Bridging the Commercial Divide, NETL's Applied R&D to TCF Award

Data, methods, and tools to unlock unconventional REE & critical mineral resources

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U.S. DEPARTMENT OF ENERGY

Disclaimer

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Geo-data Science to Unlock Unconventional Rare Earth Element and Critical Mineral Domestic Potential

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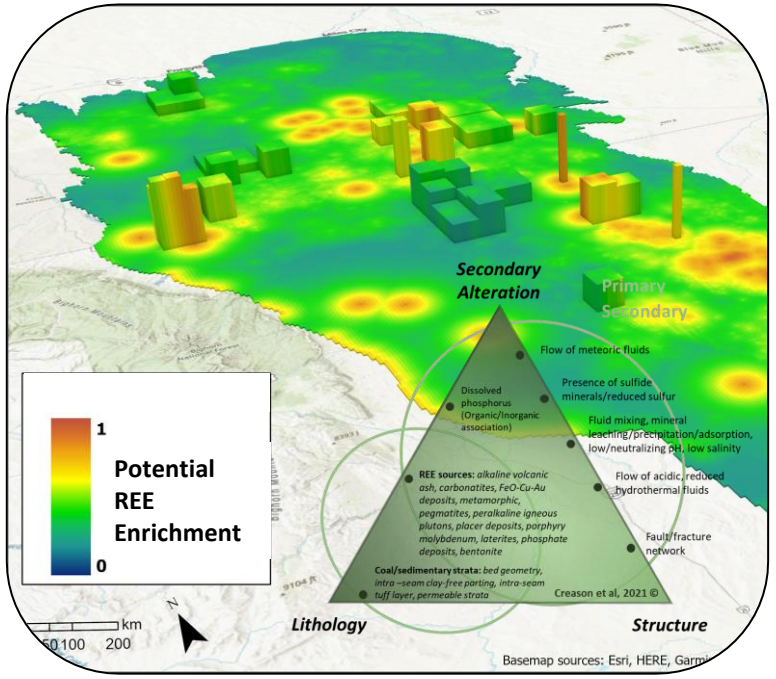
7 years, 12 peer-reviewed data products to establish & quantify URC potential

Systematic Methods & Data to Find & Quantify REE/CMs *in situ*

Montross, et al., 2022. On a unified core characterization methodology to support the **systematic assessment of rare earth element and critical mineral bearing** unconventional carbon ores and sedimentary strata. *Minerals*.

1st AI-Informed Unconventional Resource Assessment Method



Creason, et al., 2023. **A Geo-Data Science Method for Assessing Unconventional Rare-Earth Occurrences in Sedimentary Systems.** *Natural Resources Research.*

Big data computing to enable supply chains & mine waste beneficiation

Yesenchak, et al, **National Critical Minerals Data Dashboard**, 3/21/2023, DOI 10.18141/1962402

Justman, et al. 2022. **A database and framework for carbon ore resources and associated supply chain data.** *Data in Brief*.

Critical Mineral Occurrences are Not Random…

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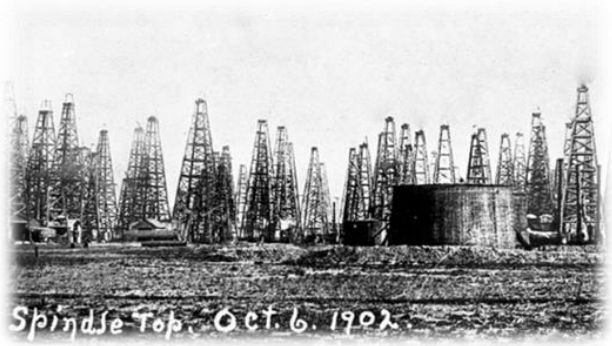
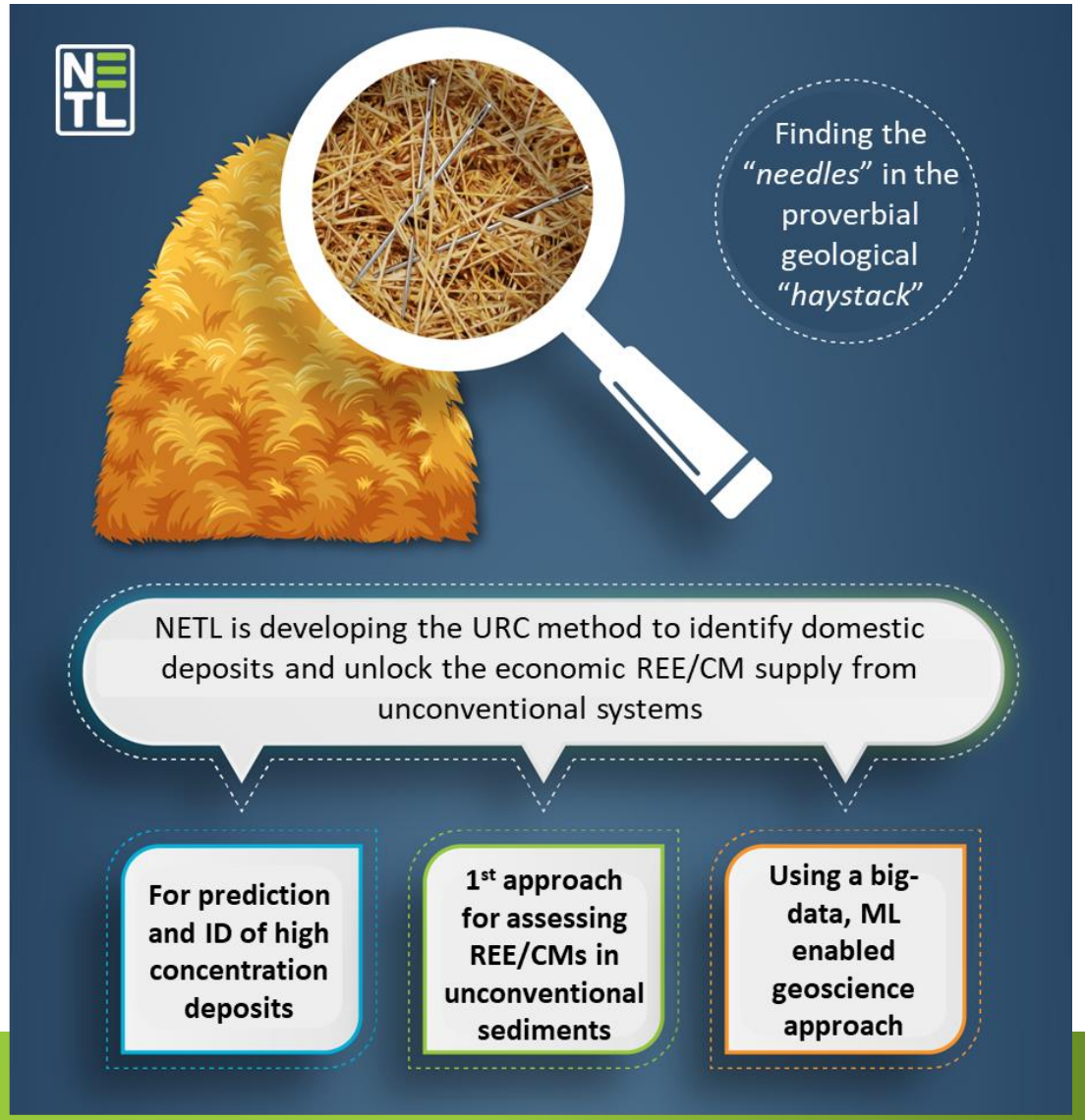
Mineral resources come from geologic media…



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

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

To unlock domestic REE & CM potential, requires data & knowledge informed predictions



U.S. DEPARTMENT OF ENERGY

*The "dry hole" metric for oil/gas wells went from 40% in the 1960s to about 10% in 2010 – EIA

URC Assessment Method Development

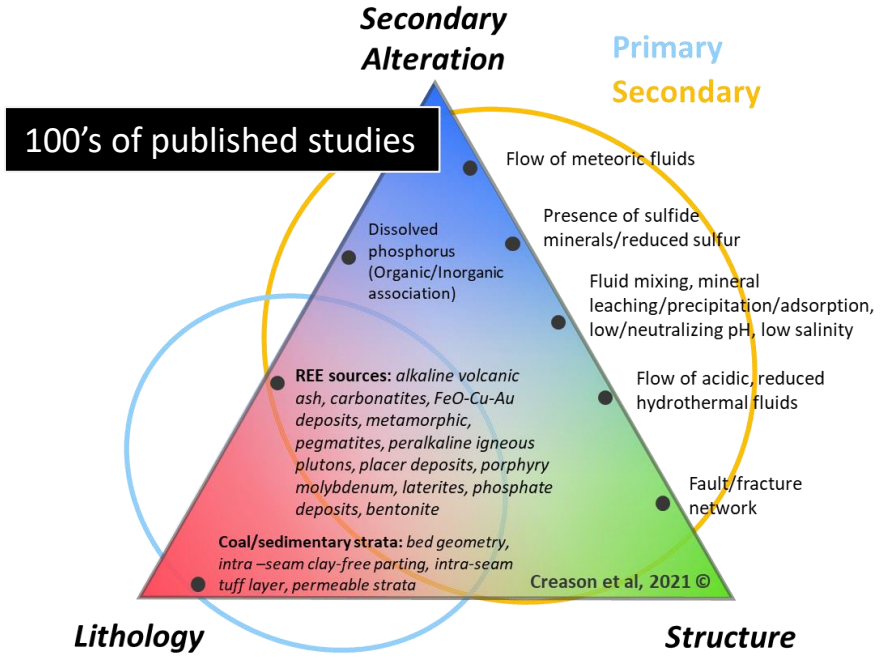
Research Objective

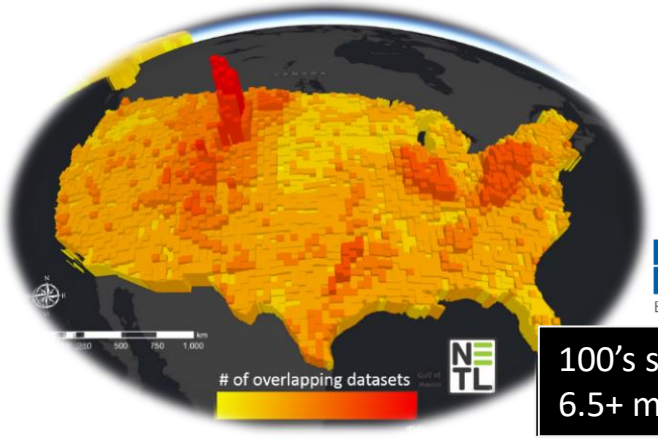
Develop an assessment methodology for systematically predicting **Unconventional Rare-earth and Critical mineral (URC) occurrences** in sedimentary strata …

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

- Is based off known **mechanisms** that result in accumulation of REE/CMs in sedimentary strata
- Can be used to identify **areas** with ***higher REE/CM prospectivity***
- Can be used to constrain whether REE/CM concentrations and volumes indicate **viability** **of** ***commercial extraction***

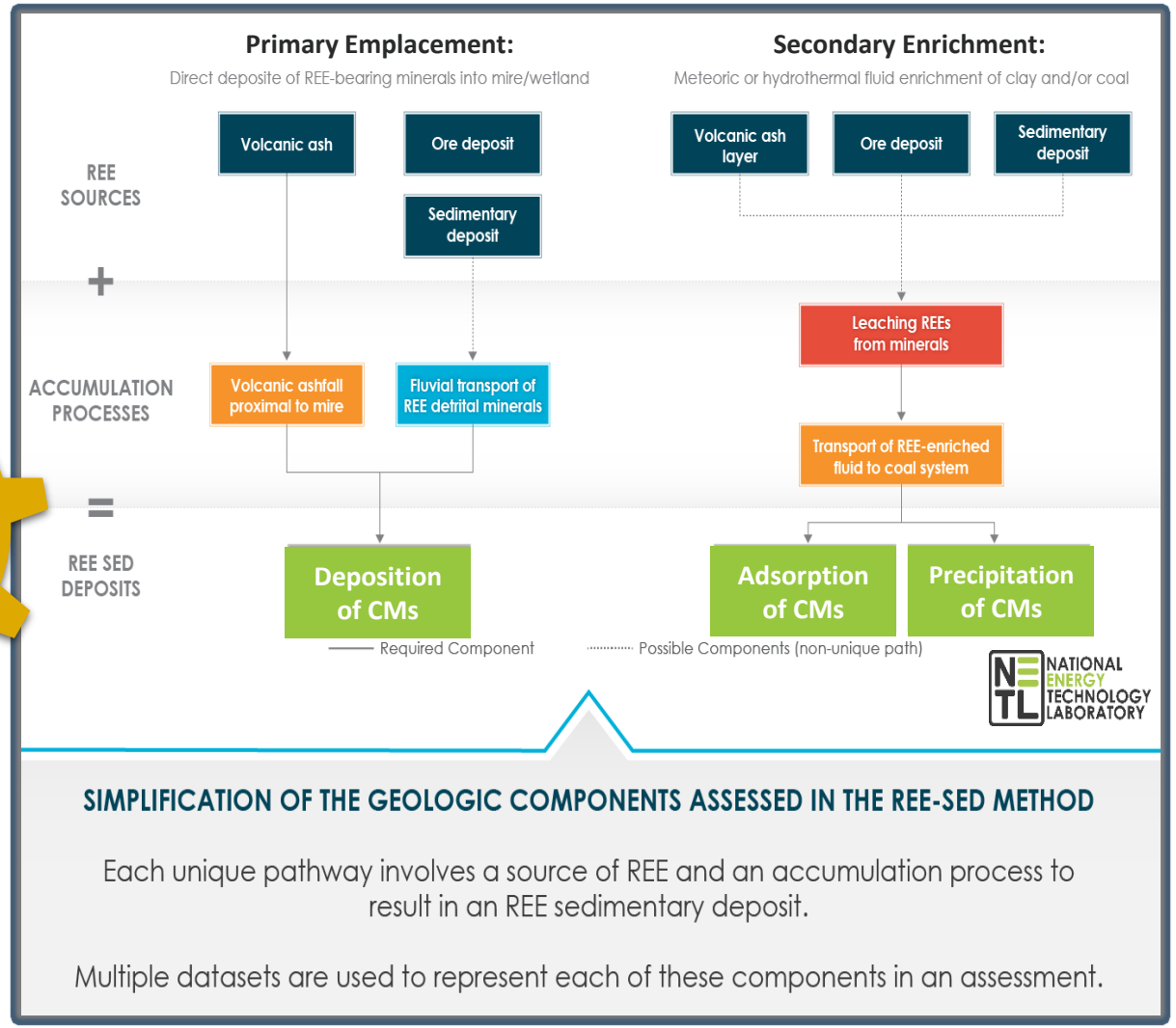
Geologic Processes + Data Underpin URC Method





EDX Energy Data eXchange

100's spatial datasets
6.5+ million records



Creason, C.G., Justman, D., Rose, K., Montross, S., Bean, A., Mark-Moser, M., Wingo, P., Sabbatino, M., Thomas, R.B. (2023). *A Geo-Data Science Method for Assessing Unconventional Rare-Earth Occurrences in Sedimentary Systems.* Natural Resources Research.

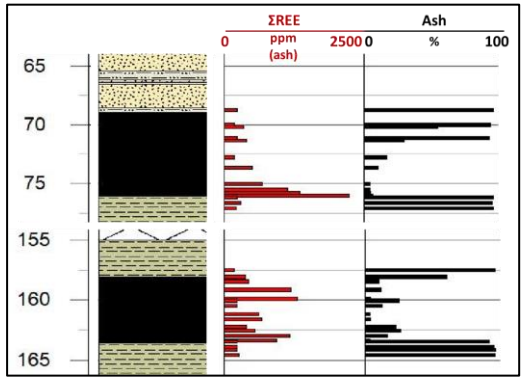
R&D partnership validates resource & accelerates future exploration/development

NETL needed "real world" data for development & validation of it's unconventional REE/CM assessment model & tools

Ramaco provided strategic cores/samples from Brook Mine site through a CRADA

Cores were used to complete **1st systematic vertical analysis of continuous rock cores** for REEs

Characterization method is 1st of its kind for REE/CM in unconventional ores

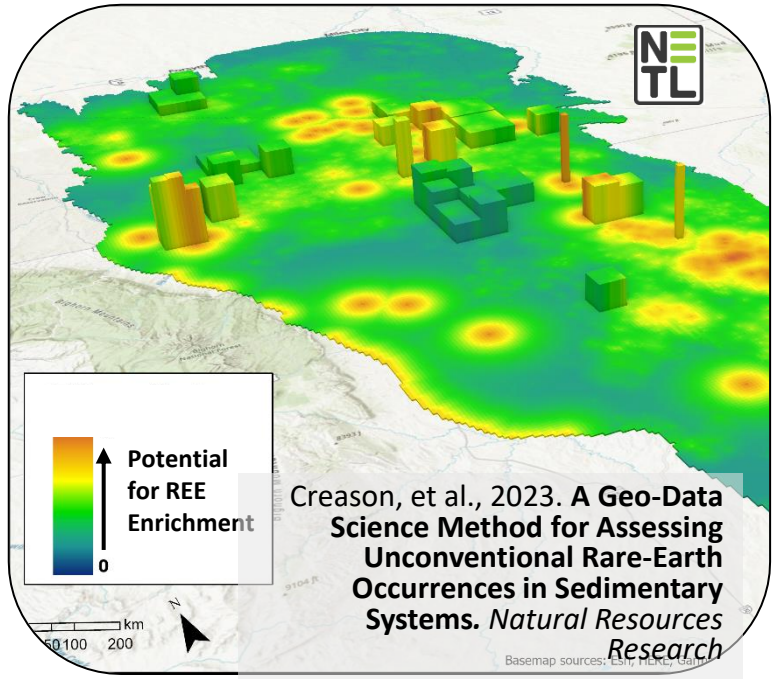


Result: Discovery of world-class accumulation zones enriched in middle & heavy REE

Montross, et al., 2022. On a unified core characterization methodology to support the systematic assessment of rare earth element and critical mineral bearing unconventional carbon ores and sedimentary strata, *Minerals*

Corroborated with additional cores & analyses

Result: World's 1st peer-reviewed artificial intelligence-informed unconventional **REE/CM resource assessment model**



Prediction of REE resource potential for north-central Powder River Basin, including Brook Mine site.
Gridded cells = locations with validation data

Basic Science R&D

Increases the knowledge base of a field of research while applied science uses that knowledge to solve specific problems.

Applied Science R&D

The discipline dealing with the art or science of applying scientific knowledge to practical problems

Actionable Science R&D

Defined as science delivered to a decision-maker that is timely…and meaningful—in terms of safety, economics, health, welfare, security, or any other values that matter to society.
-National Academies of Sciences

Commercial & Regulatory Applications

From peer-reviewed & validated concepts…

BIL

Field deployment & commercial adoption

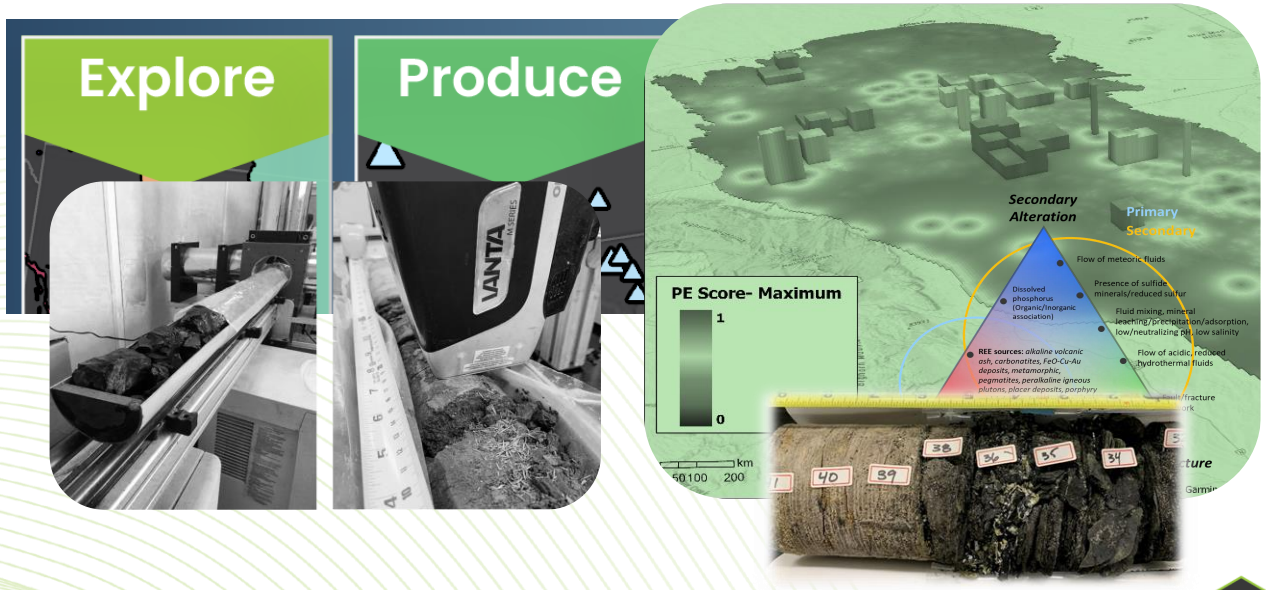
DOE OTT Technology Commercialization Fund Award:

Deploying a New Tool for Rapid Characterization & Quantification of REE/CM Resources

Using Advanced X-ray Fluorescence and Custom Machine-Learning Technologies

Key Idea/Takeaway:

Deployment of a user friendly, commercial-ready, coupled system (ML-informed software + database) that enables rapid, surface to subsurface characterization & quantification of REE/CM in unconventional feedstocks



RAMACO CARBON

WEIR

Prime Recipient: National Energy Technology Laboratory

PI: Kelly Rose **Co-PI:** C. Gabe Creason

Key Participants: Ramaco Carbon & Weir International Inc.

DOE OTT TCF Funds: $1,799,219

Partner Cost Share: $960,000**

(**pledged amount is higher bu`t only 50% will be logged)

OTT Office of Technology Transitions

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

ML/AI Tool for Rapid Characterization of REE/CM

Project Summary

***What*: Accelerating application and commercial utilization of an NETL-developed technology** to rapidly characterize critical mineral occurrences within unconventional feedstocks

How:

Impact:

ML/AI Tool for Rapid Characterization of REE/CM

Project Summary

***What*: Accelerating application and commercial utilization of an NETL-developed technology** to rapidly characterize critical mineral occurrences within unconventional feedstocks

How: Deploying a state-of-the-art machine-learning enhanced x-ray fluorescence (XRF) characterization system **that enables near real-time detection of unconventional critical mineral resources both at the surface and subsurface**

Impact:

ML/AI Tool for Rapid Characterization of REE/CM

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Impact: Field-deployable system will characterize the mineralogical (chemical) form and distribution of the material's critical mineral content, **providing strategic information for extraction approaches and technologies**

Background & Motivation

- **Current approaches** for detecting the quantity and/or form of critical minerals (e.g., ICP-MS, LIBS, XRD) **are costly and time-intensive**.

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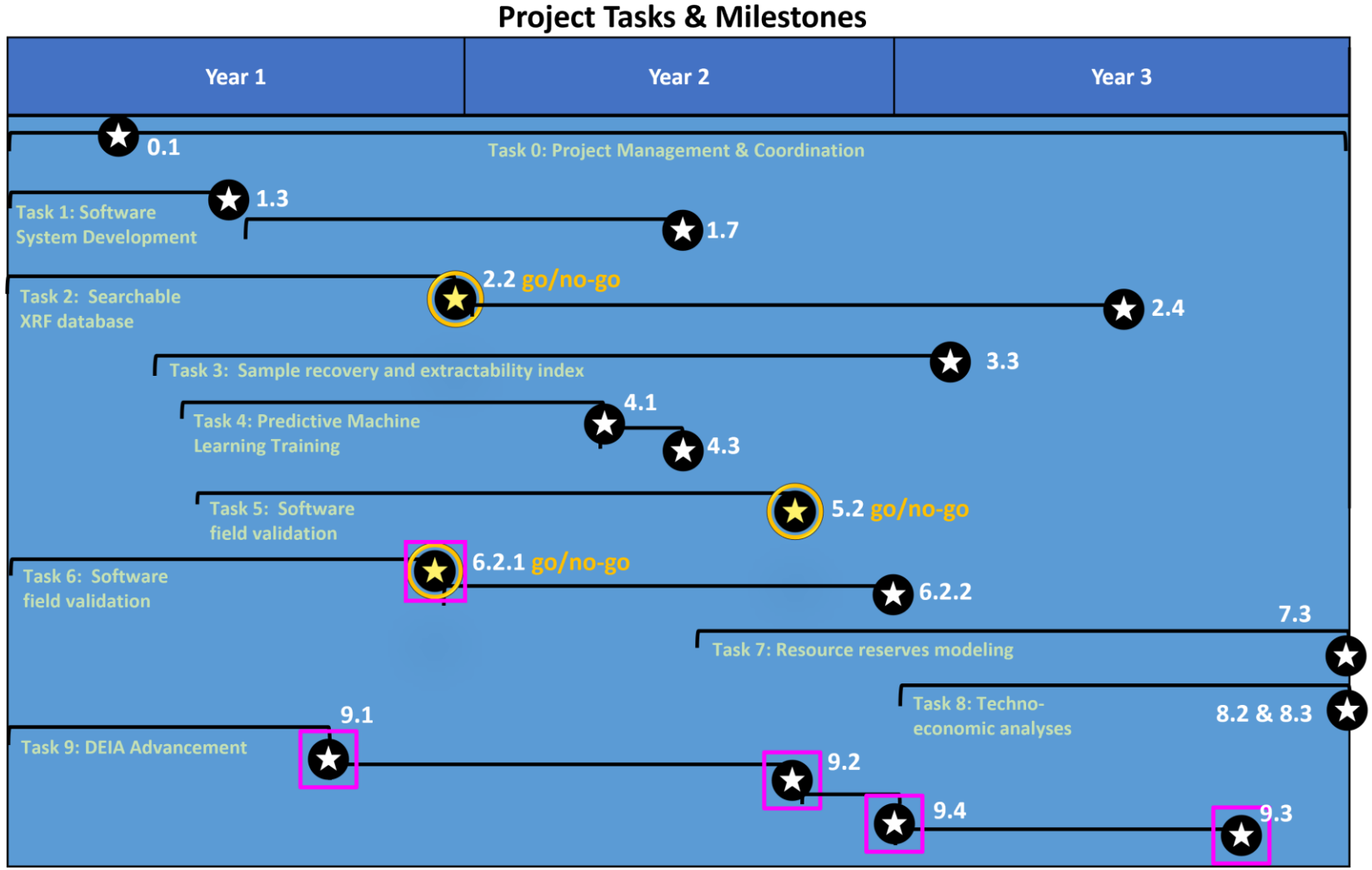
- This project will **leverage 7+ years of FECM/NETL-RIC applied R&D to enable rapid and cost-effective detection** of critical minerals from unconventional sources.
  - This technology will **enable commercial stakeholders to make timely, inexpensive assessments of potential resources**, reducing the need to collect, pay, and wait for ICP-MS sample analyses.

Project Outline, Key Tasks

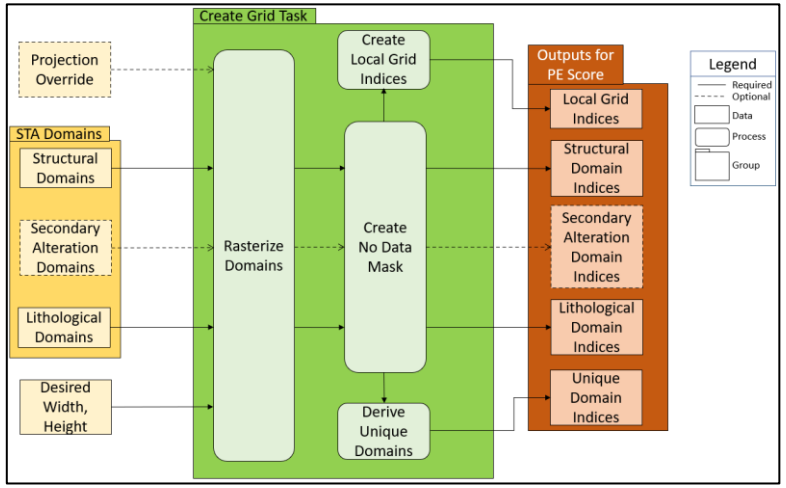
1. **Software** development, beta demonstration
2. Validation **database** (element-mineral assemblage).
3. Sample **extractability index** dataset
4. **ML training & testing** for REE form prediction
5. Software **field demonstration**
6. **Downhole XRF** field deployment & testing
7. Resource **reserve modeling** (contrast lab to field/tool)
8. **Techno-economic analysis** of tool commercial potential
9. **DEIA** engagements

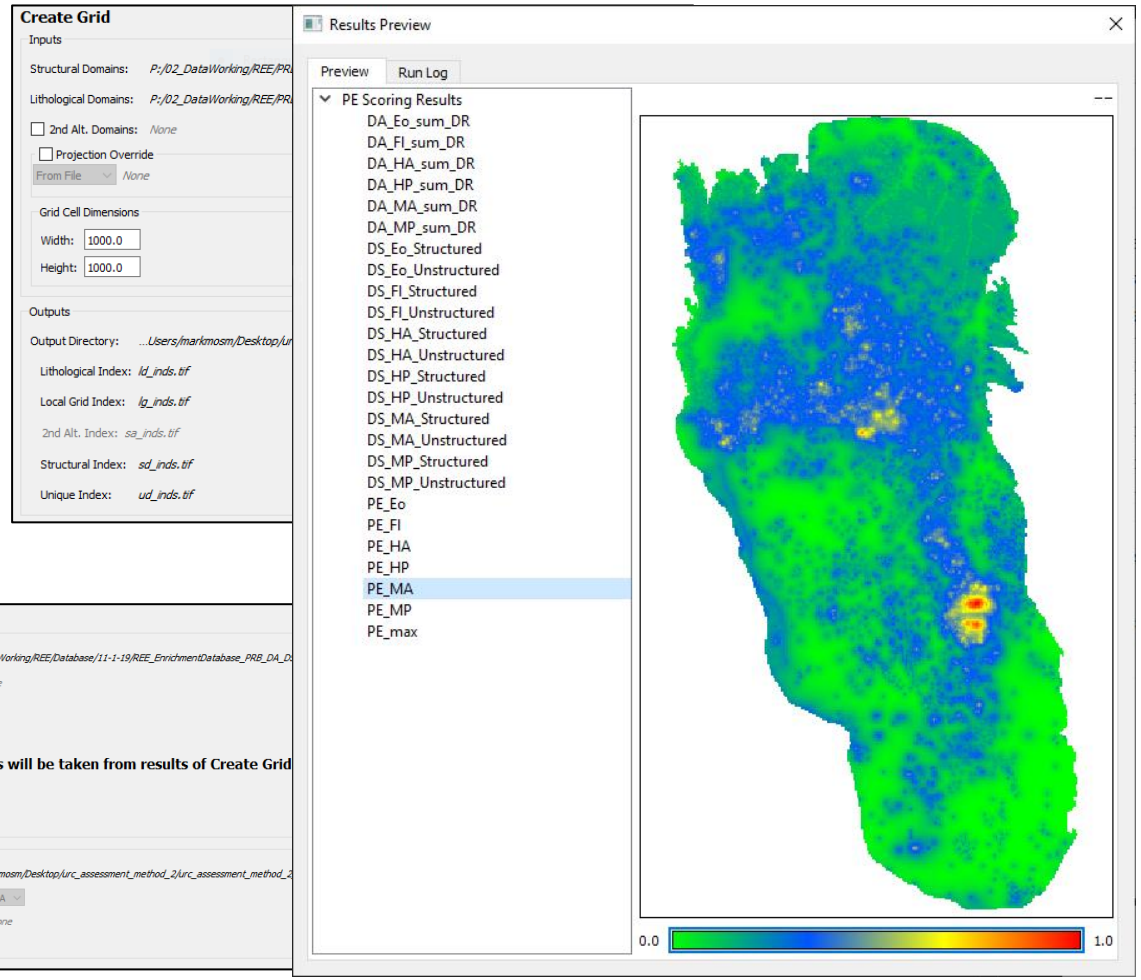


NETL Current Activities

Software Development

- Modifying existing URC resource assessment tool code for multi-scale analyses
- Incorporating data pre-processing capabilities, additional machine learning capabilities
- Creating unified graphical user interface





Wingo et al., (2023). A Python Tool for Predicting and Assessing Unconventional Rare-Earth and Critical Mineral Resources. Journal of Open-Source Software, 8(89), 5500, https://doi.org/10.21105/joss.05500

NETL Current Activities

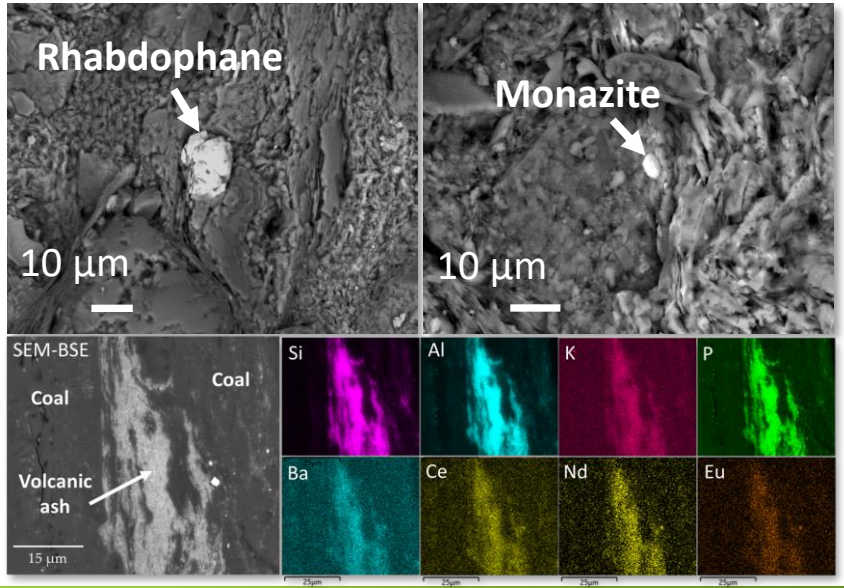
Database Development

- Developing database schema and architecture to support machine-learning tasks
- Characterizing element-mineral assemblages (pXRF, LIBS, ICP-MS, XRD)
- Lithologic characterization, geophysical measurements

Core Characterization

Handheld XRF

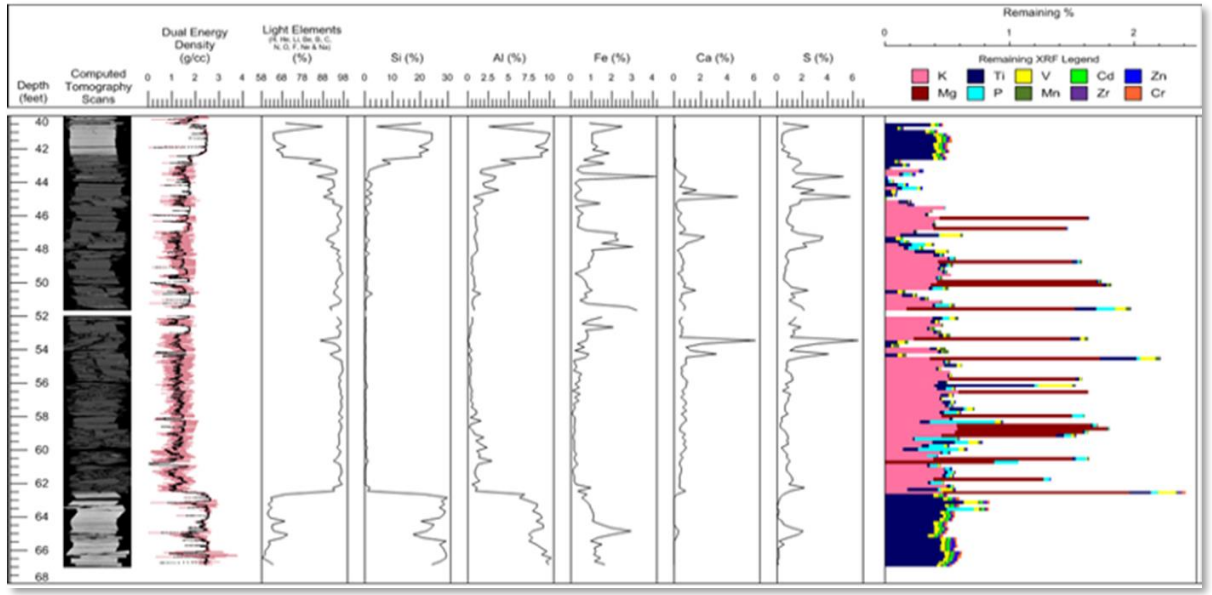
Mineralogy



Next Steps

- Additional data collection, cleaning/processing through summer
- Testing and training of machine learning models

Multi-Sensor Core Logging



Downhole Deployment

TCF Project Summary

- Demonstrating a **field-deployable system** for characterizing the phase and distribution of CM
- ML-informed software system **will support rapid, quantitative evaluation** and assessment of critical mineral potential in materials at the surface, and, where boreholes are available, from downhole scans as well
- Key outcome will be an inexpensive, portable, user-friendly software package **for characterizing CM in unconventional feedstocks**

Citations

Select Pubs, Data, Tools

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4. Justman, D., Creason, C.G., Gordon, A., Yesenchack, R., Mark-Moser, M., Rose, K., Montross, S., Wingo, P., Sabbatino, M. (2023). A Regional Geospatial Characterization of Rare-Earth Occurrence Potential within Unconventional Sedimentary Systems of the Central Appalachian Basin. Natural Resources Research. In preparation
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Thank you!

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