NETL REE-SED Assessment Method

Developing a Geo-data Science Driven Approach to Assess REEs in Coal and Related Systems

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Research Innovation Center

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U.S. DEPARTMENT OF ENERGY

Accelerating access to domestic REE resources from sedimentary/coal systems

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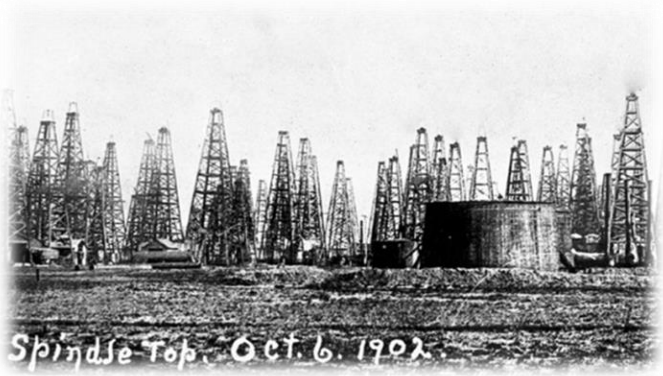
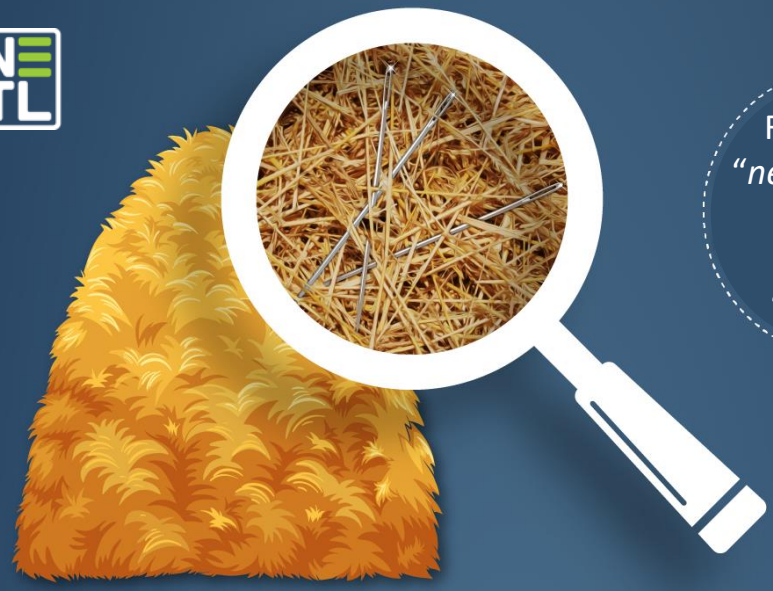
Mineral resources come from geologic media…



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

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

To unlock domestic REE-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 coal and sedimentary systems

- For prediction and ID of high concentration deposits
- 1st approach for assessing REEs in coal-related sediments
- Using a big-data, ML enabled geoscience approach

Project Overview

Developing an assessment methodology for **systematically predicting REE occurrences in coal and coal-related strata** that…

https://www.explorenature.org/center-event/x-marks-spot-irvine-scavenger-hunt/

- Is based off known **mechanisms** that result in accumulation of REEs in coal & coal related strata
- Can be used to identify **areas** with ***higher REE prospectivity***
- Can be used to constrain whether REE concentrations and volumes suggest **viability** **of** ***commercial extraction*** in priority US coal bearing basins

Where and when are REEs enriched in coal and coal-related strata?

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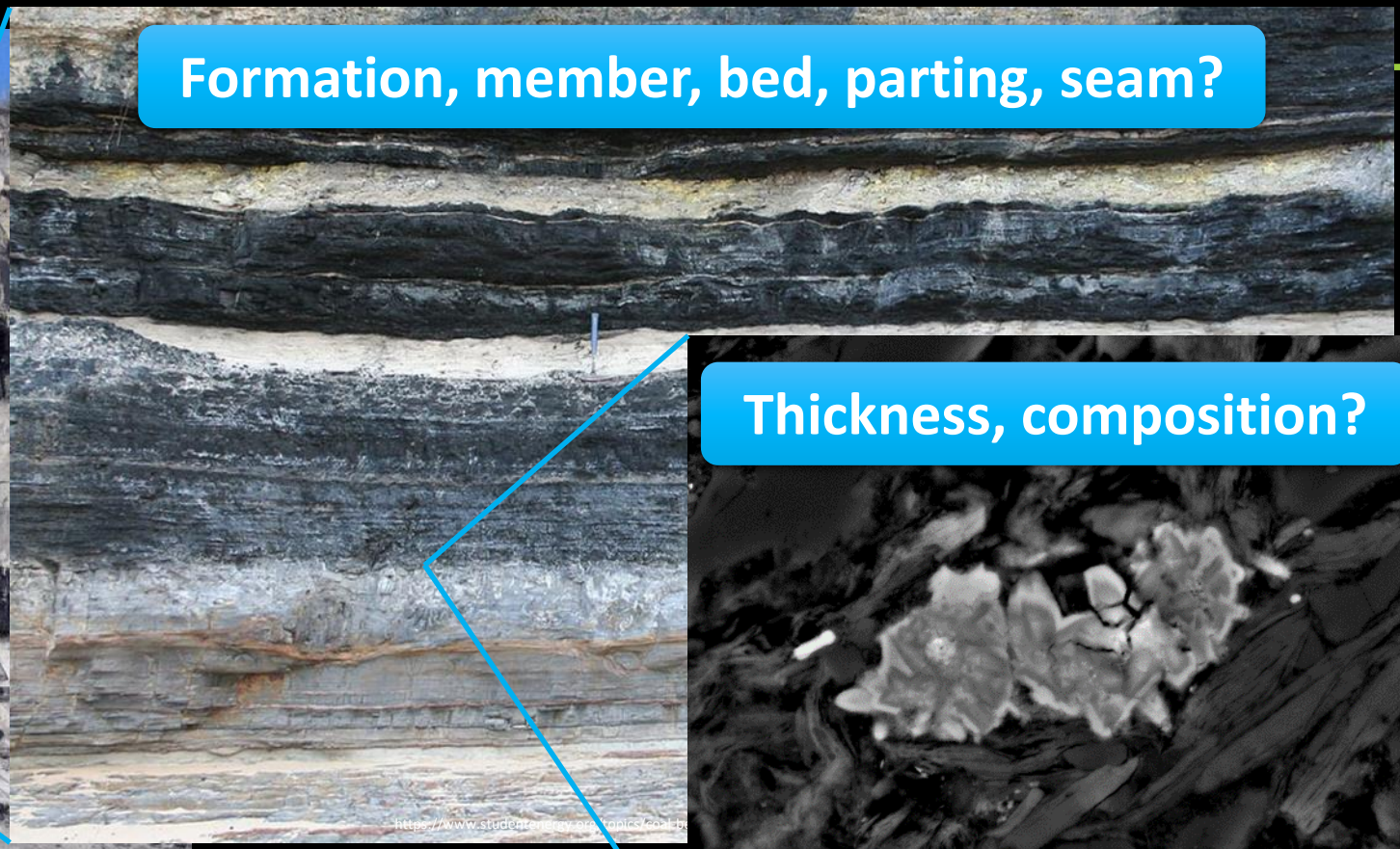
Region, basin, outcrop, depth/time?

…All of these scales are relevant!

Formation, member, bed, parting, seam?



Thickness, composition?

Project Overview (cont.)

Research Objective

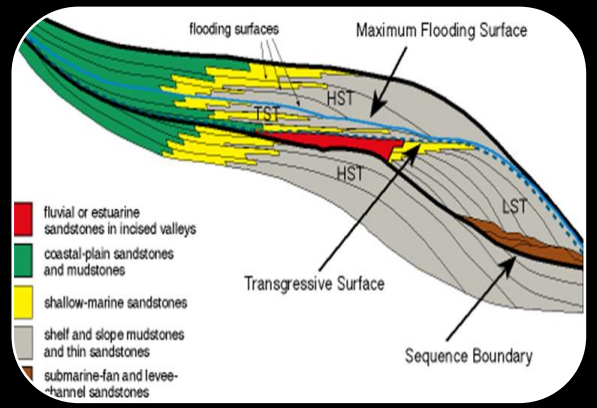
- Develop an **approach for systematically assessing REE occurrences in coal and related sedimentary strata** to identify areas of predicted higher prospectivity, and ultimately apply that approach to assess if REE occur in adequate concentrations and volumes to support commercial extraction in priority U.S. basins.

Research Outcome

- The first science-based method for predicting potential REE deposits in coal-related strata.
- Strategic and robust, validated….
- Contribute to the economic commercialization of domestic REE resource that is currently viewed as uneconomic and uncompetitive
- **Three major areas of focus:**
    1) REE-SED assessment method development
    2) REE-SED geologic sample/core characterization
    3) REE-SED waste streams and by-products assessment

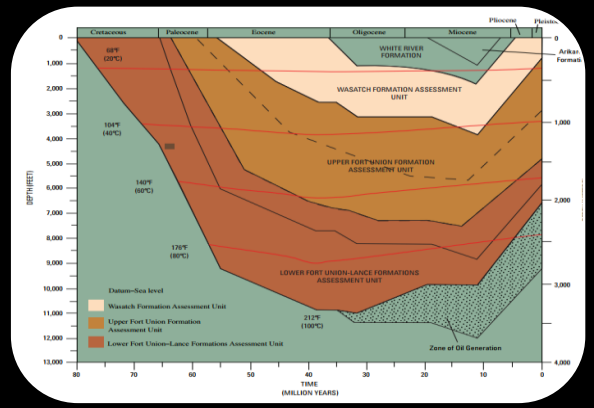
REE-SED: A Systematic Approach

- The occurrence of natural resources are not random, they are a product of geologic processes
- Systematic geoscience methods can improve prediction of resource occurrences. 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



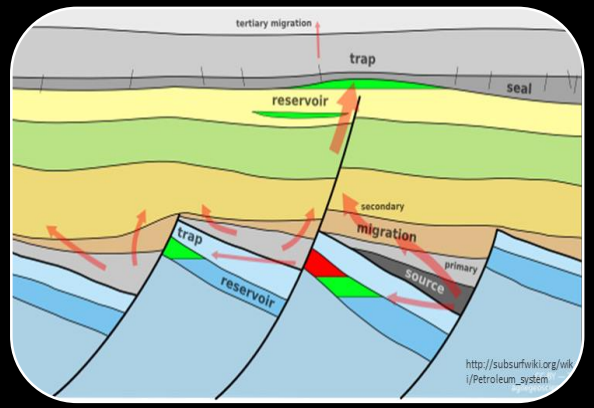
Sequence stratigraphy

- Process-based approach allowing for the **prediction of sedimentary facies** (e.g., spatial variation of coal seam thickness)
- Restricted to paralic coals



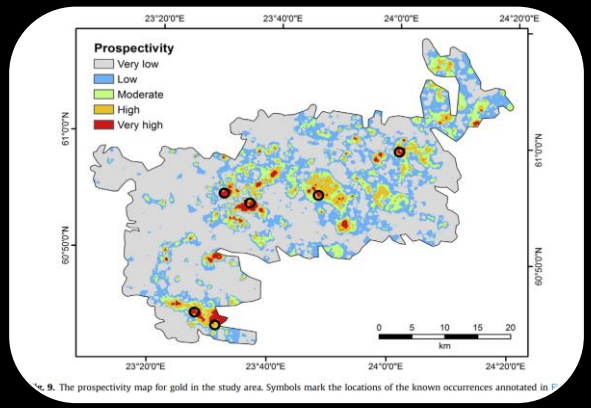
Basin Modeling

- **Regional-scale analysis of basin formation and evolution** (e.g., subsidence history, stratigraphic architecture)
- Complementary to sequence stratigraphy



Geostatistical Reservoir Modeling

- Multidisciplinary approach for **characterizing fluid flow within a reservoir** based on the geologic, geochemical, and petrophysical architecture



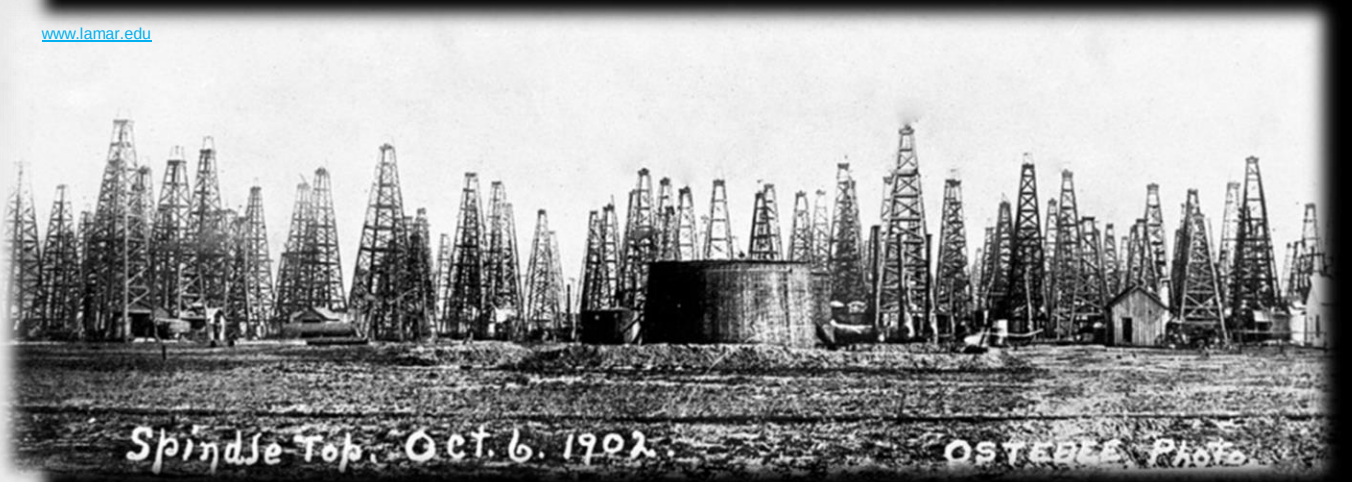
Mineral prospectivity mapping

- Coupled geochemical-geostatistical approach for **predicting the spatial distribution of rocks enriched in REEs**

Systematic Assessments Save $, Drive Breakthroughs

Oil & Gas Exploration, 1900's

www.lamar.edu



Random grab samples & "probing" are costly

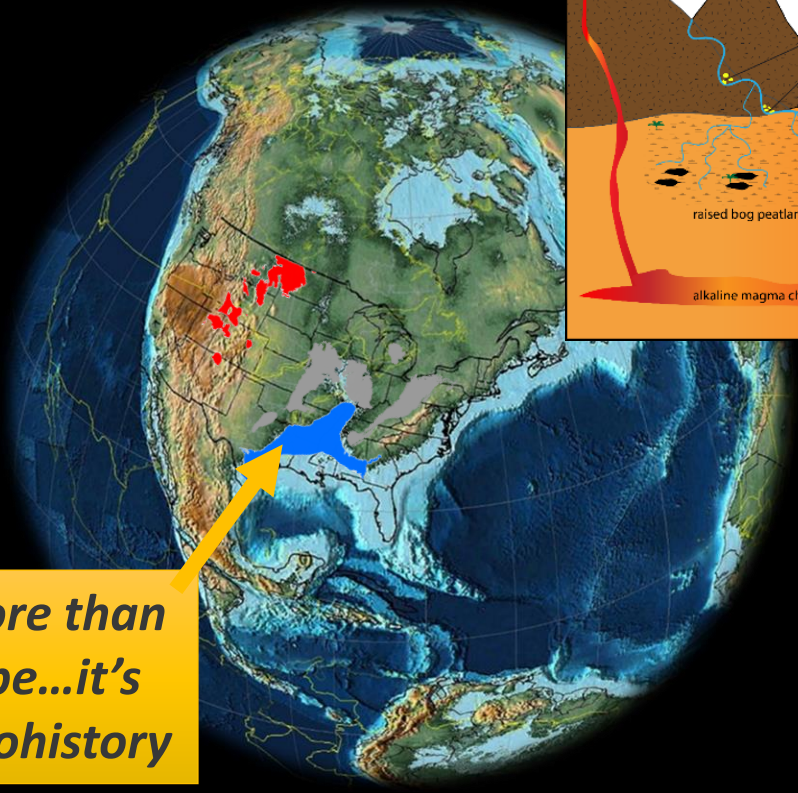
Systematic, geoscience founded, methods & models are key to **efficient & effective** natural resource exploration

Oil & Gas Exploration, present-day

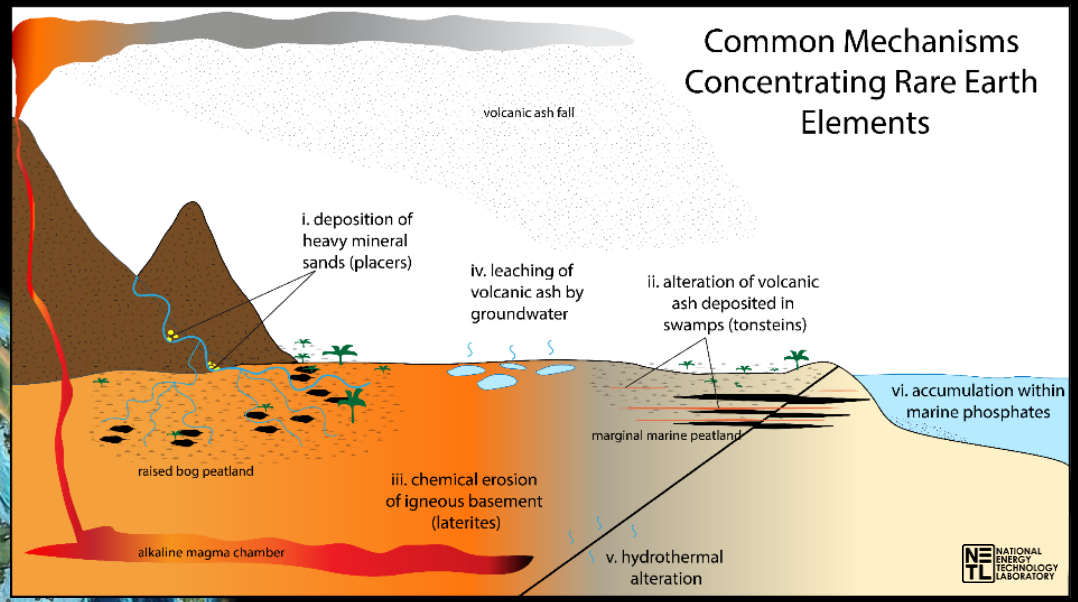
Creating a science & data-driven framework…

…for evaluating data within geologic context

Utilizing a custom data framework that includes publicly-available geological, geochemical, and geospatial datasets from NETL, USGS, and other open sources

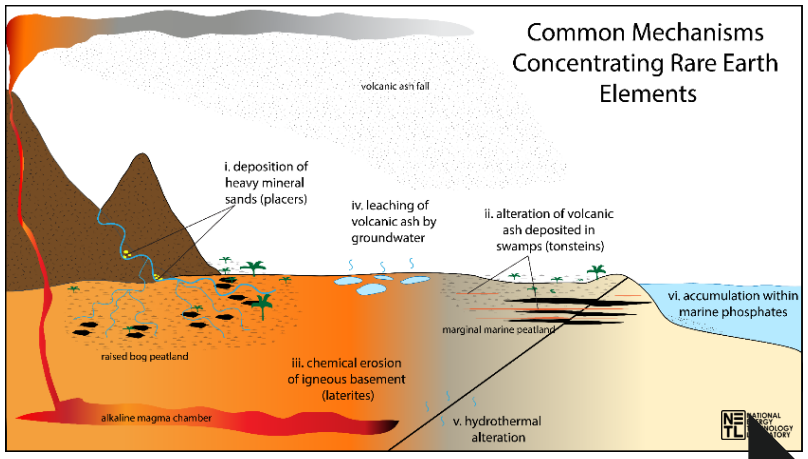


It's about more than just rock type…it's about the geohistory

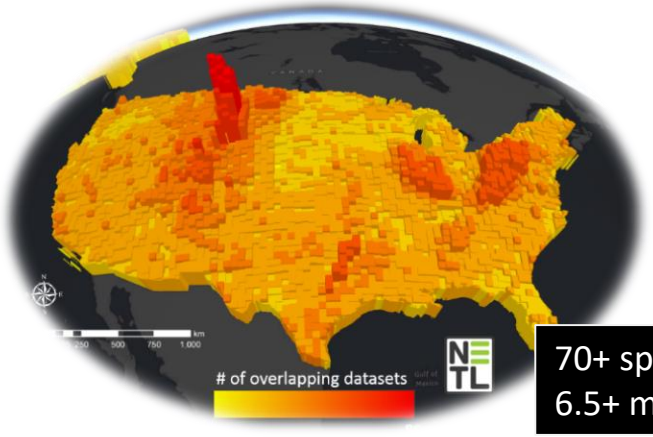


- **Based off geologic processes that result in accumulation of REEs in coal systems**
- **Can be used to identify areas with *higher REE prospectivity***
- **Can be used to constrain whether REE concentrations and volumes suggest viability of *commercial extraction* in priority US coal bearing basins**

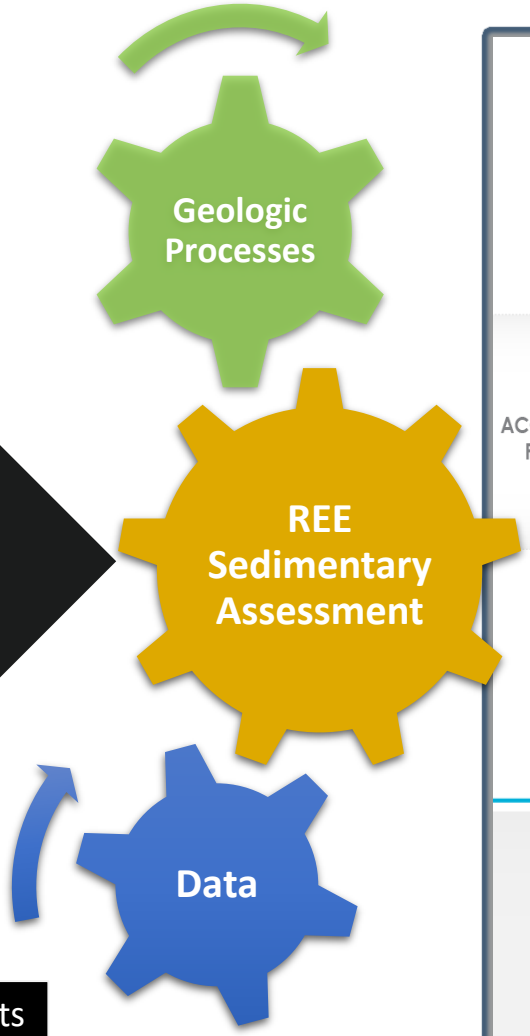
Geologic processes + Data underpin REE-SED Method

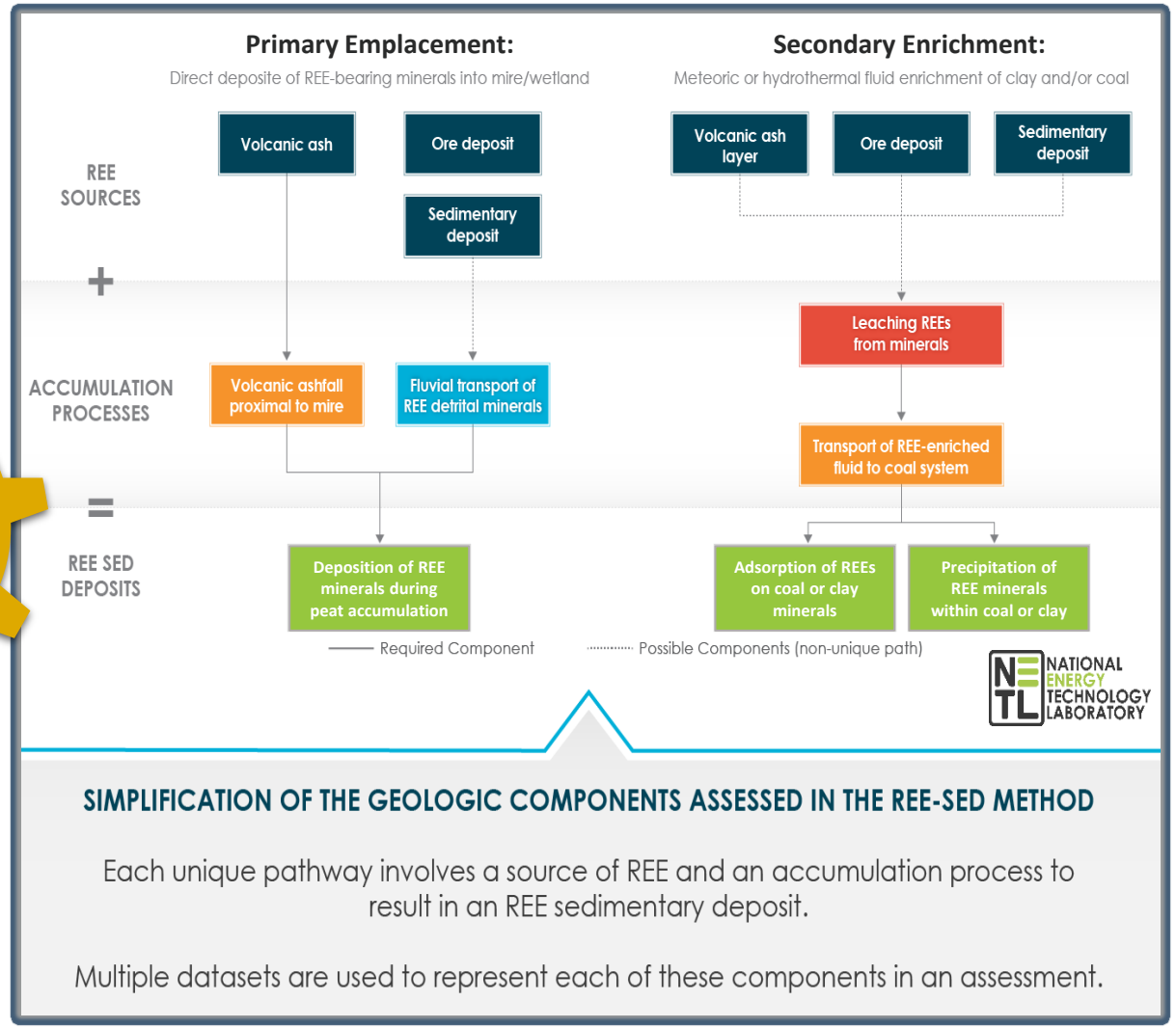


Distilled knowledge from 100's of geologic studies of REE SED systems combined with millions of data records to the method



70+ spatial datasets
6.5+ million records





REE-SED Assessment Approach

Two Main Components

1. *Characterization & Prospecting: Assessing the Potential for REE-Coal Deposits*

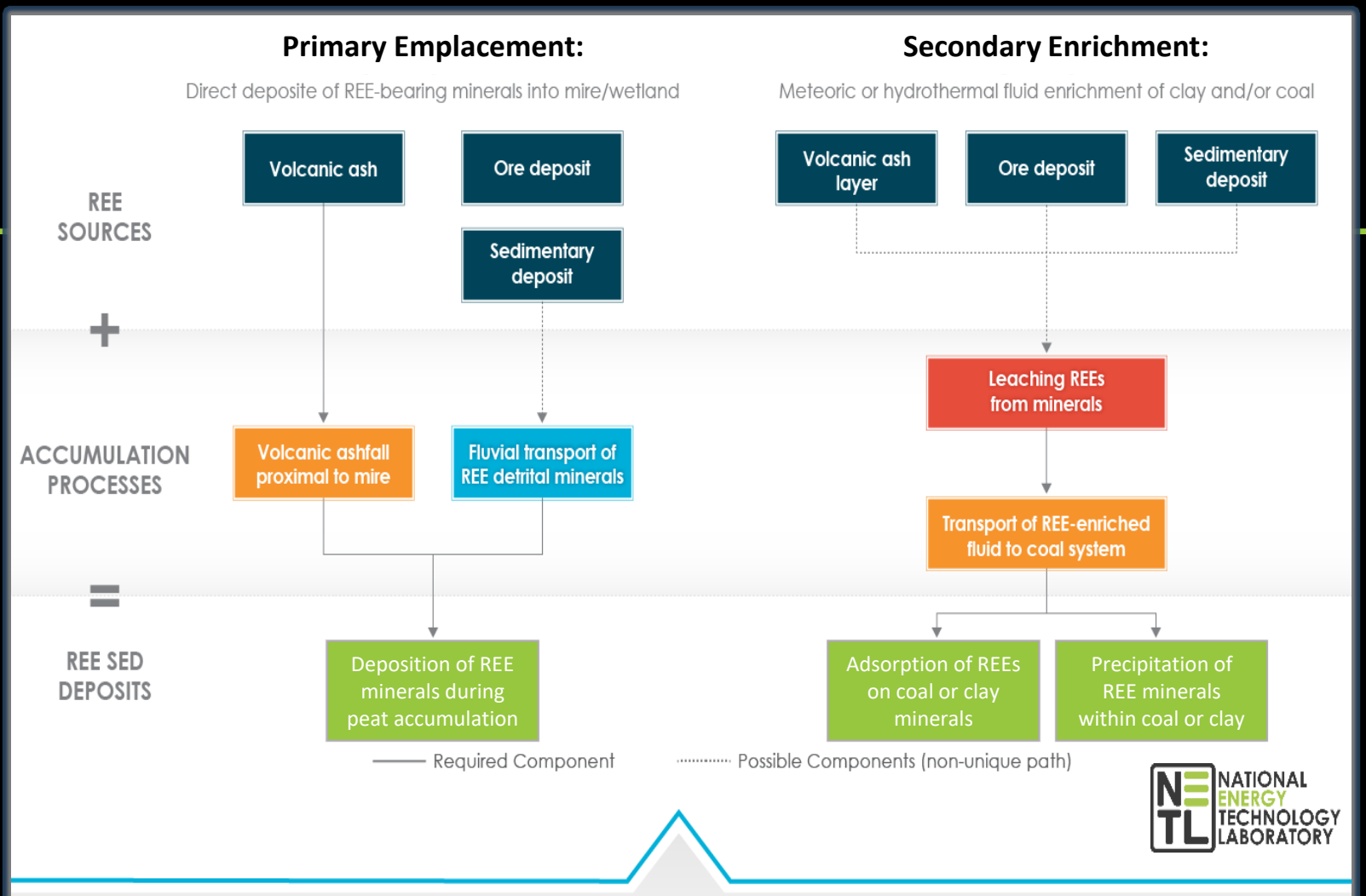
Criteria to inform where conditions most favorable for REE-enrichment of coals

- **Geological data:** lithology, core descriptions, well logs, ash isopach maps
  - **Sources**: USGS US-STRAT, USGS CRAs, USGS SGMC, published literature
- **Geochemical data:** elemental concentrations
  - **Sources**: USGS CoalQual, NUREsed, NGS, NGD
- **Coal basin regional geohistory:** paleographic reconstructions, paleo-depositional environment, regional volcanism/orogenesis
  - **Sources**: published literature
- **Known REE occurrences**
  - **Sources**: USGS bedrock deposits

2. *Spatial/Volumetric Assessment and Potential Resource Estimation*

Tools to assess REE coal spatial extent and assess REE coal resource potential

- **Geostatistical analysis** of geological/geochemical data to identify spatial patterns/anomalies in both regional and local scale (cluster, hot spot analyses)
- Seam-based **geometry calculations** using core data, well logs, other geological data (circular cross sections)
- Local/regional **coal production history**

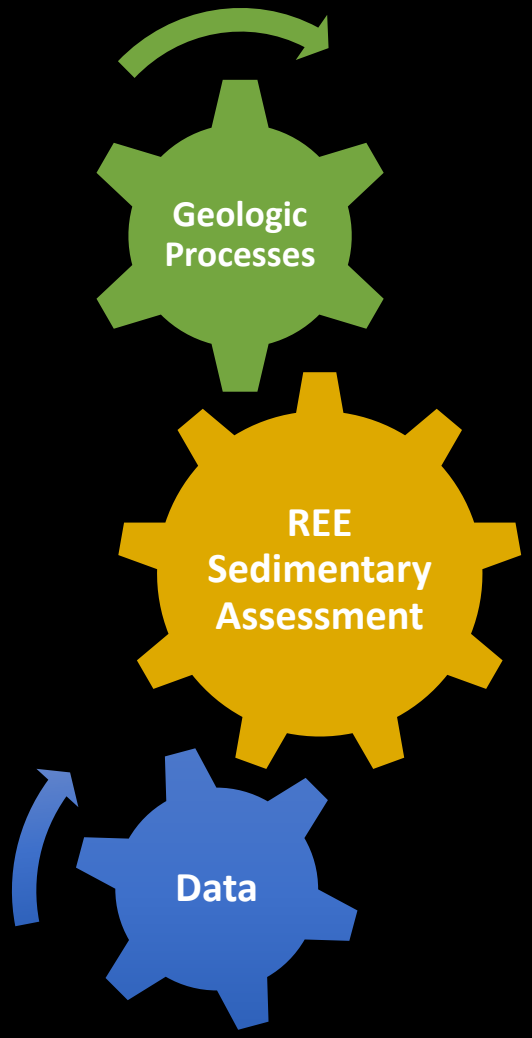


SIMPLIFICATION OF THE GEOLOGIC COMPONENTS ASSESSED IN THE REE-SED METHOD

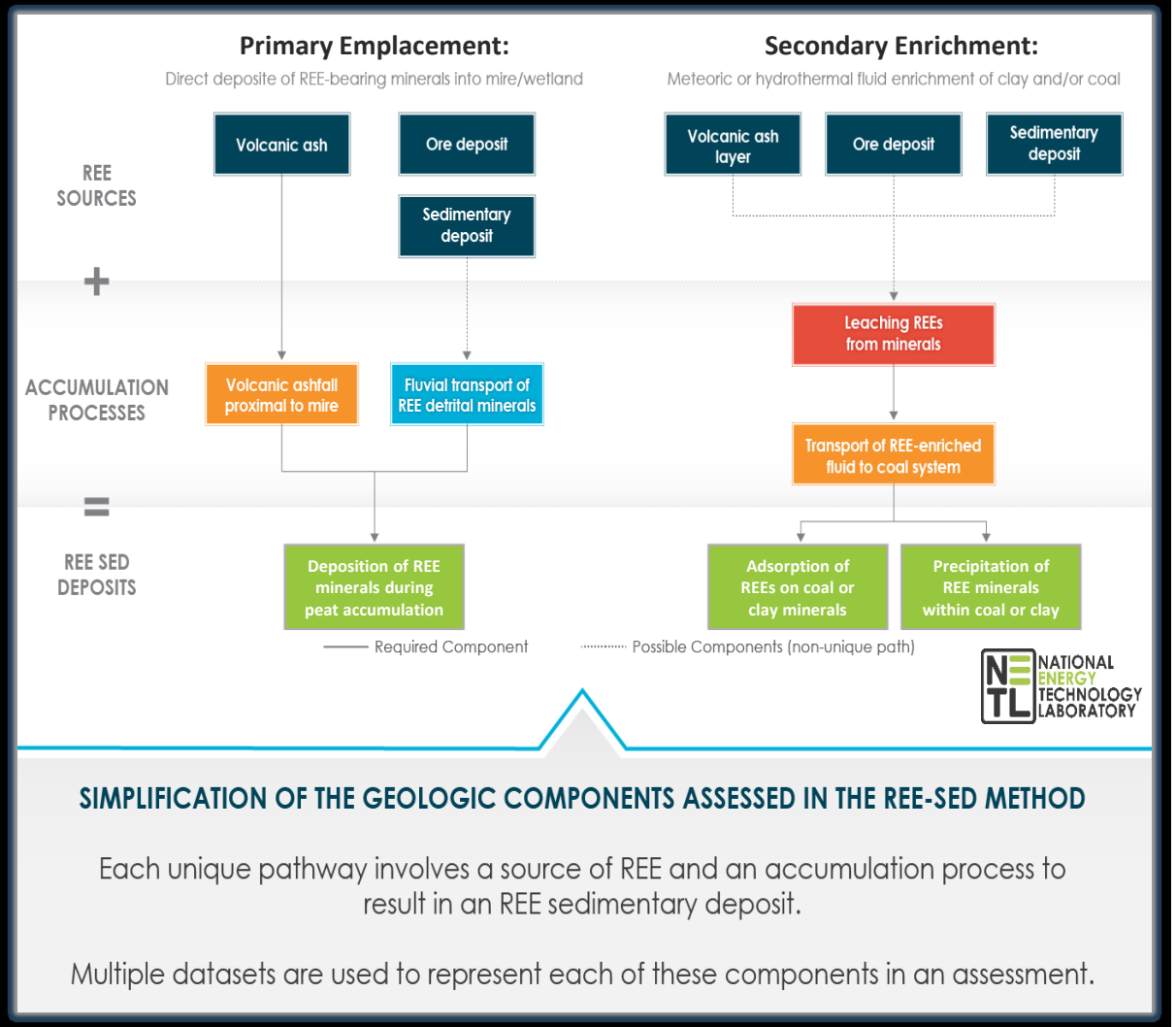
Each unique pathway involves a source of REE and an accumulation process to result in an REE sedimentary deposit.

Multiple datasets are used to represent each of these components in an assessment.

Geologic processes + Data underpin REE-SED Method



- Compiled database of over 200 publicly available, basin- and national-scale spatial datasets
  - Justman, D., Creason, C.G., Sabbatino, M., Rocco, N., DiGuilio, J., Rose, K., Thomas, R.B., REE and Coal Open Geodatabase, 2018-09-25, https://edx.netl.doe.gov/dataset/ree-and-coal-open-geodatabase, DOI: 10.18141/1475030
- Leveraged established assessment strategies from petroleum and mineral resources to evaluate past geological conditions
- Determined relationships between REE concentrations and distributions
- Identified critical information gaps and **future data needs** for testing of resource assessment method



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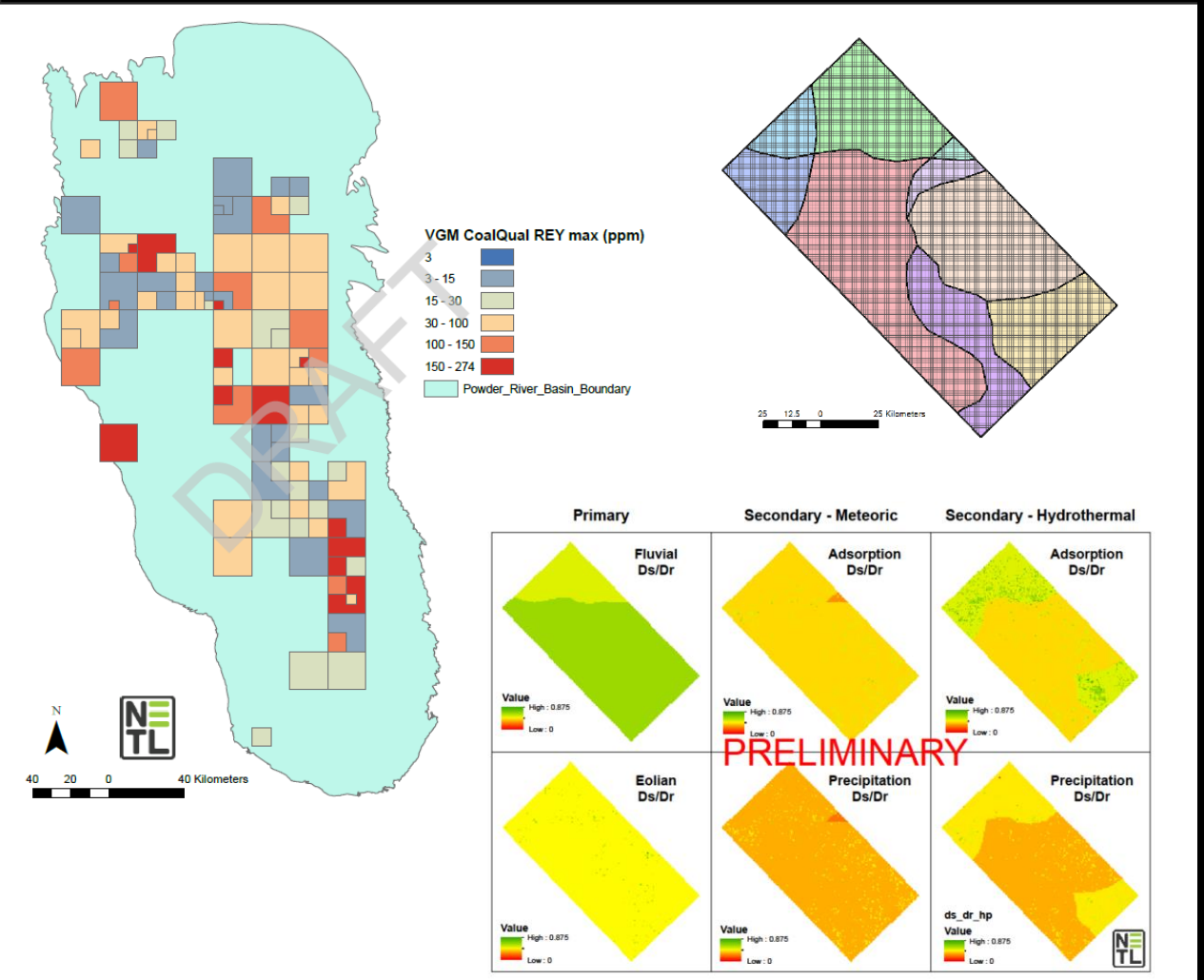
Testing the REE-SED Assessment Method

Current Status



- **Performed pilot assessment in region of Powder River Basin**
  - Synthesized geologic knowledge and data for REE-SED system
  - Predicted regions of higher REE prospectivity for different REE-SED accumulation mechanisms
- **Re-deploying method at full basin-scale (PRB, C. App. Basin)**
  - Testing and validating python code for applying the method
  - Performing sensitivity analysis to ID key components, datasets
  - Developing additional metrics to represent uncertainty
- **Incorporating fuzzy logic into workflow using SIMPA tool**
  - Resolve 'hard' domain boundaries, visualize uncertainty
  - As means to integrate temporal constraints (order of operations, time-varying components)
- **Calibrating method based on USGS CoalQual data, additional REE coal core data**
  - Validate results of multi-scale assessments
  - ID and address key knowledge and data gaps

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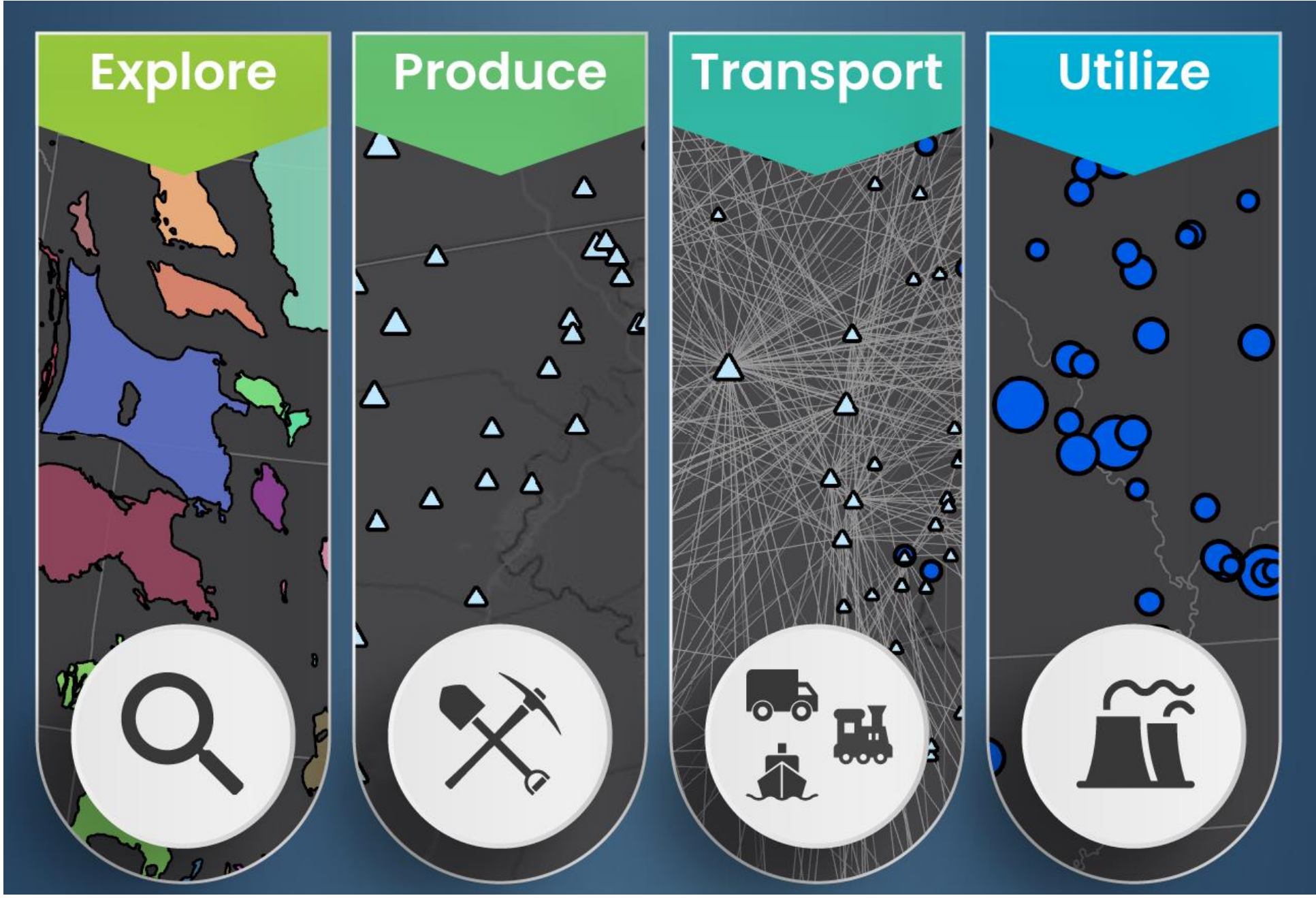
Beyond the Basin

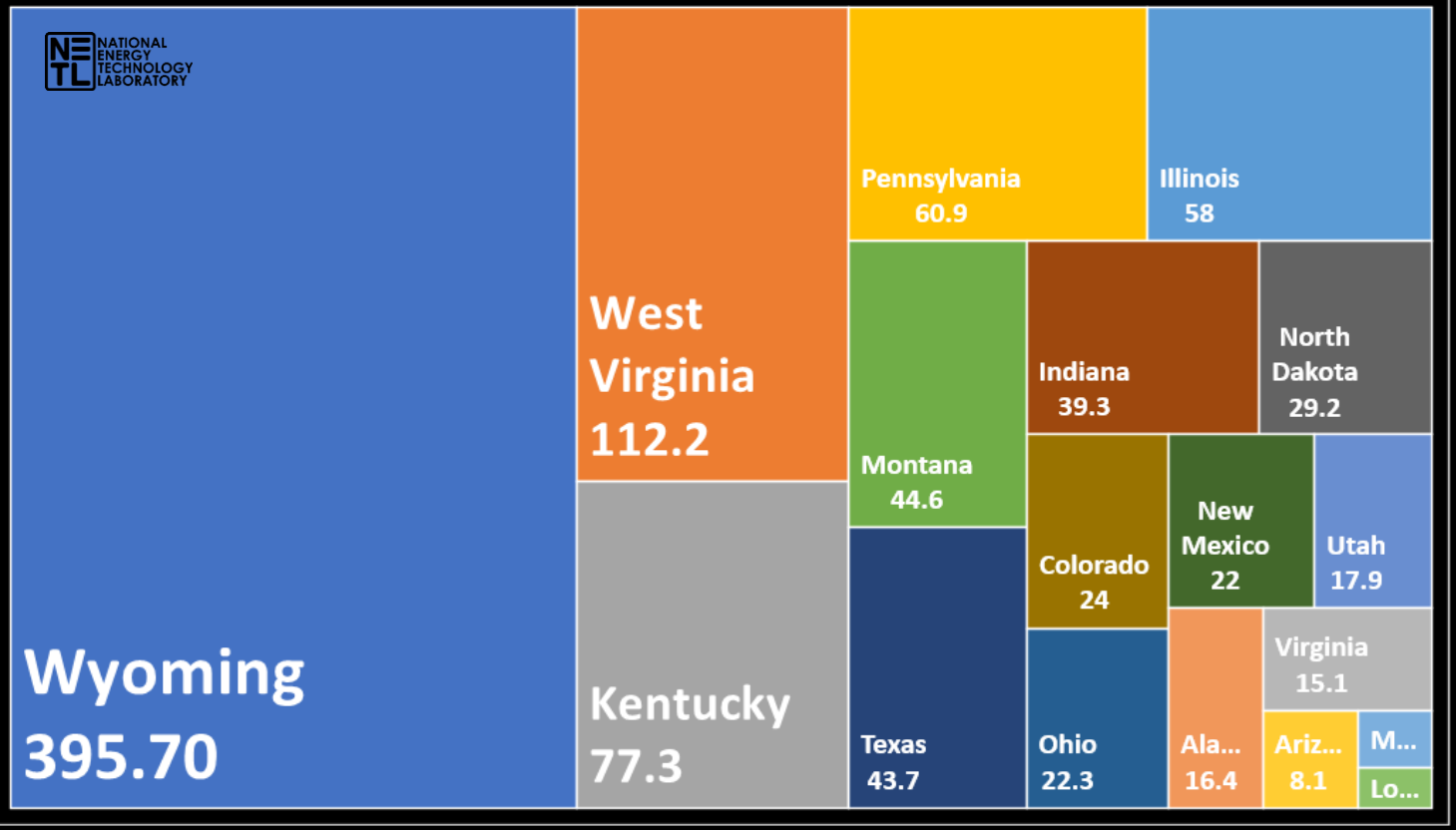
Predicting REE-SED resources from geologic media and byproducts



Where are REE enriched coals & byproducts likely to be a viable commodity?

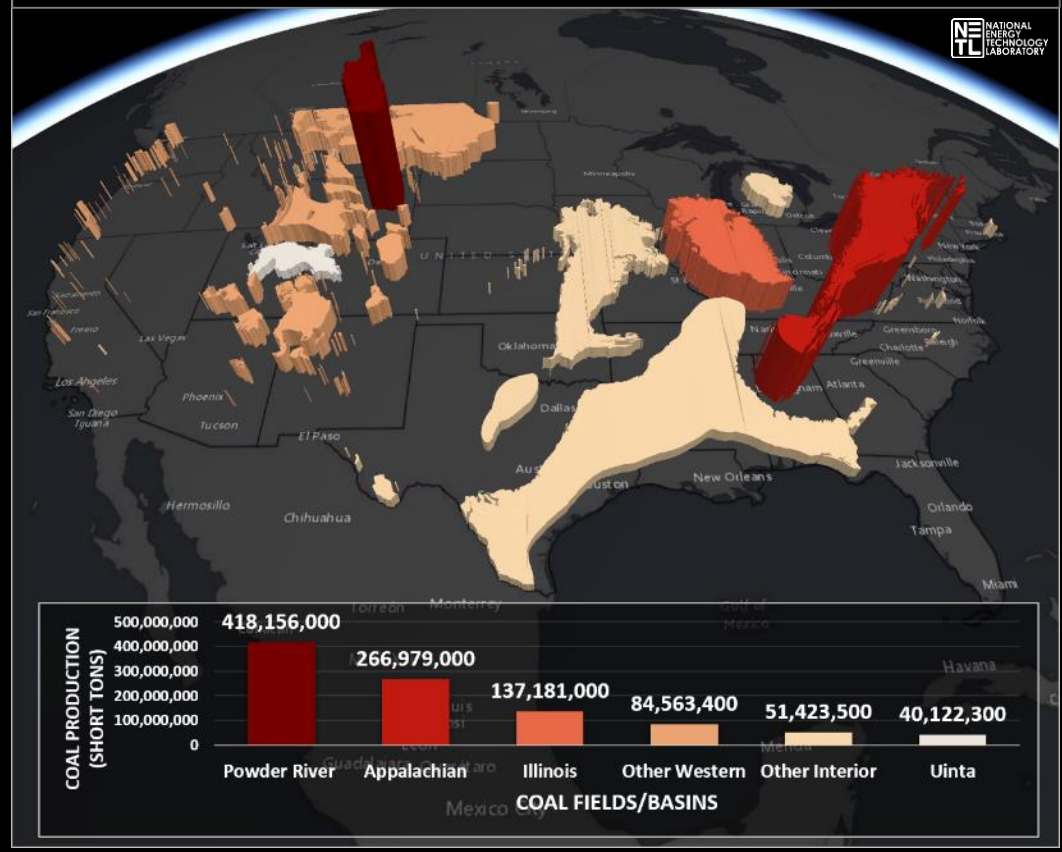
How may these resources vary?

MILLIONS OF SHORT TONS OF COAL PRODUCED BY STATE (2014)



Data sources: Energy Information Administration (EIA) state level data (2015)

SHORT TONS OF COAL PRODUCED BY FIELDS AND BASINS (2014)



Data Source: EIA

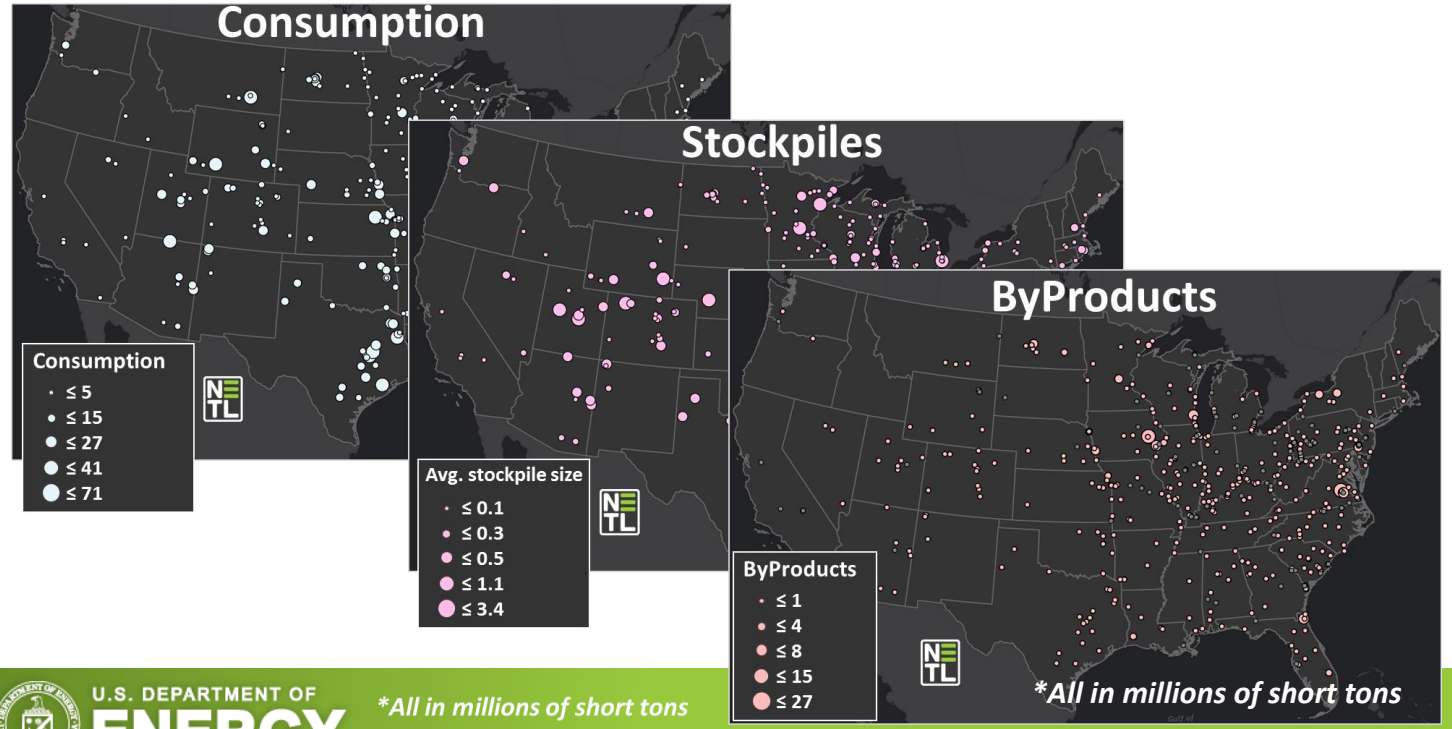
Predicting REE-resources from coal related sources to byproducts

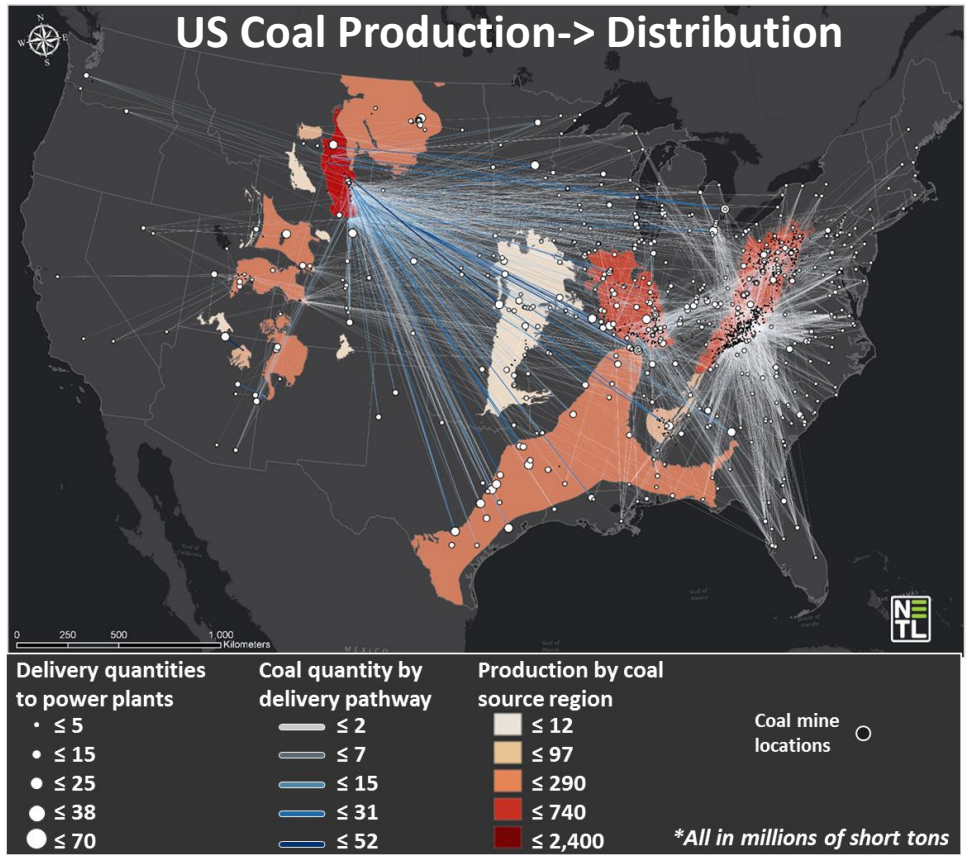
Characterize domestic coal throughout its lifecycle to optimize as a resource:

- 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.



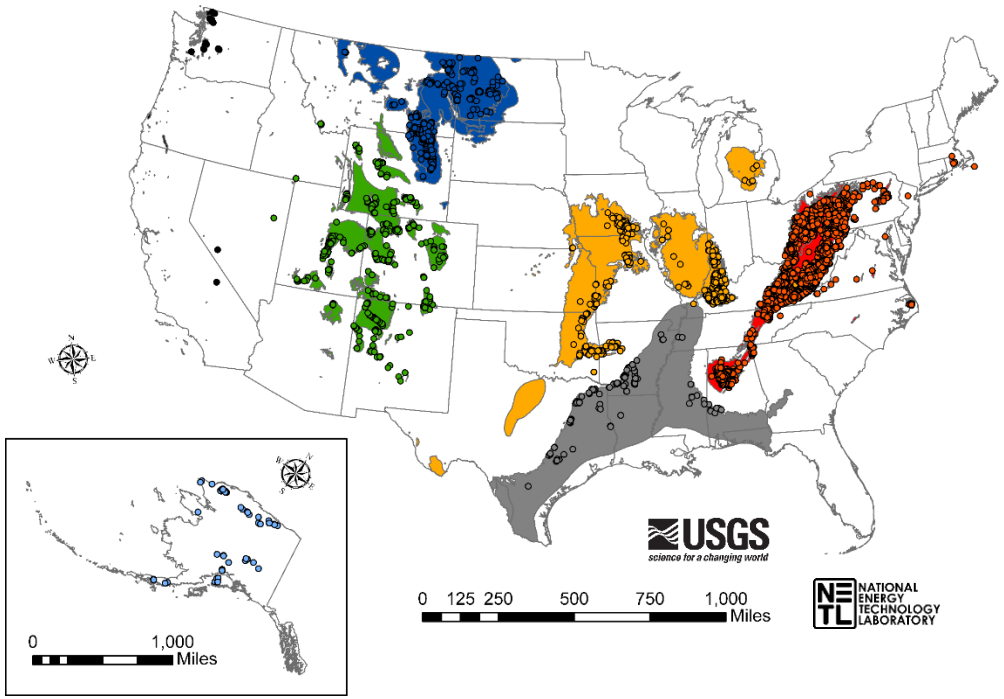


Geodatabase containing over 90,000 records spanning:

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

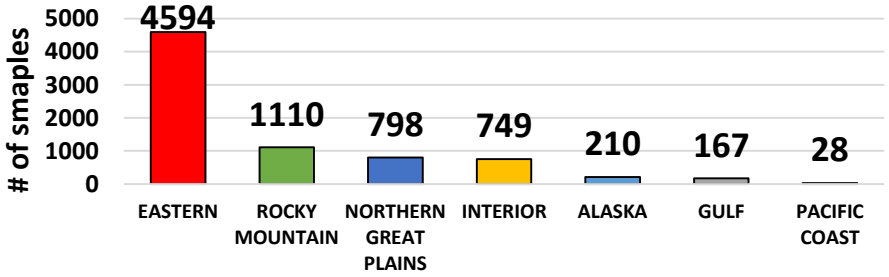
Additional Data Needed to Support Predictions

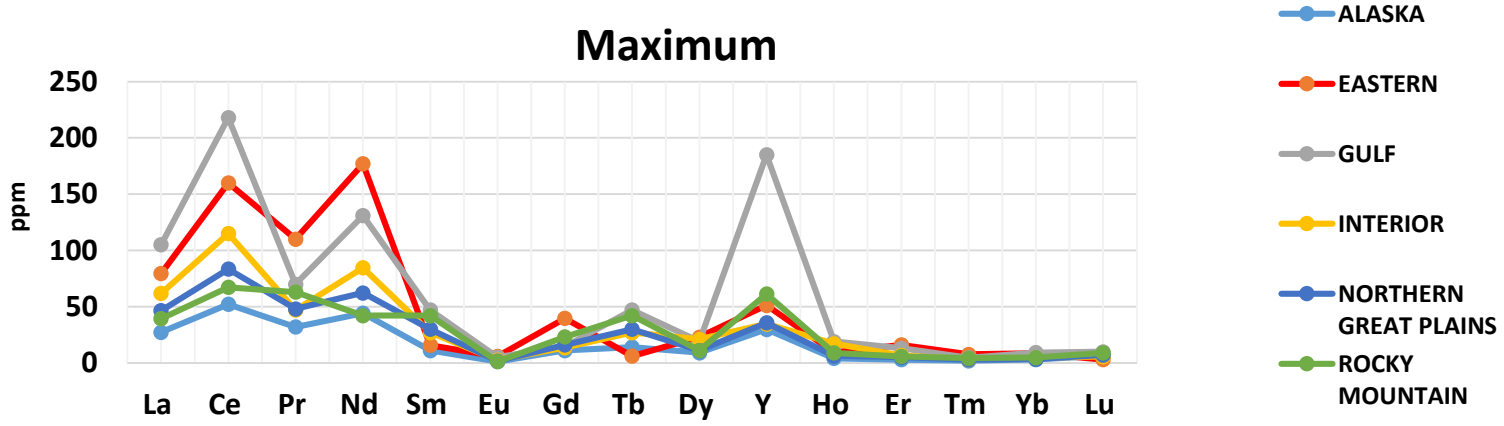
CoalQual, other critical datasets insufficient for resource assessment



KEY CONSIDERATIONS:

- Samples **vertically homogenized** (averaged) across coal seams
- Majority of samples collected in **Eastern coals** (App Basin)
- On their own, **these measurements are insufficient**
  - Need to integrate measured information with other measurements and contextual information to inform prediction

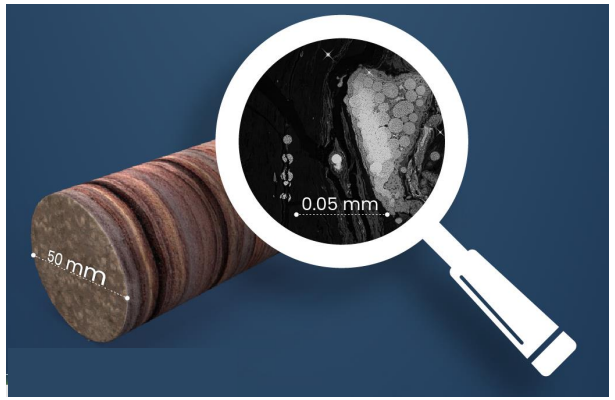




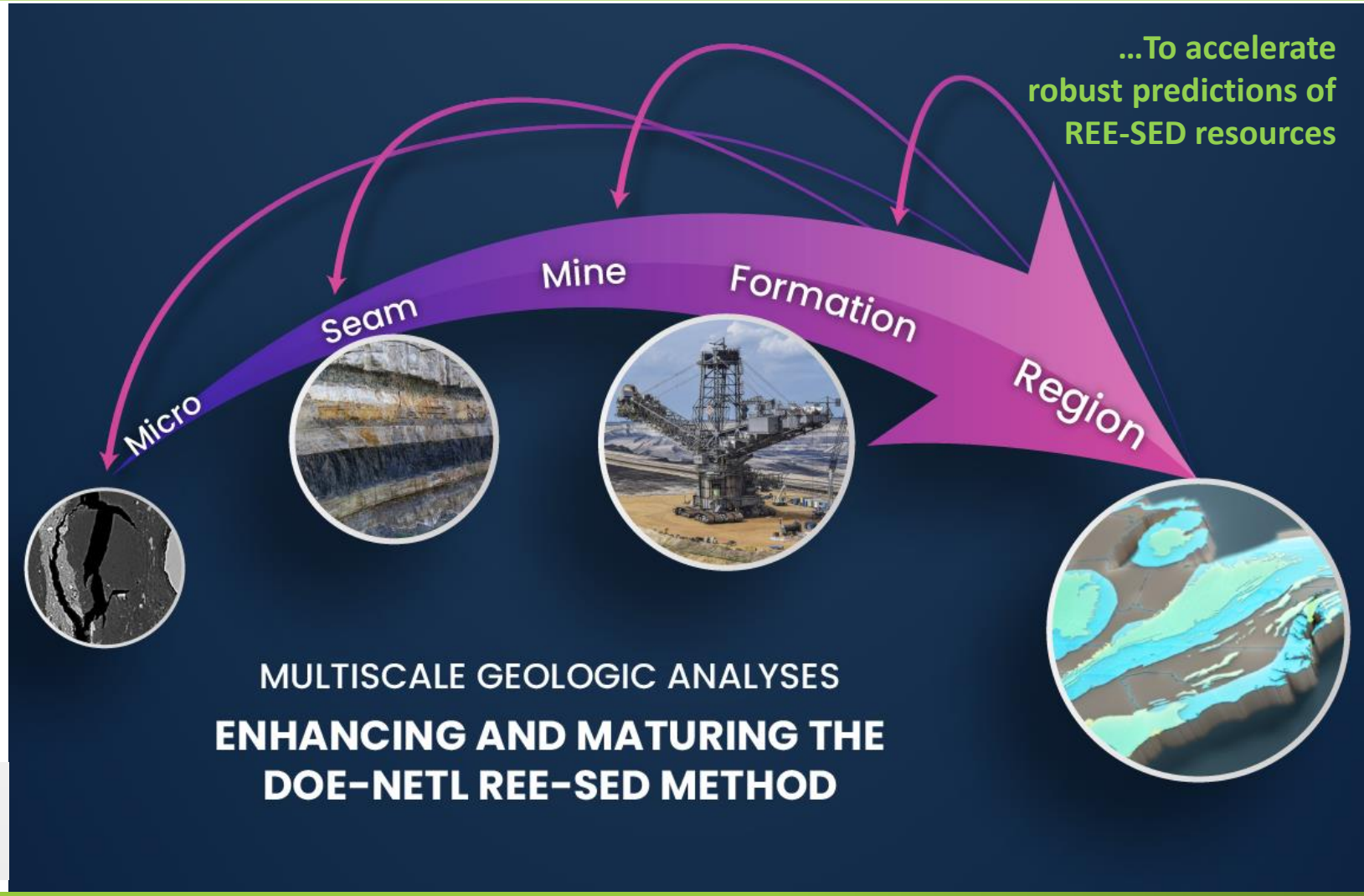
Spatial scale matters – Data collection to improve predictions

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

…Strategic sampling & analytics

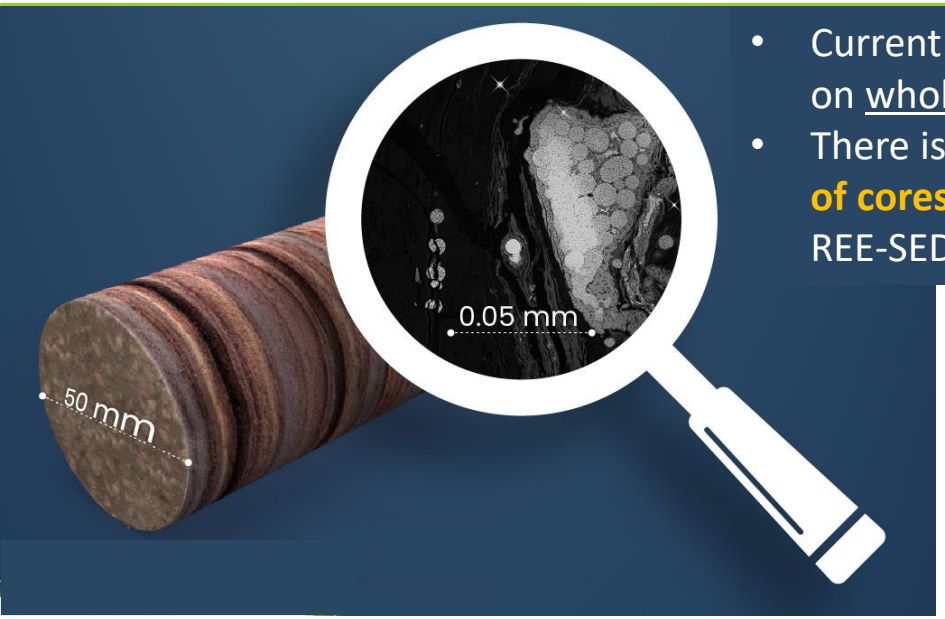


… & key government, industry & academic engagement



Documenting High Concentration Deposits

New measurements show REE concentrations vary with geology

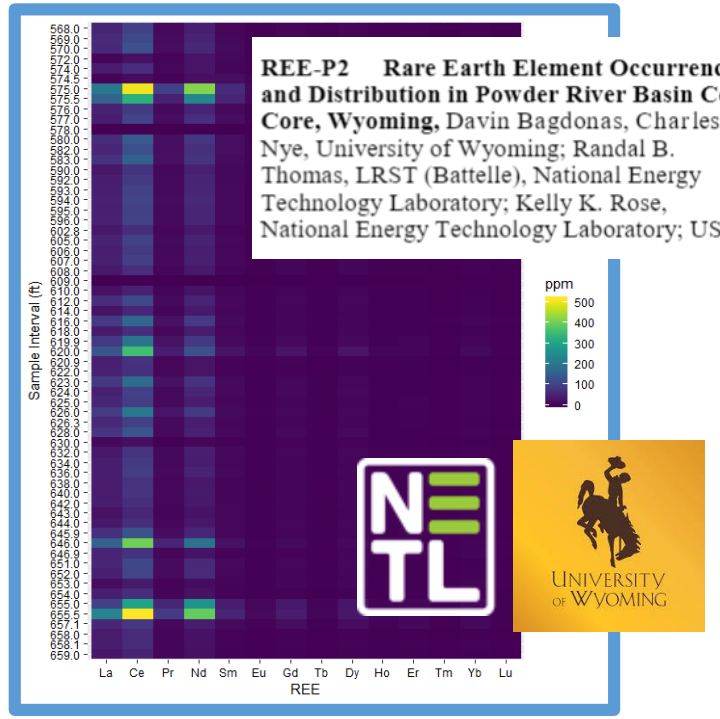


- Current REE databases (e.g. CoalQual) are based on whole sample measurements
- There is a **need for discrete, finer scale sampling of cores,** data to improve prospecting and ID of REE-SED ore quality deposits

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

Thirty-Sixth Annual INTERNATIONAL PITTSBURGH COAL CONFERENCE

University of Pittsburgh · Swanson School of Engineering



- 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.

GUI Assessment Tool in Development

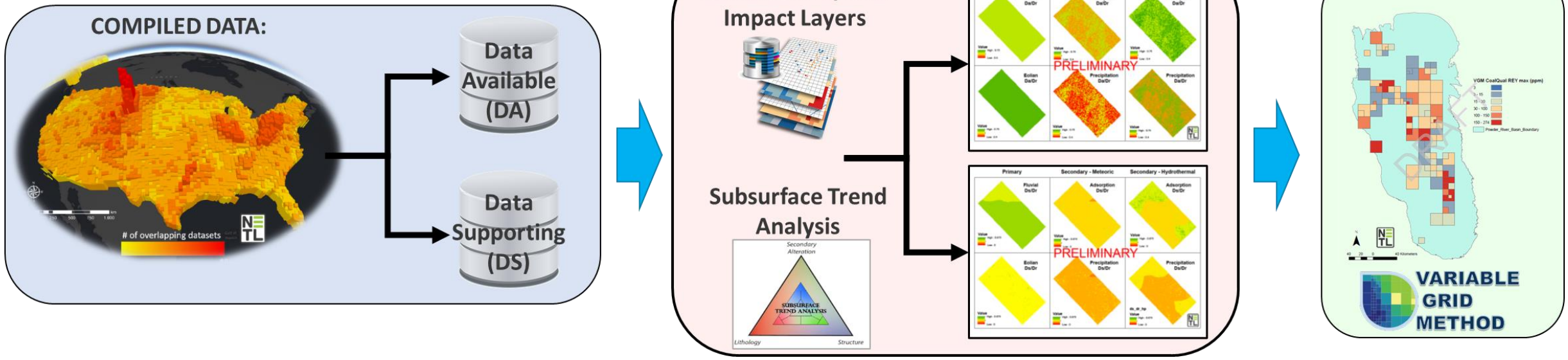
Ongoing work to guide end-user implementation of REE-SED Method

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

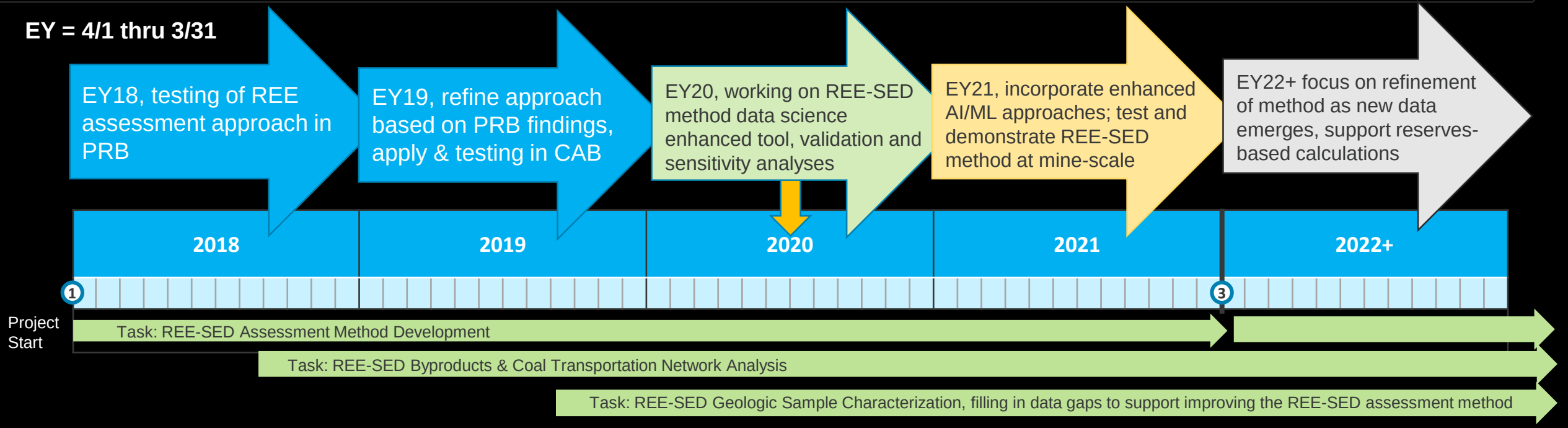
1. **Semi-automated data compilation into REE-SED database**
2. **NETL's STA tool for REE-SED inputs; results visualized spatially using NETL's CSIL tool**
3. **NETL's VGM to understand distribution of validation data, uncertainty quantification**

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

Bauer & Rose, 2015



REE-SED Assessment Method Timeline



- Test and demonstrate method in select basins
- Help determine if REE concentrations and volumes support commercial extraction in priority U.S. coal bearing sedimentary basins

Next steps

- Strategic collaborations to support demonstration & refinement of REE-SED method for geologic resource evaluations
- Application of REE-SED method to coal byproducts and transportation network analysis to forecast priority byproduct prospects
- Continue acquisition and curation of key REE-SED characterization data resources
- Evolve REE-SED assessment method to support techno-economic and reserves based-analyses

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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 (~spring 2021)

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

The REE-SED team has assembled an data collection https://edx.netl.doe.gov/geocube/#collections/ree of open-data resources via EDX that may be useful for resource evaluations in the future.

A technical report summarizing the REE enrichment mechanisms published in the literature to date is under review, **forthcoming via EDX (Fall 2020)**

Pubs to Date

Bauer, J., Justman, D., Mark-Moser, M., Romeo, L., and K. Rose. In Press. Exploring beneath the basemap. In D. Wright and C. Harder (Eds) GIS for Science (vol 2). Expected release and publication in Fall 2020.

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.

Rose, K., Bauer, J.R., and Mark-Moser, M., 2020, A systematic, science-driven approach for predicting subsurface properties, *Interpretation, 8:1, 167-181* https://doi.org/10.1190/INT-2019-0019.1

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

U.S. DEPARTMENT OF ENERGY

GAIA Group: Kelly Rose, Gabe Creason, Devin Justman, Scott Montross, R. Burt Thomas, MacKenzie Mark-Moser, Paige Morkner, Nicole Rocco, and Mike Sabbatino

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

Acknowledgements & Disclaimers

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