NETL REE/CM-SED Assessment Method

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

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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

Mineral resources come from geologic media...

Economic deposits are not random...

Systematic, geologic-driven methods improve predictability...

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

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

Finding REE “needles” in the proverbial geological “haystack”

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
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 not 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
• 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**

- 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

REE Sedimentary Assessment

Geologic Processes

Common Mechanisms Concentrating Rare Earth Elements

Precipitation of REE minerals within coal or clay minerals

Adsorption of REEs on coal or clay minerals

Precipitation of REE minerals within coal or clay

Leaching REEs from minerals

Transport of REE-enriched fluid to coal system

Volcanic ash

One deposit

Sedimentary deposit

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.

Primary Emplacement:
Direct deposit of REE-bearing minerals into mine/wetland

Secondary Enrichment:
Meteoritic or hydrothermal fluid enrichment of clay and/or coal

REE SOURCES
Volcanic ash

One deposit

Sedimentary deposit

REE SED DEPOSITS
Deposition of REE minerals during post-accumulation

Adensation of REEs on coal or clay minerals

Precipitation of REE minerals within coal or clay

REE ACCUMULATION PROCESSES
Volcanic ashfall proximal to mine

Fluid transport of REE detrital minerals

Leaching REEs from minerals

Transport of REE-enriched fluid to coal system

Data

Implementing the REE/CM-SED Assessment Method

Assess possible types of REE/CM emplacement mechanisms

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

For each grid cell:

\[ \text{PE Score} = \sum \frac{D_{Sn}}{Dr} \]

PE metrics:
- % data available
- % data supporting
- Net support

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*
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

9.1 Recent & Next Steps

- 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

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
GUI Assessment Tool in Development
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)

Compiled & collated using internal tools

Validation in prep
GUI Assessment Tool in Development

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

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

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.

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.

Geodatabase containing over 90,000 records spanning:
- 2168 mines
- 636 power plants
- 85,072 domestic coal deliveries

*All in millions of short tons
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

MULTISCALE GEOLOGIC ANALYSES
ENHANCING AND MATURING THE DOE-NETL REE-SED METHOD

...To accelerate robust predictions of REE-SED resources
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

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

- 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

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 Appalachian 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)

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

• Goal: To increase geospatial data to inform exploration and strategic development of REE/CM resources in the Central Appalachian Basin.

• 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 203-615 ppm

• 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

Initial Report to the President on Empowering Workers Through Revitalizing Energy Communities

Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization

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

IWG Report Figure 2
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
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.”


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

Check EDX for:

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

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https://edx.netl.doe.gov/geocube/#collections/ree

Datasets
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