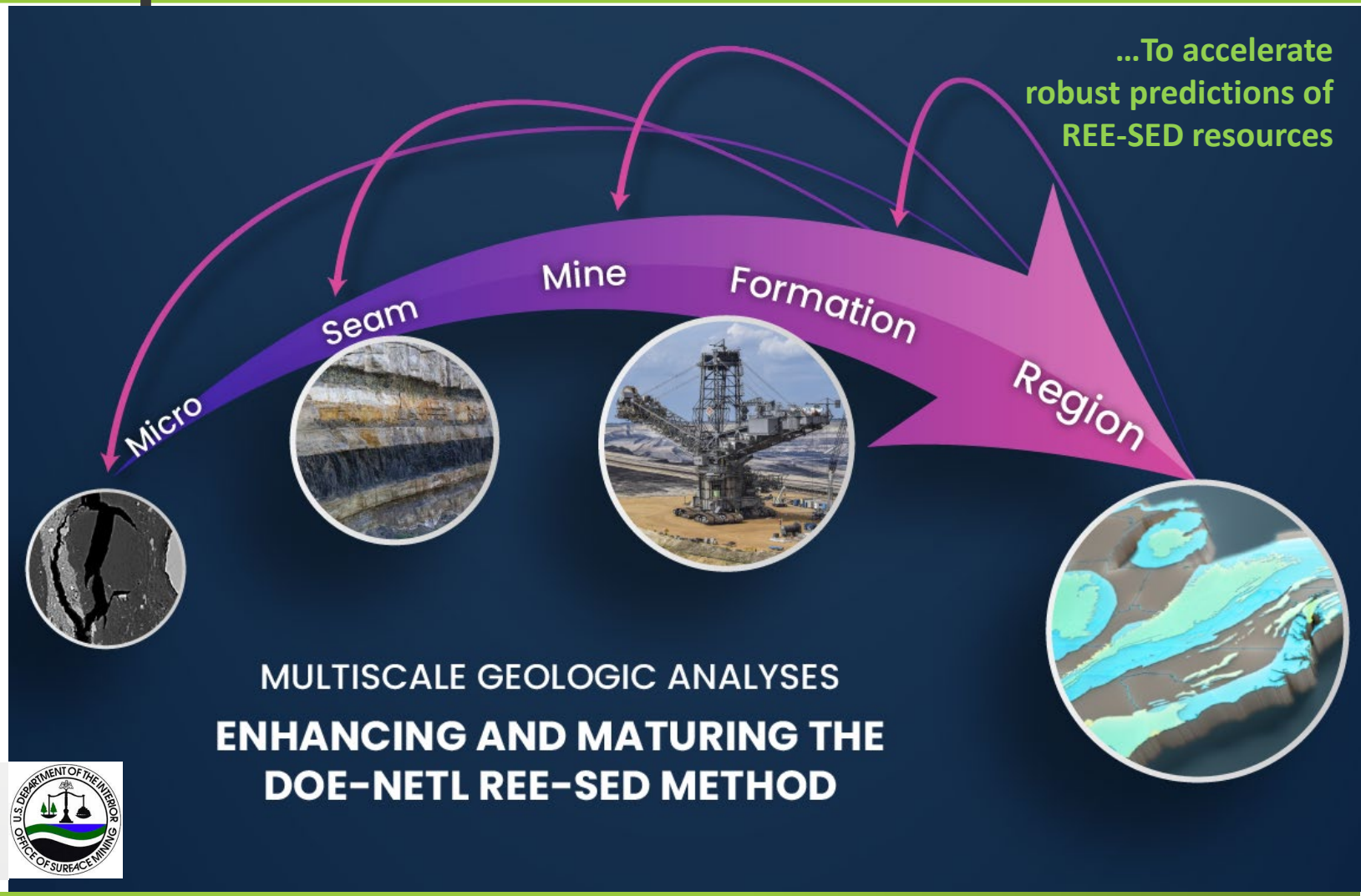


Team is working to fill in REE-SED data gaps…

…Strategic sampling & analytics

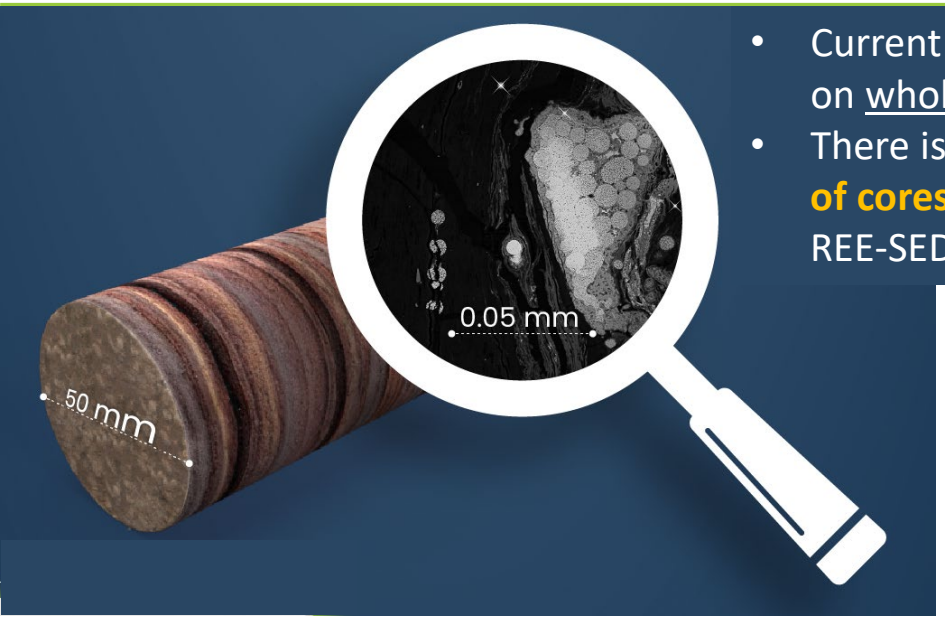


… & key government, industry & academic engagement



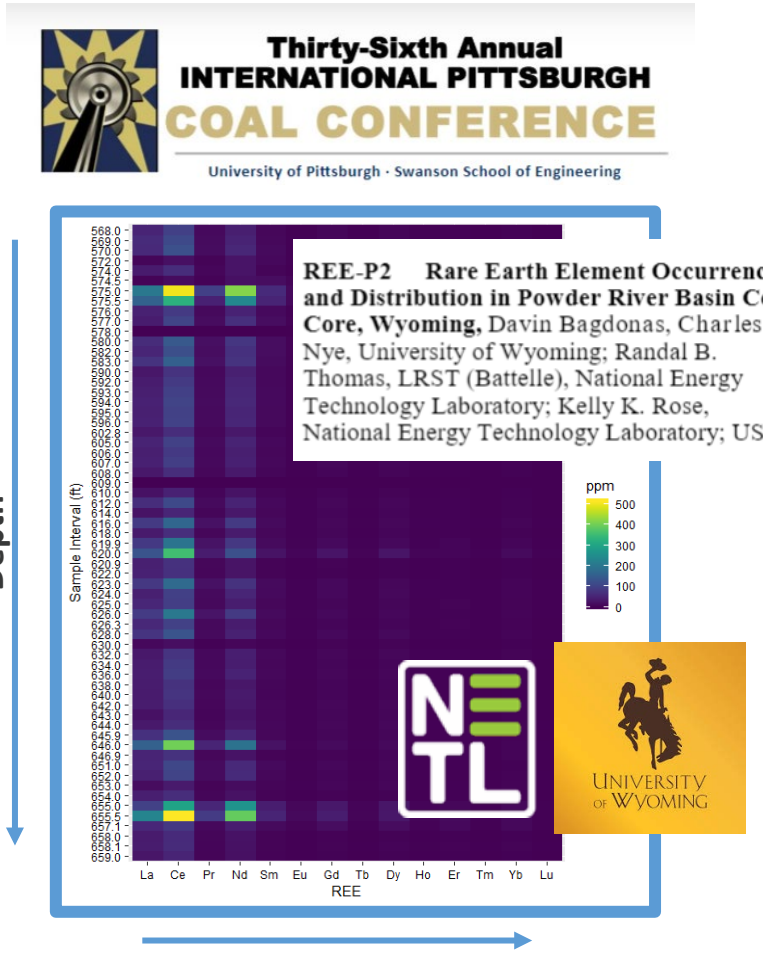
Task 9.2 Documenting High Concentration Deposits

New measurements show REE concentrations vary with geology



- Current REE databases (e.g. CoalQual) are based on whole sample measurements
- There is a **need for discrete, finer scale sampling of cores,** data to improve prospecting and ID of REE-SED ore quality deposits

NETL and U of Wyoming study **demonstrated vertical, lithologic controls on REE occurrence** (Bagdonas et al., 2019)



- 2nd study with industry cores has also documented geologic variability
  - *Including a **~10' thick ore horizon with REE ranging from 500 to over 2700 ppm***
- New efforts with USGS, WVGES expanding data collection from additional cores

Filling in data gaps, documenting high concentration deposits & improving predictions

Bagdonas, D., Nye, C., Thomas, R., and Rose, K., 2019, Rare Earth Element Occurrence and Distribution in Powder River Basin Coal Core, Wyoming, 2019 Thirty Sixth Proceedings of the **International Pittsburgh Coal Conference**, September 3 - 6, 2019, 13 pgs.

Cores of Opportunity

Rare Earth Elements subtask 9.2

Goal: To increase geospatial data to inform strategic development of REE/CM resources in the Central Appalachin and Powder River basins.

NETL-RAMACO Carbon CRADA partnership

- Systematic sampling and analysis of continuous cores that intersect 4 major PRB coal seams
- NETL-RIC researchers identified 5 discrete REE enrichment zones
  - They are associated with high carbon sedimentary layers
- A focused inter- and intra seam analysis of REE concentrations were conducted to constrain spatial (x,y,z) distribution of REE in large (>1' thick) coal seams

USGS-WVGES-NETL EarthMRI (EMRI) collaboration

- NETL-PAL analyzed 45 underclay samples collected from rock cores drilled through coal producing formations in WV
- REE concentrations 203-615 ppm (whole rock basis)

NETL-University of Wyoming, SER collaboration

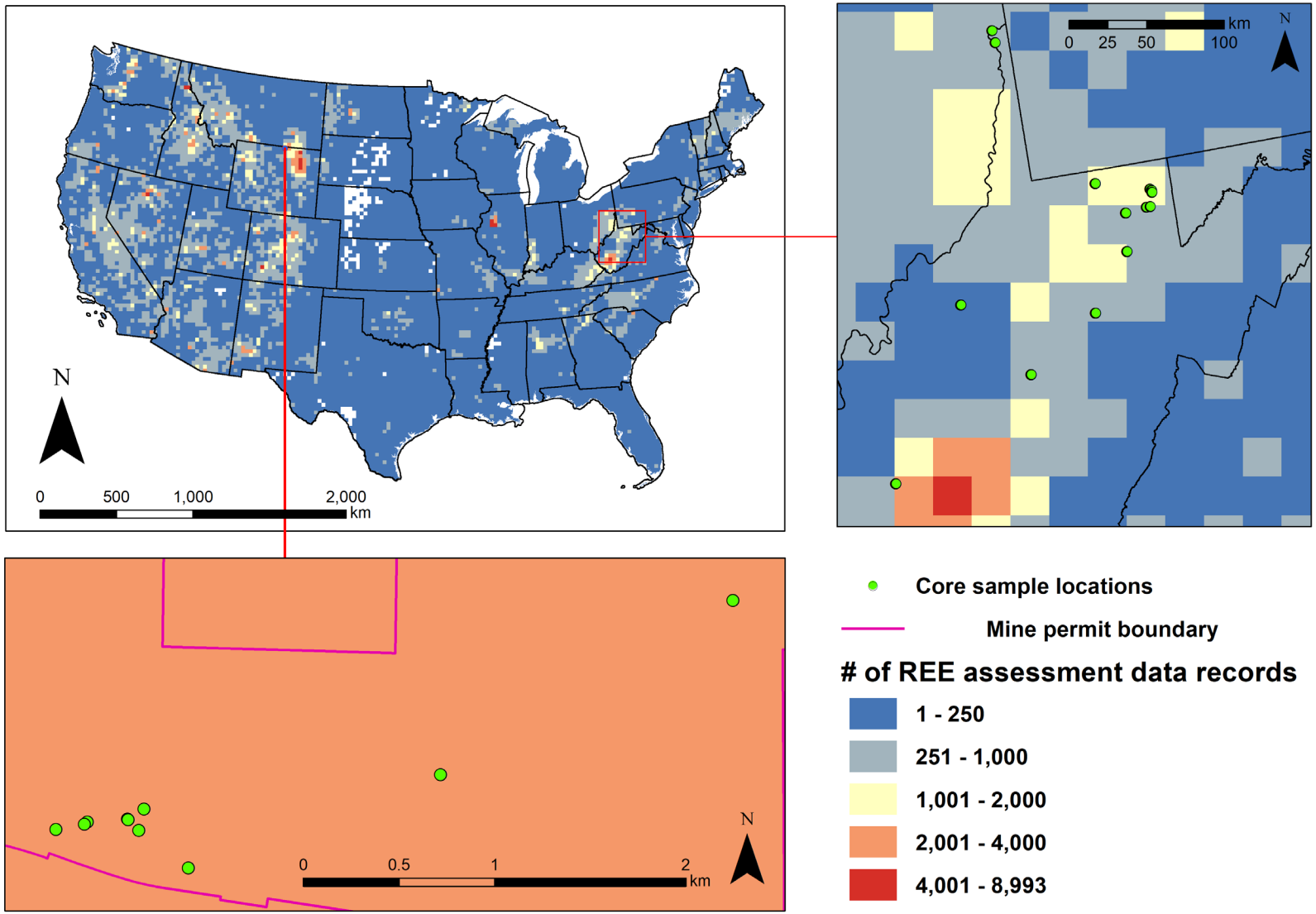
- Sub-sampling and analysis of 50 samples from a coal core collected from central PRB.
- REE concentrations 11-1900 ppm (ash basis)

Montross, S.N., Bagdonas, D., Creason, C.G., Phillips, E., Thomas, R.B., Britton, J., Rose, K., and Quillinan, S. On a unified core characterization methodology to support the systematic assessment of rare earth and critical mineral bearing unconventional carbon ores and sedimentary strata. (in prep for submission to *Minerals* Special Issue, May, 2021)

Recent Accomplishments: REE Task 9.2

Investigating different scales of resource predictions

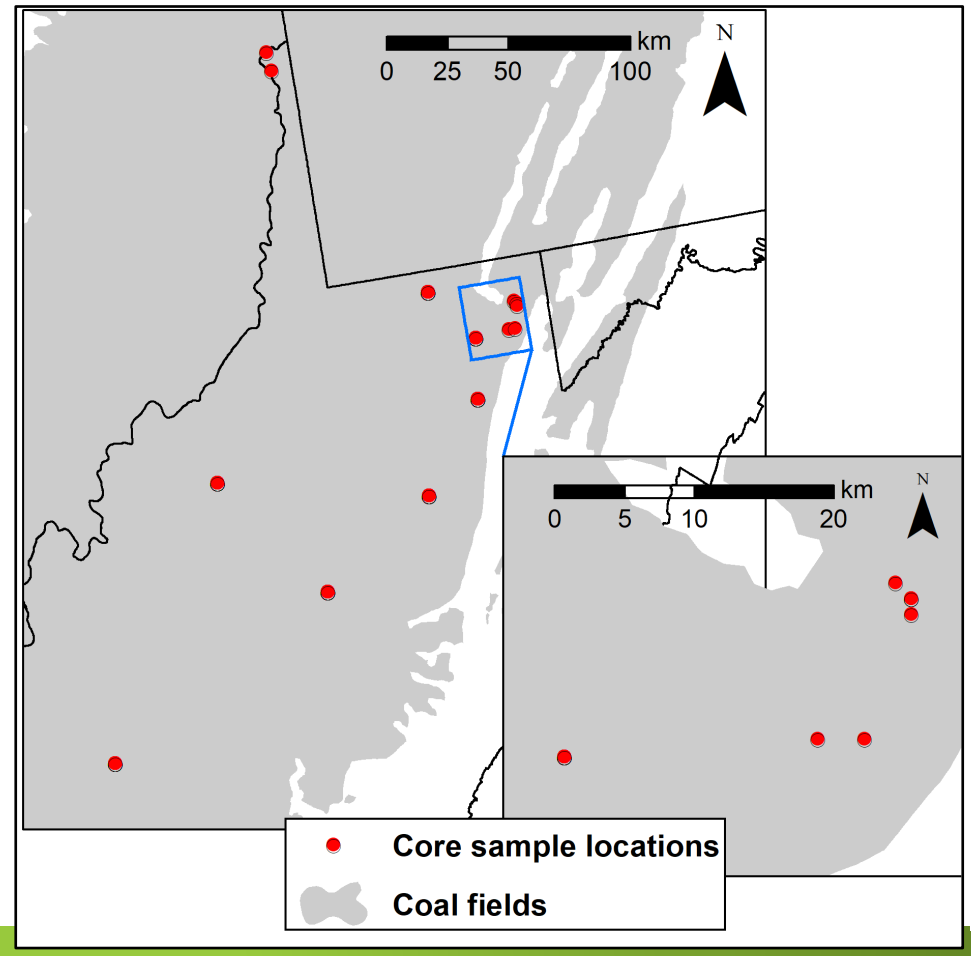
- Mine scale
  - Ramaco partnership in PRB
- Sub-basin scale
  - WVGES partnership for Central Appalachian region



Accomplishments: REE Task 9.2

USGS-WVGES-NETL EarthMRI (EMRI) Underclay REE Project

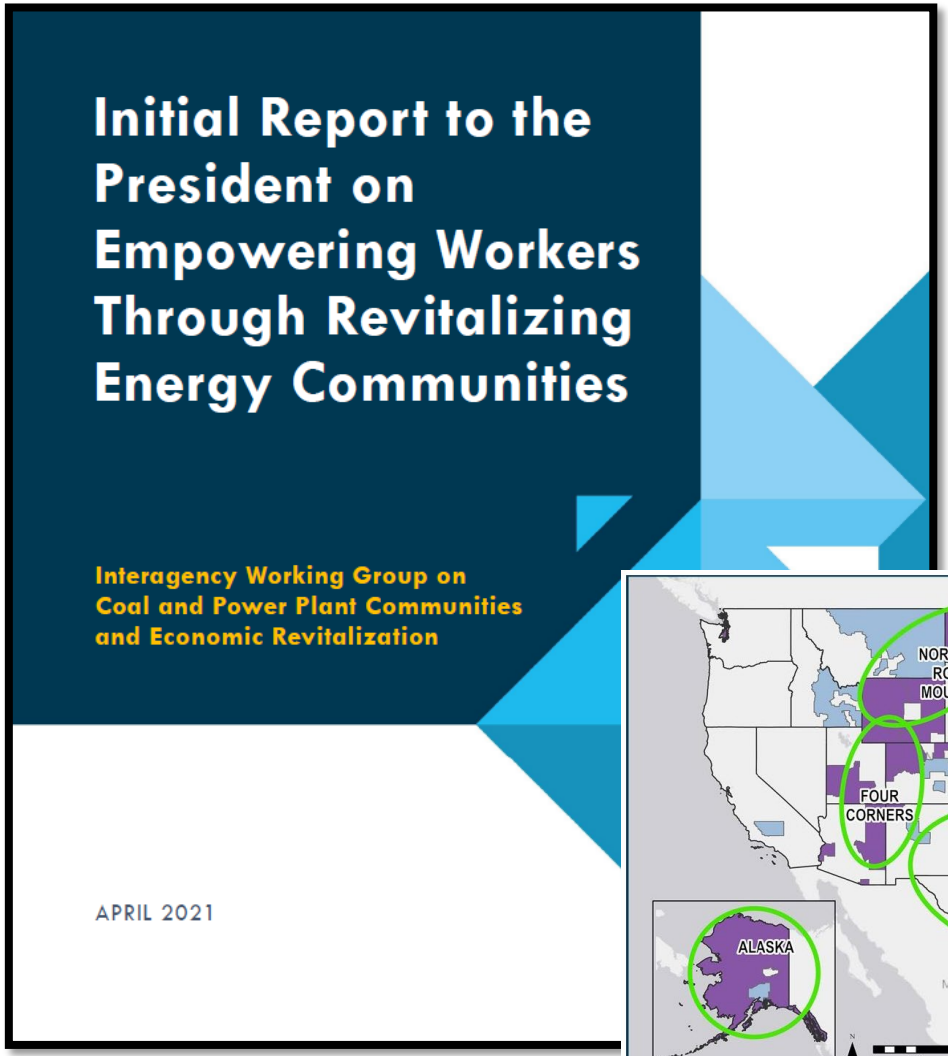
- **<u>Goal: To increase geospatial data to inform exploration and strategic development of REE/CM resources in the Central Appalachin Basin.</u>**
- NETL-RIC analyzed 45 underclay samples collected from rock cores drilled through coal producing formations in WV.
  - *Freeport, Kittanning, Mahoning, No. 5 Block, Stockton, and Brush Creek formations.*
- REE concentrations range from <u>203-615 ppm</u>

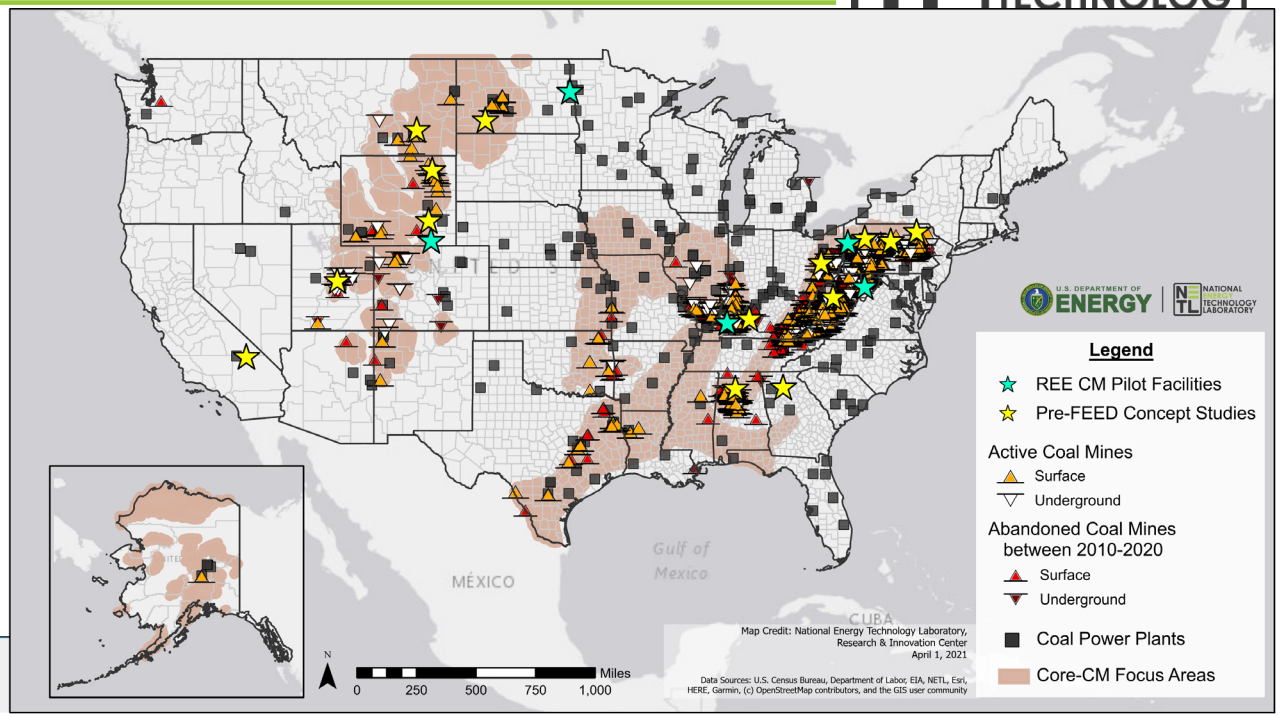


- **Ongoing work (Remaining EY20)**
  - Identify REE bearing mineral phases in promising samples.
  - Create lithostratigraphic/lithogeochemical log to correlate REE concentrations with formation and lithology. ***For integration into REE-SED tool, REE Task 9.1***

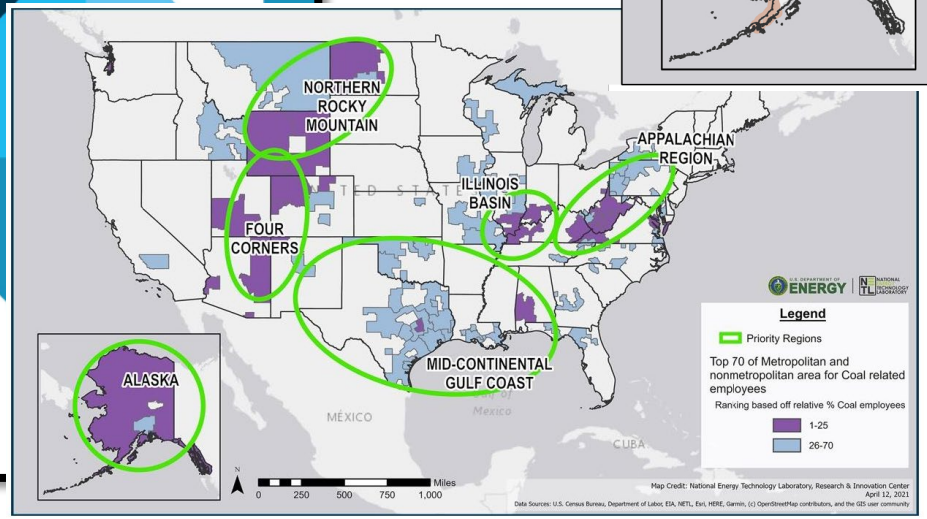
https://www.sciencebase.gov/catalog/item/601963c6d34edf5c66f0d0e5

New EY21 Task 9.4 – Coordination, Data Virtualization





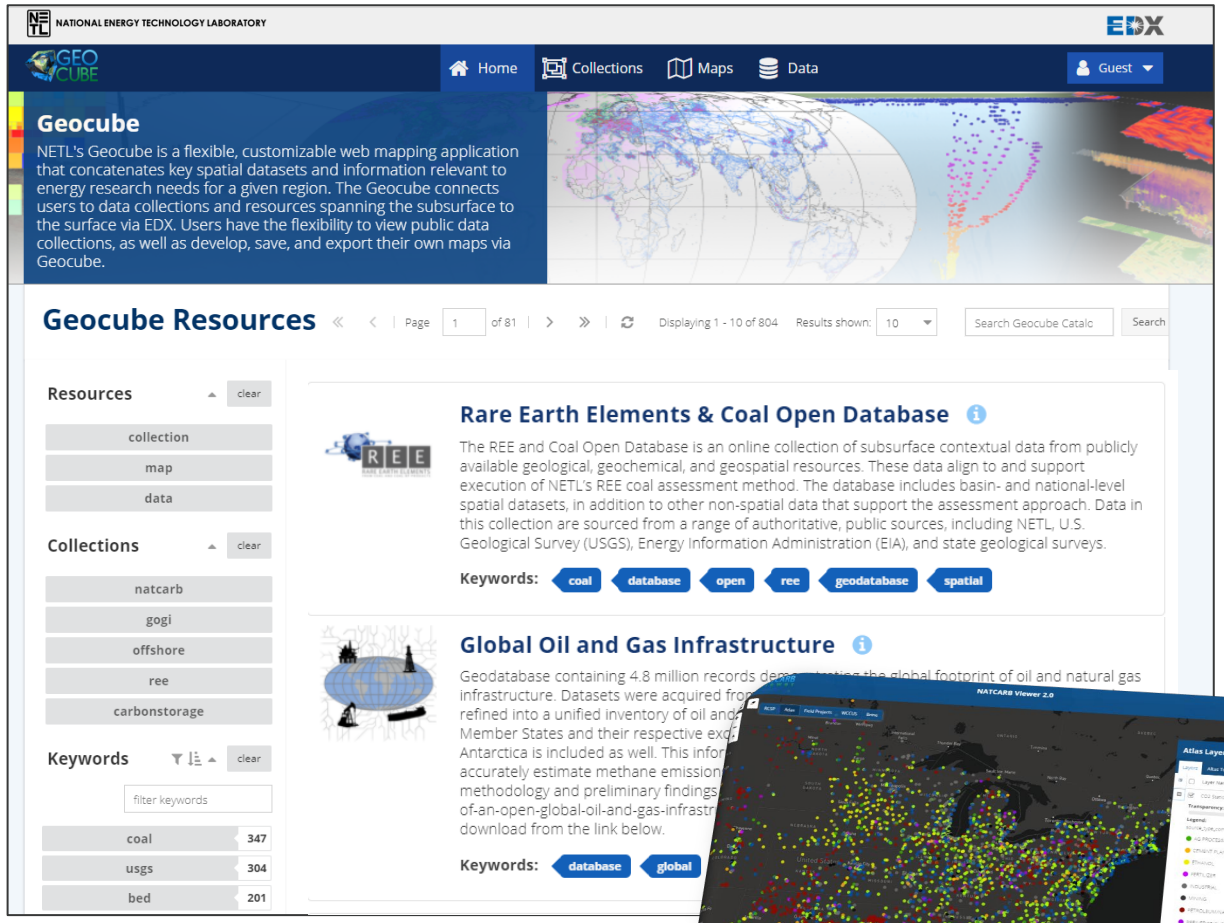
NETL Task 9 Team Analysis of UCR REE/CM Domestic Potential

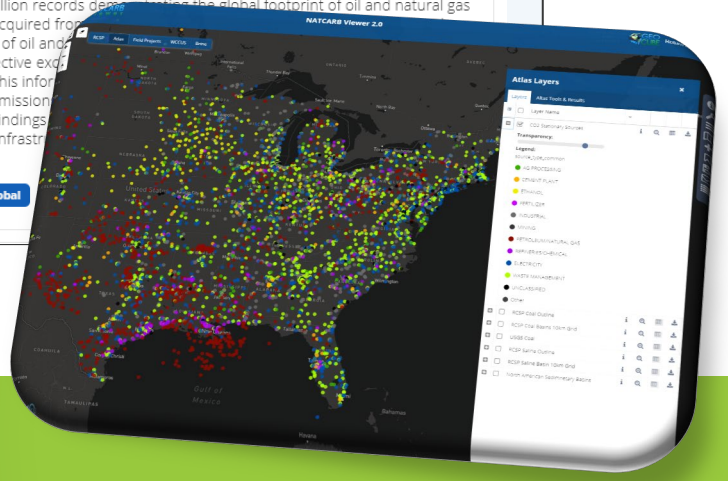


IWG Report Figure 2

Task 9.4 Enhancing EDX & GeoCube for UCR REE/CM Community

https://edx.netl.doe.gov/geocube





- **Support discovery, access and use of geospatial data & analytical tools** through **EDX** and EDX's web-mapping application, **GeoCube**
- **Growing catalog of geospatial resources available through EDX**
  - From traditional formats as well as EDX processing to unlock additional place-based insights for EDX resources
- **Named as 1st Priority DOE Geospatial Data Repository**
  - Aligns with geospatial management practices outlined in 2021-2025 DOE Geospatial Data Management Strategy, FGDC guidelines, and 2018 GDA covered agency requirements

Task 9.4 UCR REE/CM Community

NETL USGS MOA - Signed

Domestic MOA: AGMT-1044
USGS OPA Review Number: 2021NM-11632

APPROVED

Memorandum of Agreement

Between the

United States Geological Survey

and the

United States Department of Energy
National Energy Technology Laboratory

ACCEPTANCE:

FOR United States Geological Survey:

BY: Digitally signed by SARAH RYKER Date: 2021.03.03 14:48:53 -05'00'

Sarah J. Ryker, Ph.D.
Associate Director for Energy and Minerals

DATE: March 3, 2021

FOR National Energy Technology Laboratory:

BY: BRIAN ANDERSON Digitally signed by BRIAN ANDERSON Date: 2021.03.03 08:51:48 -05'00'

Brian J. Anderson, Ph.D.
Director, National Energy Technology Laboratory

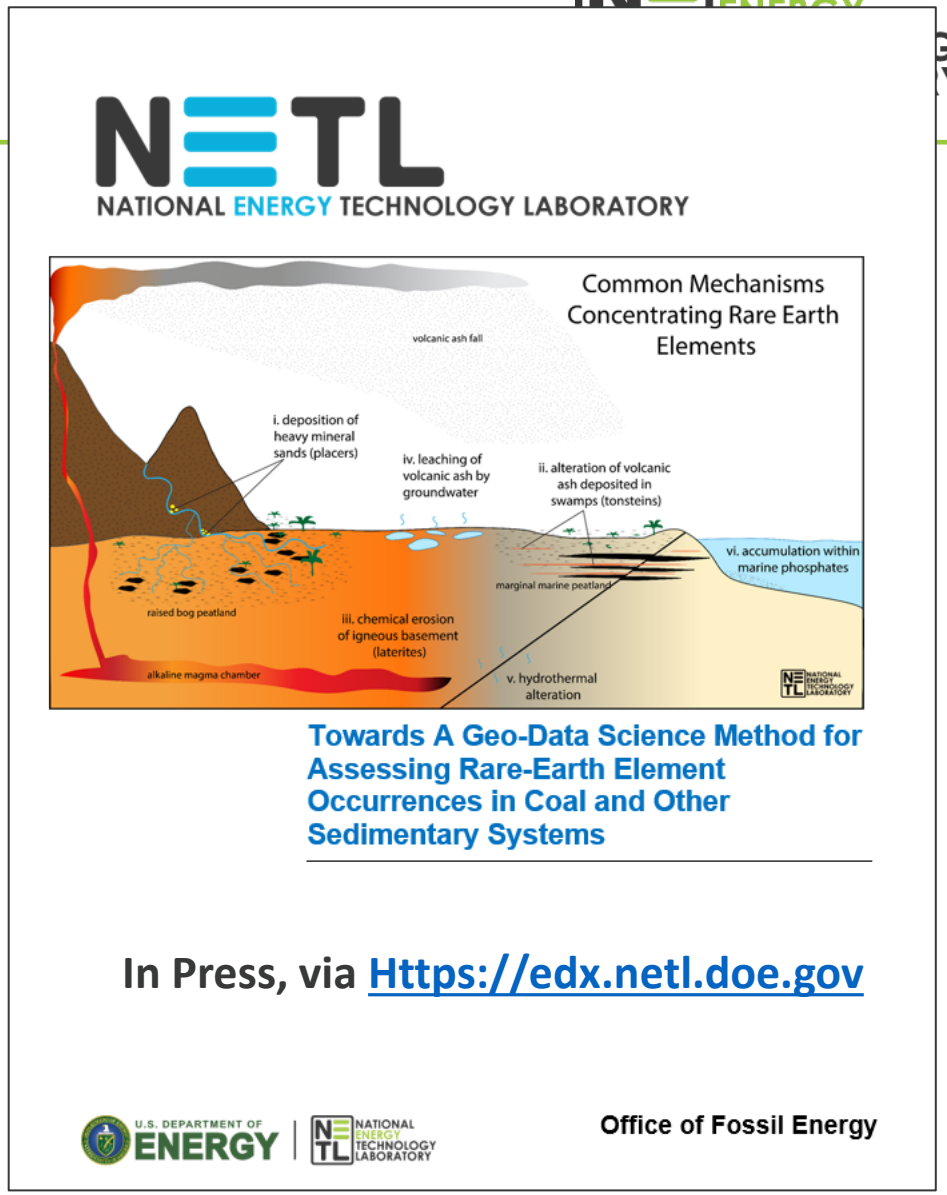
DATE: March 3, 2021

I. Purpose

The purpose of this Memorandum of Agreement (MOA) between the National Energy Technology Laboratory (hereinafter "NETL") of the United States Department of Energy (DOE) and the United States Geological Survey (hereinafter "USGS") is to establish an arrangement for cooperation in the analyses of rare earth elements in coal, coal by-products, waters impaired by drainage from past coal mining, and in emissions control from utilization of coal. NETL and USGS may be referred to individually as "Participant" and jointly as "Participants."

Pubs in prep, review

- **Task 9.1:** C. Gabe Creason, Scott N. Montross, Kelly Rose, Devin Justman, MacKenzie Mark-Moser, Randal Thomas, **Towards A Geo-Data Science Method for Assessing Rare-Earth Element Occurrences in Coal and Other Sedimentary Systems**, in review, NETL-TRS-X-2021; NETL Technical Report Series; 2021 ← In press
- **Task 9.1:** Creason, C. G., Bean, A., Rose, K., Justman, D., Thomas, R., Montross, S., Wingo, P., Mark-Moser, M., Ruppert, L., **A Geo-Data Science Method for Assessing Rare Earth Element Occurrences in Coal and Other Sedimentary Systems**, in prep, *Coal Geology*
- **Task 9.1.2:** Justman, D., Rose, K., Thomas, B. (2021). **A database and framework associated with US coal resources and supply chains.** *Data in Brief.* In Prep.
- **Task 9.2:** Montross, S.N., Bagdonas, D., Creason, C.G., Phillips, E., Thomas, R.B., Britton, J., Rose, K., and Quillinan, S. **On a unified core characterization methodology to support the systematic assessment of rare earth and critical mineral bearing unconventional carbon ores and sedimentary strata**. (in prep, *Minerals*, 2021)



NATIONAL ENERGY TECHNOLOGY LABORATORY

Ultimately, this project seeks to improve prediction **of where and how much** REEs exist in domestic sediments

Check EDX® Energy Data eXchange for:

- Datasets
- Publications
- Information
- & future release of the REE-SED tool

Contact: Kelly Rose
kelly.rose@netl.doe.gov

https://edx.netl.doe.gov/geocube/#collections/ree
of open-data resources via EDX that may be useful for ucr REE/CM resource evaluations

GEOCUBE

Rare Earth Elements & Coal Open Database

The REE and Coal Open Database is an online collection of subsurface contextual data from publicly available geological, geochemical, and geospatial resources. These data align to and support execution of NETL's REE coal assessment method. The database includes basin- and national-level spatial datasets, in addition to other non-spatial data that support the assessment approach. Data in this collection are sourced from a range of authoritative, public sources, including NETL, U.S. Geological Survey (USGS), Energy Information Administration (EIA), and state geological surveys.

Keywords: coal, database, open, ree, geodatabase, spatial

GAIA Group: Kelly Rose, Andrew Bean, Gabe Creason, Devin Justman, Scott Montross, R. Burt Thomas, MacKenzie Mark-Moser, and Mike Sabbatino

***Download* the REE-SED Infographic!**

U.S. DEPARTMENT OF ENERGY

https://www.netl.doe.gov/sites/default/files/2020-08/REE-SED%20Infographic-01.png