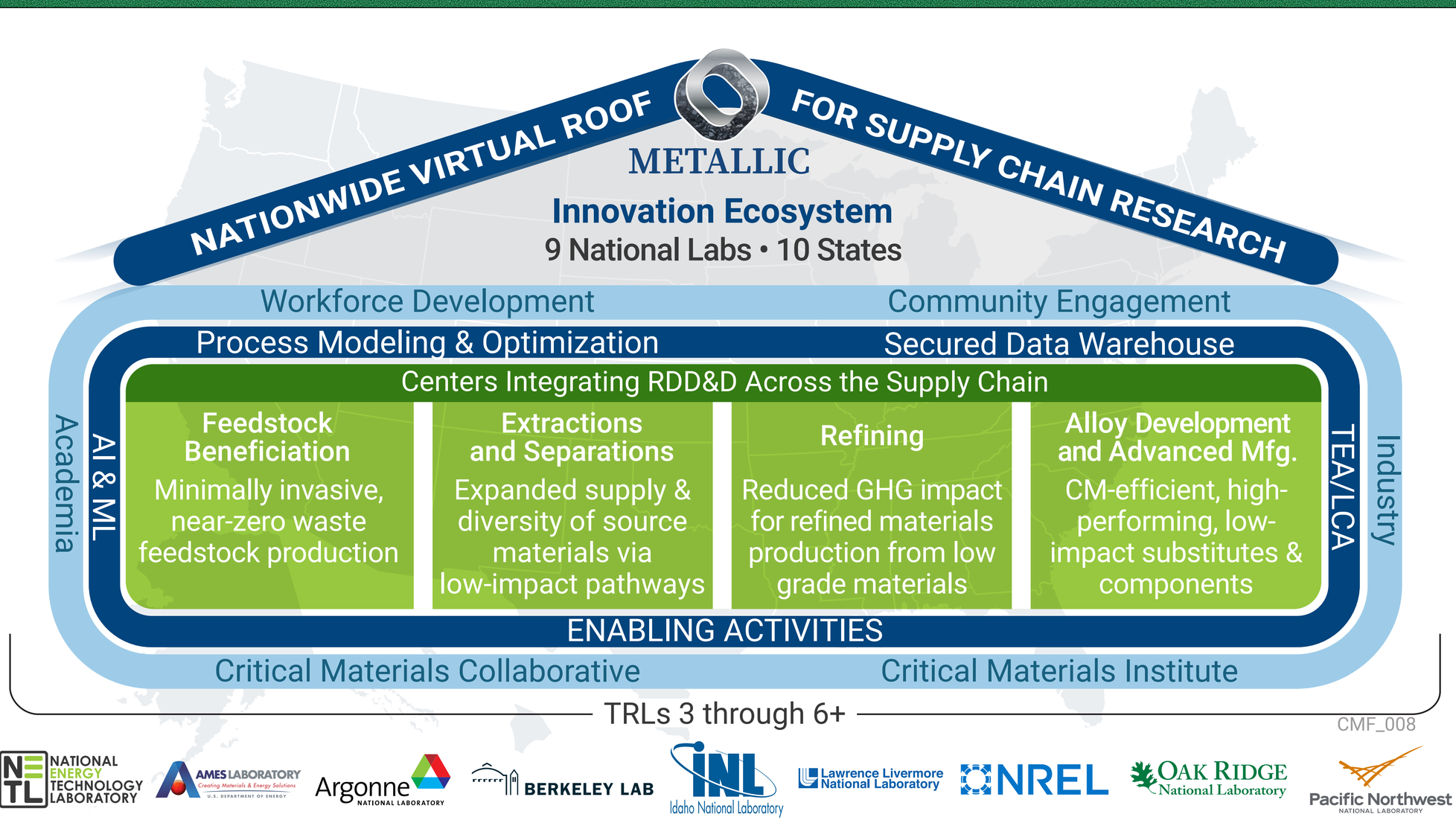
Minerals to Materials Supply Chain Research Facility (METALLIC) Accelerates Critical Materials Technology Development & Innovation

METALLIC coalesces the capabilities and expertise of nine national laboratories (NLs) to address the challenges of establishing new critical minerals and materials (CMM) supply chains.



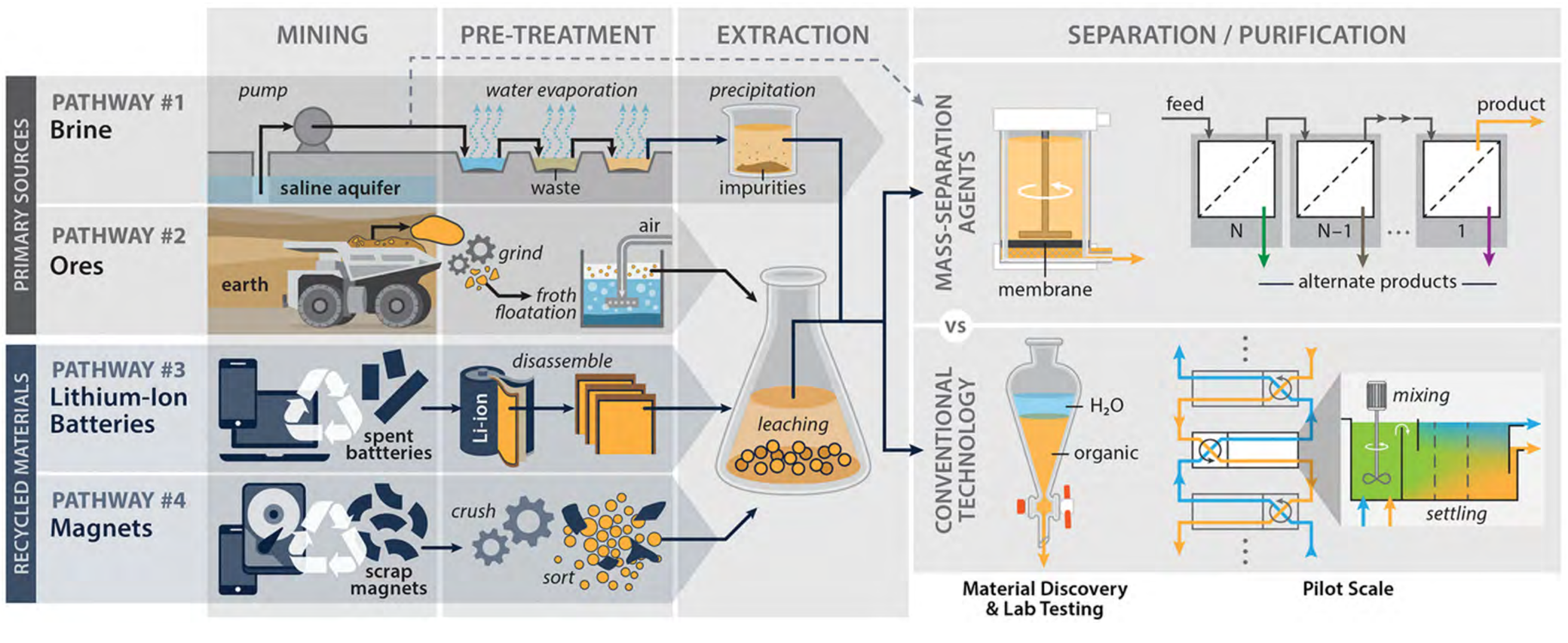
METALLIC: An Innovation Ecosystem

The NETL-led effort establishes METALLIC as the destination to validate, improve, and help commercialize technologies developed by domestic entities, amplifying the impact of the Department of Energy (DOE) and other U.S. government investments. It builds upon prior DOE efforts, thereby maximizing the value of existing capabilities within the national laboratory complex and broadening the scope of CMM supply chain areas which can be addressed. Taken together, this fosters an unparalleled ecosystem of innovation.

Ultimately, METALLIC will rapidly advance technology from the laboratory to commercial deployment, helping to secure domestic supplies of CMM by:

- Providing a combination of facilities & expertise that reduce the time and cost of technology deployment
- Rapidly identifying optimal process designs and minimizing risk to scale-up through process modeling
- Supporting the establishment of domestic CMM supply chains as a trusted and integrated center of expertise

PrOMMiS: Transforming the National Landscape for Critical Minerals and Rare Earths



PrOMMiS (Process Optimization and Modeling for Minerals Sustainability) is an NETL-led multi-institutional collaboration building a framework and modeling platform to enable design choices with costing, to perform process optimization, and to accelerate development and deployment of extraction and purification processes for critical minerals/rare earth elements at reduced risk. PrOMMiS integrates NETL-associated process tools and models from the Institute for Design of Advanced Energy Systems (IDAES), Carbon Capture Simulation Initiative (CCSI) and other programs, and leverages current and recently completed projects as case studies for testing and validation.

PrOMMiS helps to guarantee national strategic objectives for critical materials:

- Secure supply chains.
- Economic competitiveness.
- Environmental responsibility.

NATIONAL ENERGY TECHNOLOGY LABORATORY

BERKELEY LAB

Sandia National Laboratories

Carnegie Mellon University

WestVirginiaUniversity.

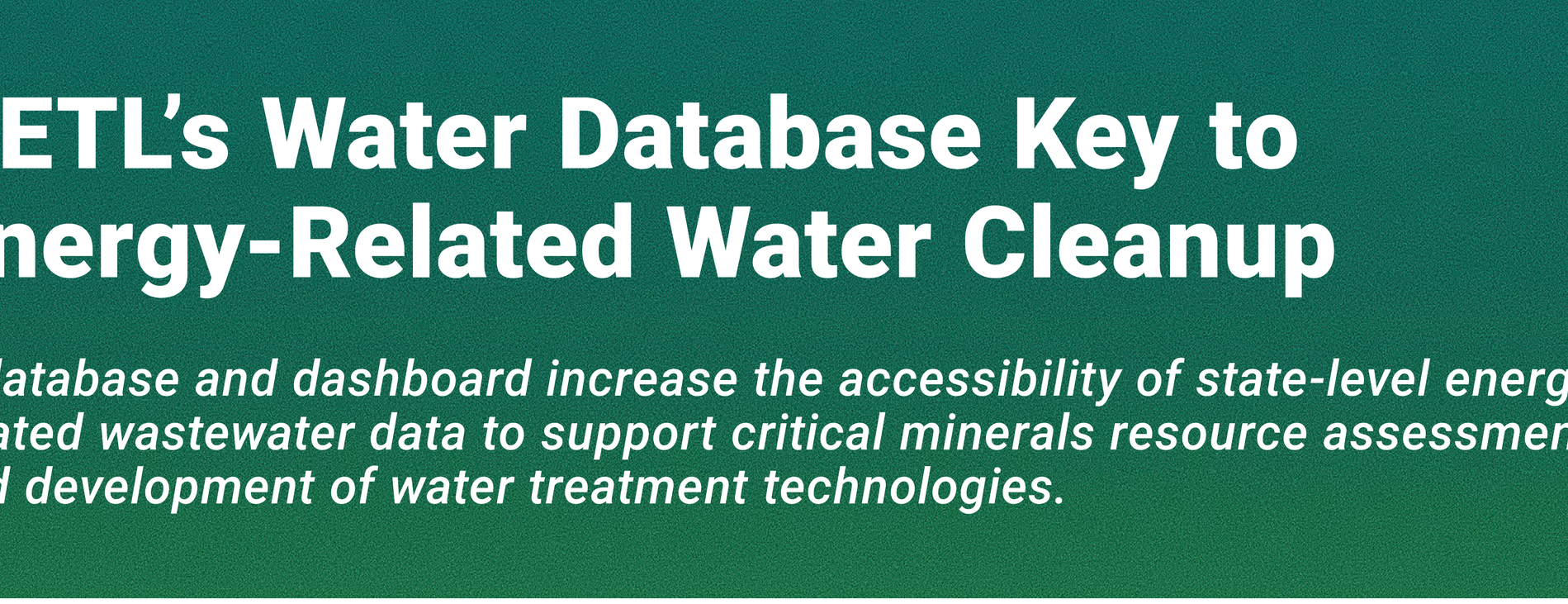
UNIVERSITY OF NOTRE DAME

Georgia Tech

U.S. DEPARTMENT OF ENERGY

NETL's Water Database Key to Energy-Related Water Cleanup

A database and dashboard increase the accessibility of state-level energy-related wastewater data to support critical minerals resource assessments and development of water treatment technologies.



NEWTS state-level database dashboard.

The National Energy Water Treatment and Speciation (NEWTS) database—which provides information about chemical constituents found in energy-related wastewater streams such as oil and gas produced water, acid mine drainage, coal ash leachate, and brackish water—has received key updates with new datasets that have been historically difficult for researchers to access.

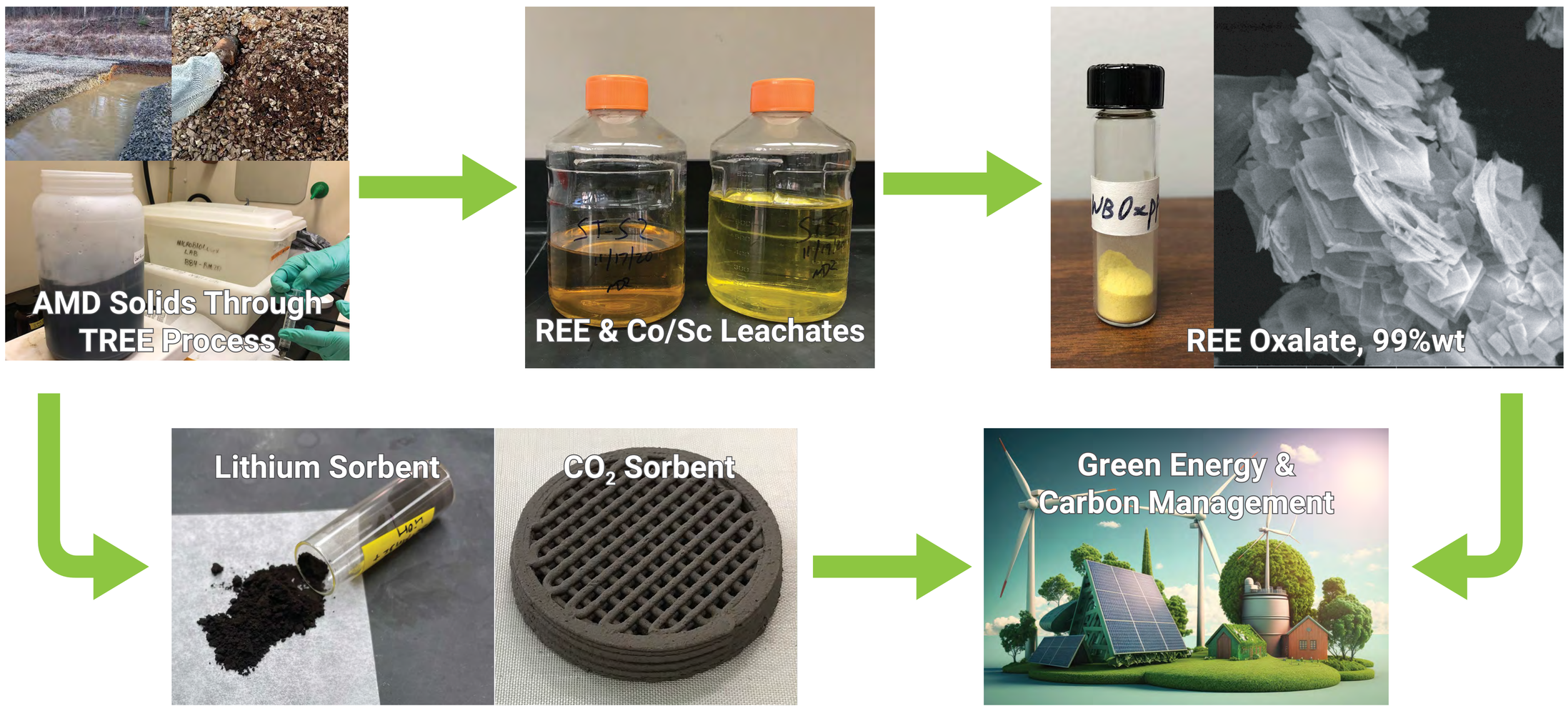
- A new state-level database dashboard that simplifies visualization and investigation of data acquired from state environmental protection agencies.
- An integrated state-level dataset that standardizes data formatting and reporting for more than 300,000 water samples.
- Publication of historical produced water data from 850 samples collected in the 1960s.
- New data used to train the Constituent Data Replacement Tool (Co-DART), a machine-learning tool for predicting missing chemical constituent data.

DOE PROGRAM

ADVANCED REMEDIATION TECHNOLOGIES

Informed Rare Earth Extraction From Mine Drainage Treatment Waste

NETL and collaborators recover meaningful supplies of rare earth elements (REE), cobalt, and functional residuals for green energy and carbon management while addressing legacy environmental wastes.



Targeted Rare Earth Extraction (TREE) from Acid Mine Drainage (AMD) Solids

As part of the Critical Minerals Characterization Program, NETL scientists characterized critical minerals in 100+ acid mine drainage treatment wastes (AMD solids) in collaboration with students from the University of Pittsburgh and Hedin Environmental, while utilizing synchrotron microprobe analyses at Stanford Synchrotron RadiationLightsource and geochemical modeling by the U.S. Geological Survey.Results of this work:

- A patent-pending step leaching protocol–Targeted Rare Earth Extraction (TREE)–to effectively recover multiple critical minerals (REE, cobalt and/or scandium) and functional residuals used for green energy and carbon management from legacy wastes, including Appalachian AMD solid, coal ash, drill cuttings, and mine tailings, across the country.
- Opportunity to transform abundant waste streams into environmental and economic assets–1,102 tons REE/year in Appalachia alone–to meet goals for DOE Offices of FECM and Environmental Management and the U.S. Environmental Protection

DOE PROGRAM
MINERALS SUSTAINABILITY

NETL PARTNERS

HedinEnvironmental

SSRL

SLAC NATIONAL ACCELERATOR LABORATORY

University of Pittsburgh

USGS science for a changing world

NETL Science – Unconventional Domestic Mineral Wealth

NETL is developing scientific strategies to establish technical recoverability from unconventional mineral deposits. These abundant but low-grade resources will enable domestic supplies of minerals critical for clean energy and national defense.

Researcher Obarr examines rock core with a handheld X-ray fluorescent spectrometer.

The Critical Minerals Characterization Program has identified multiple promising pathways to utilize legacy fossil waste streams and unconventional resources to (1) recover significant quantities of a variety of critical minerals and materials (CMM) and (2) produce novel CMM for new energy applications.

- Work portfolio includes multiple patents and spans from proof-of-concept to CRADAs for developing and testing promising technologies.
- Multiple ongoing case studies that include developing carbon-based materials from coal and rare earth element recovery from acid mine drainage.
- These efforts rely on advanced analytical methods to characterize the nature of CMM in unconventional resources, including methods developed at NETL and user facilities throughout the national lab complex.
- NETL researchers are helping to unlock the collective strength of the DOE national lab complex through the newly launched METALLIC effort.
- Enhanced recovery and production will also support new domestic jobs in mining, manufacturing, and environmental stewardship.

DOE PROGRAM

MINERALS SUSTAINABILITY

NETL PARTNERS

Argonne NATIONAL LABORATORY
tsmc
OAK RIDGE National Laboratory
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN
SLAC NATIONAL ACCELERATOR LABORATORY
University of Pittsburgh
Brookhaven National Laboratory
SSRL
NREL Transforming ENERGY
USGS science for a changing world
AMES LABORATORY Creating Materials & Energy Solutions U.S. DEPARTMENT OF ENERGY
Lawrence Livermore National Laboratory
Pacific Northwest NATIONAL LABORATORY
INL Idaho National Laboratory
hedinenvironmental
BERKELEY LAB Bringing Science Solutions to the World

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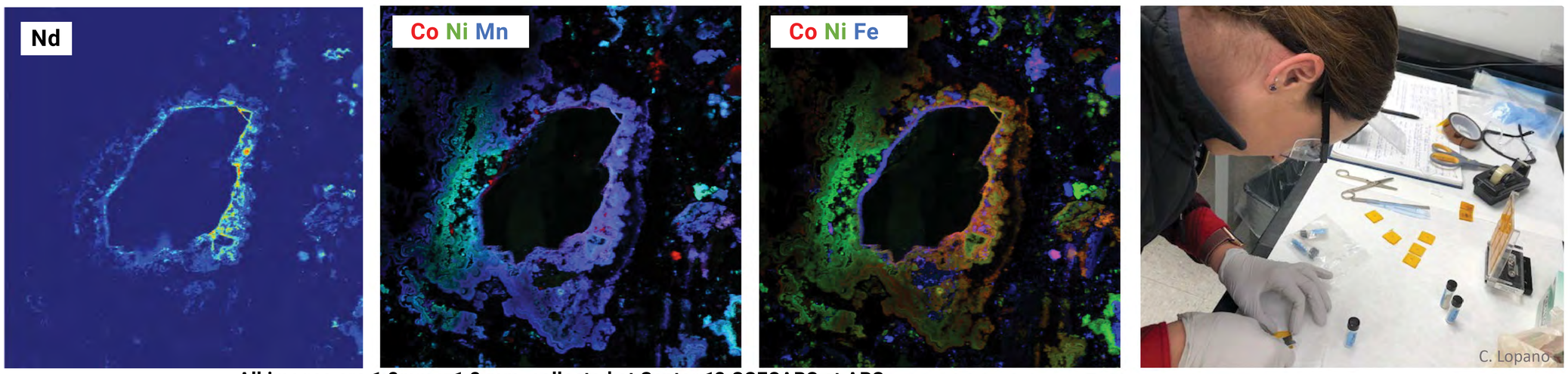
NETL-R&D-FECM-MS-000016

Advanced Characterization Techniques Help Unlock Critical Minerals From Unconventional Feedstocks

NETL demonstrates successful utilization of and data collection at DOE User Facilities for highly competitive, awarded, beamtime. In FY2024 alone, GES researchers have been awarded 160+ hrs at SSRL and NSLS-II.



All images are 1.2mm x 1.2 mm, collected at Sector 13 GSECARS at APS

Tricolor and intensity elemental maps from synchrotron X-Ray microprobe analysis.

Researchers at NETL's Research and Innovation Center use advanced characterization techniques such as Synchrotron X-ray Fluorescence Microprobe and X-ray Absorption Near Edge Structure at DOE user facilities to help determine the binding environment for critical minerals such as cobalt, nickel, zinc, manganese, and rare earth elements (REEs) in complex geologic matrices.

These techniques address the following challenges:

- Many critical minerals (particularly REEs) are widely dispersed in these matrices, making detection via traditional laboratory instrumentation problematic.
- Elemental oxidation states can be mixed, likely driving binding mechanisms.
- Developing innovative and informed sequential extractions that target the major REE and critical minerals (CM)-hosting solid fractions to efficiently and economically recover REE/CM.

DOE PROGRAM

MINERALS SUSTAINABILITY

NETL PARTNERS

Argonne NATIONAL LABORATORY

Brookhaven National Laboratory

SLAC NATIONAL ACCELERATOR LABORATORY

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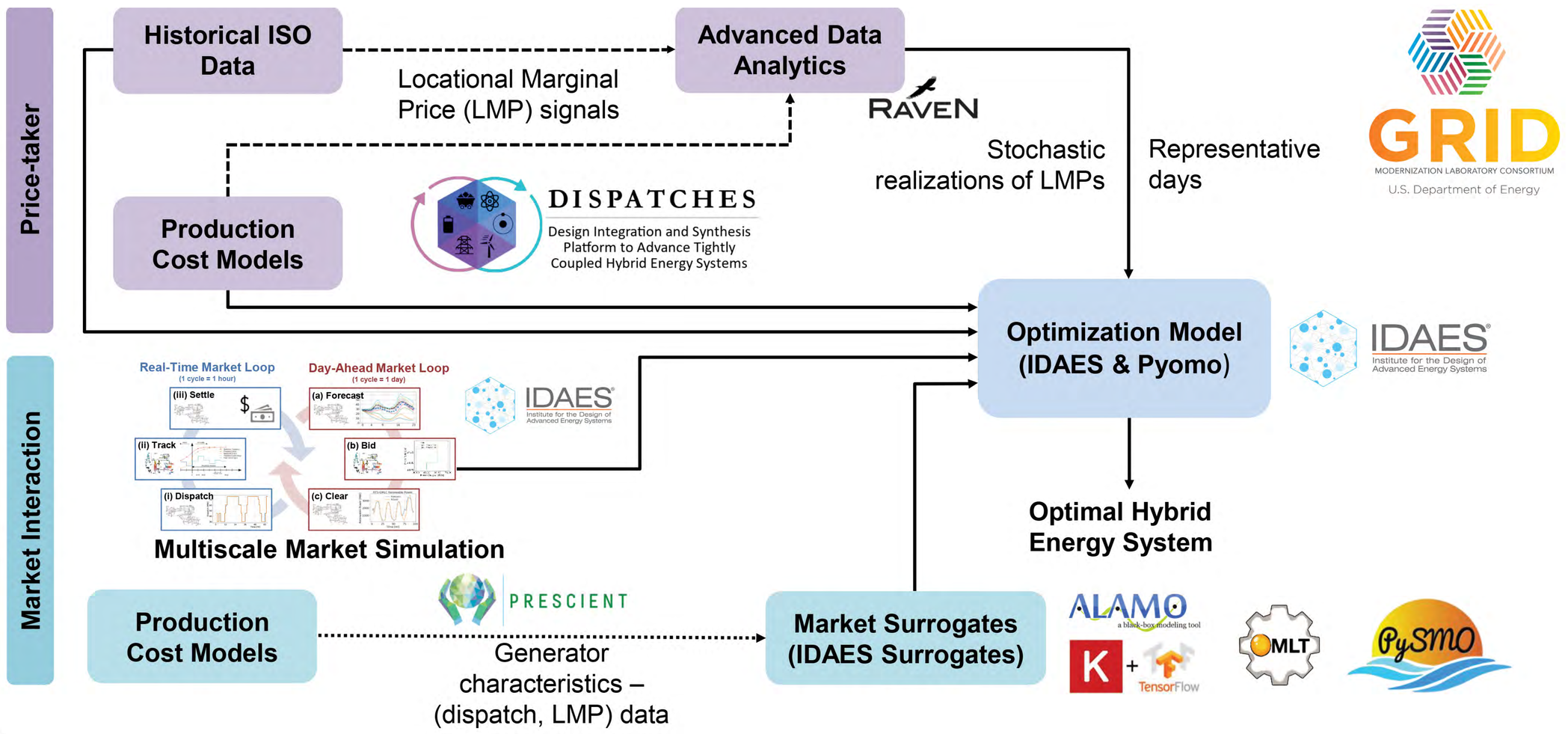
NETL-R&D-FECM-MS-000060

DISPATCHES: Market-Informed Decision-Making Capabilities for Designing Novel Integrated Energy Systems

New capabilities enable design of next-generation integrated energy systems while accounting for complex interactions between the generator and the electricity market.



DISPATCHES Workflows for Designing Integrated Energy Systems

Traditional approaches for designing integrated energy systems ignore complex interactions between the generator and the electricity market, which may result in over- or under-design, -estimation of profitability, etc.

DISPATCHES workflows:

- Provide a path to incorporate varying levels of market interactions.
- Have been successfully applied to two industrial case studies:
  - Impact of hydrogen credit (§45V) and the capacity market on the economics of installing a hydrogen-based peaker in the NYISO market: For a given value of hydrogen credit, DISPATCHES determined the target capacity payment policy which could make its deployment attractive.
  - Economics of blending green hydrogen with natural gas for use in a gas turbine in the CAISO market: DISPATCHES enabled assessment of techno-economic feasibility of reducing carbon emissions by blending.
- Have been successfully applied in internal case studies involving fossil, renewable, and nuclear generators. These capabilities are essential particularly for flexible systems, co-production systems, and systems with energy storage.

DOE PROGRAM

GRID MODERNIZATION LABORATORY CONSORTIUM

NETL PARTNERS

NREL

INL Idaho National Laboratory

Sandia National Laboratories

BERKELEY LAB

UNIVERSITY OF NOTRE DAME

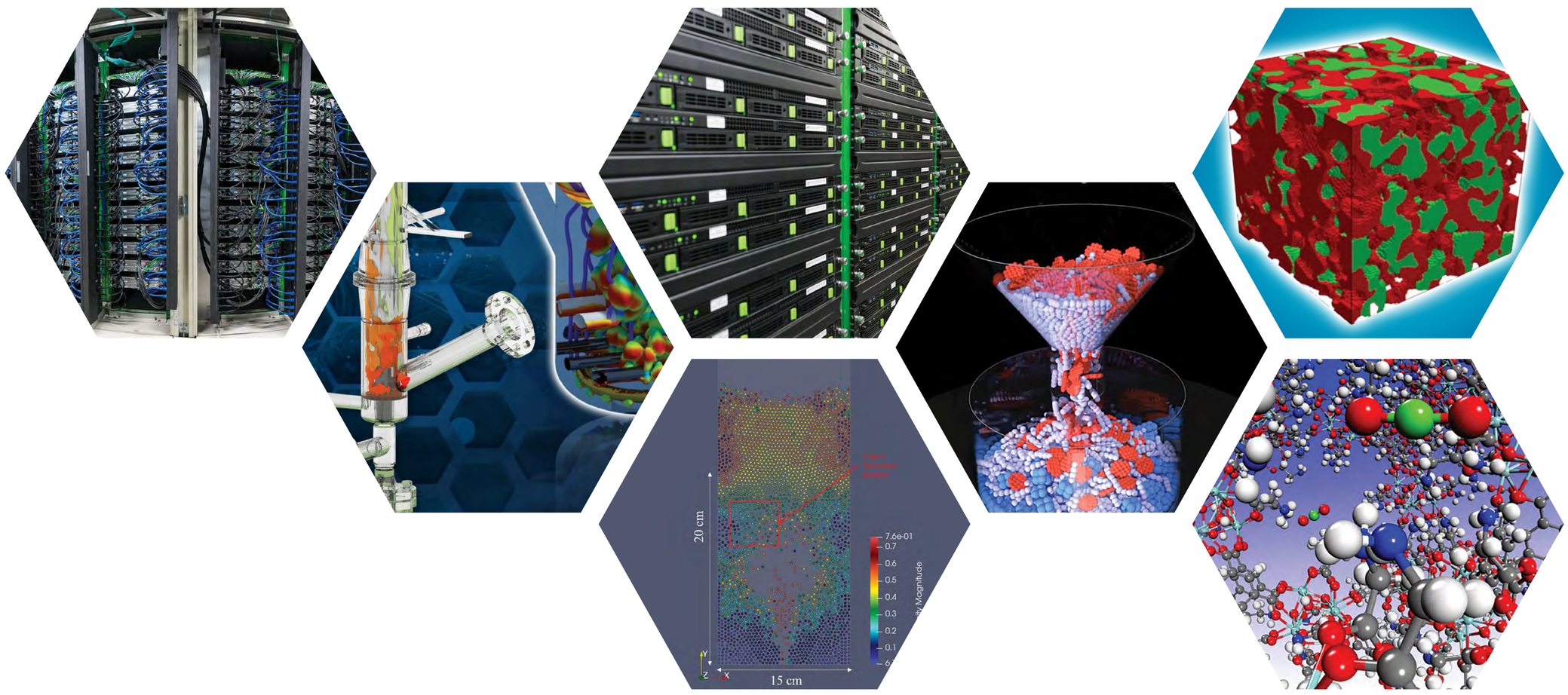
Arizona G&T Cooperatives
Touchstone Energy® Cooperatives

Constellation

NETL-R&D-OE-GMLC-000061

Computational Science and Engineering Accelerates Development of Technology for the Decarbonized Economy

Analysis and simulation of complex phenomena at unprecedented fidelity accelerates the discovery, design, and deployment of fossil energy materials, processes, and devices essential to economy-wide decarbonization.



NETL's computational science and engineering capabilities (spanning architectures, algorithms, and data) accelerate the production of critical carbon management technologies.

Key capabilities include:

- Development, validation, and application of multiphase flow tools, exemplified by NETL's MFiX Suite, help solve demanding multiphase flow problems such as those in reactor design, saving time and money.
- Discovery, design, and process optimization using first-principles computational materials simulations combined with artificial intelligence/machine learning for energy applications including catalysis, sensors, fuel cells, carbon capture and storage, hydrogen storage and transport.
- Leveraging high-performance computing (HPC), Wafer Scale Engine (WSE), and quantum computing to unravel the mysteries of complex scientific phenomena. NETL's groundbreaking R&D on WSE has demonstrated 1000x improved power efficiency and 100x faster time-to-solution than traditional HPC.

NETL PARTNERS

cerebras

U.S. DEPARTMENT OF ENERGY | Office of Science

ANSYS®

University of Pittsburgh

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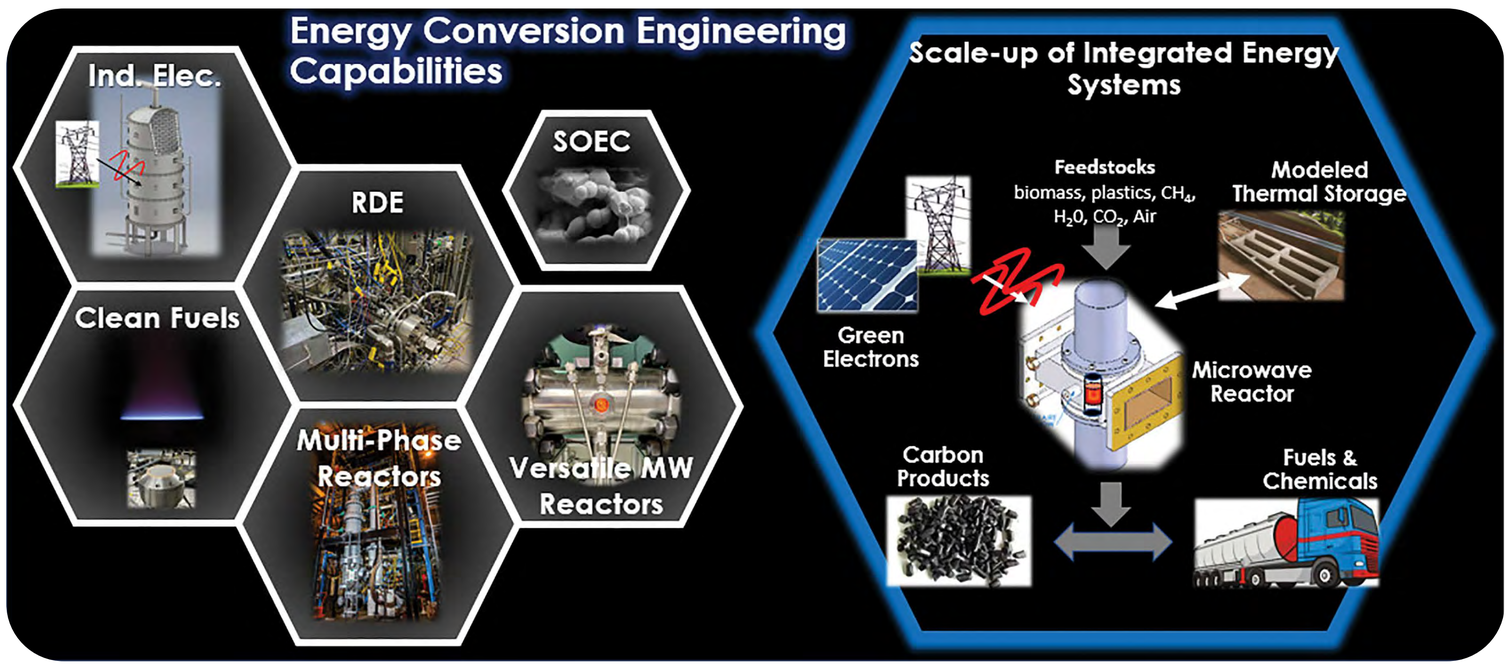
NETL-COMP-CSE-000001

Energy Conversion Engineering Accelerates Development of Clean Energy Technologies

Providing mission-critical support to FECM and valued partners toward accelerated technology development and deployment.



Summary of the R&D Capabilities of the Energy Conversion Engineering (ECE) Directorate

Energy Conversion Engineering aims to reduce industrial CO_2 emissions by improving efficiency, advancing the use of clean fuels, converting CO_2 to useful products, and electrifying industry. Current efforts include:

- Efficiency and Clean Fuels: Supporting the transition to a hydrogen economy by investigating turbine H_2/NH_3 combustion performance and advanced technologies such as rotating detonation engines and solid oxide fuel and electrolysis cells.
- CO_2 Conversion and Industrial Electrification: Advancing CO_2 conversion and other reactor technology employing catalyst materials developed under Materials Engineering and Manufacturing and by others. Reactors using microwave power generated by renewable energy enable carbon-negative products (e.g., ammonia and ethylene) and can be used by industry to replace fossil-based processes.
- Technology Acceleration: Increasing development speed and lowering costs through a cyber-physical development approach (combining real-time component models with existing technology hardware) can help new technologies traverse the valley of death, reducing R&D timetables and saving millions of dollars.

NETL PARTNERS

arpa·e CHANGING WHAT'S POSSIBLE

KBR

AIChE The Global Home of Chemical Engineers

NEXCERIS where energy meets environment

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

ExxonMobil

CECILIA

INL Idaho National Laboratory

Western Michigan University

Department of Defense

covestro

NREL

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE Hydrogen & Fuel Cell Technologies Office (HFTO)

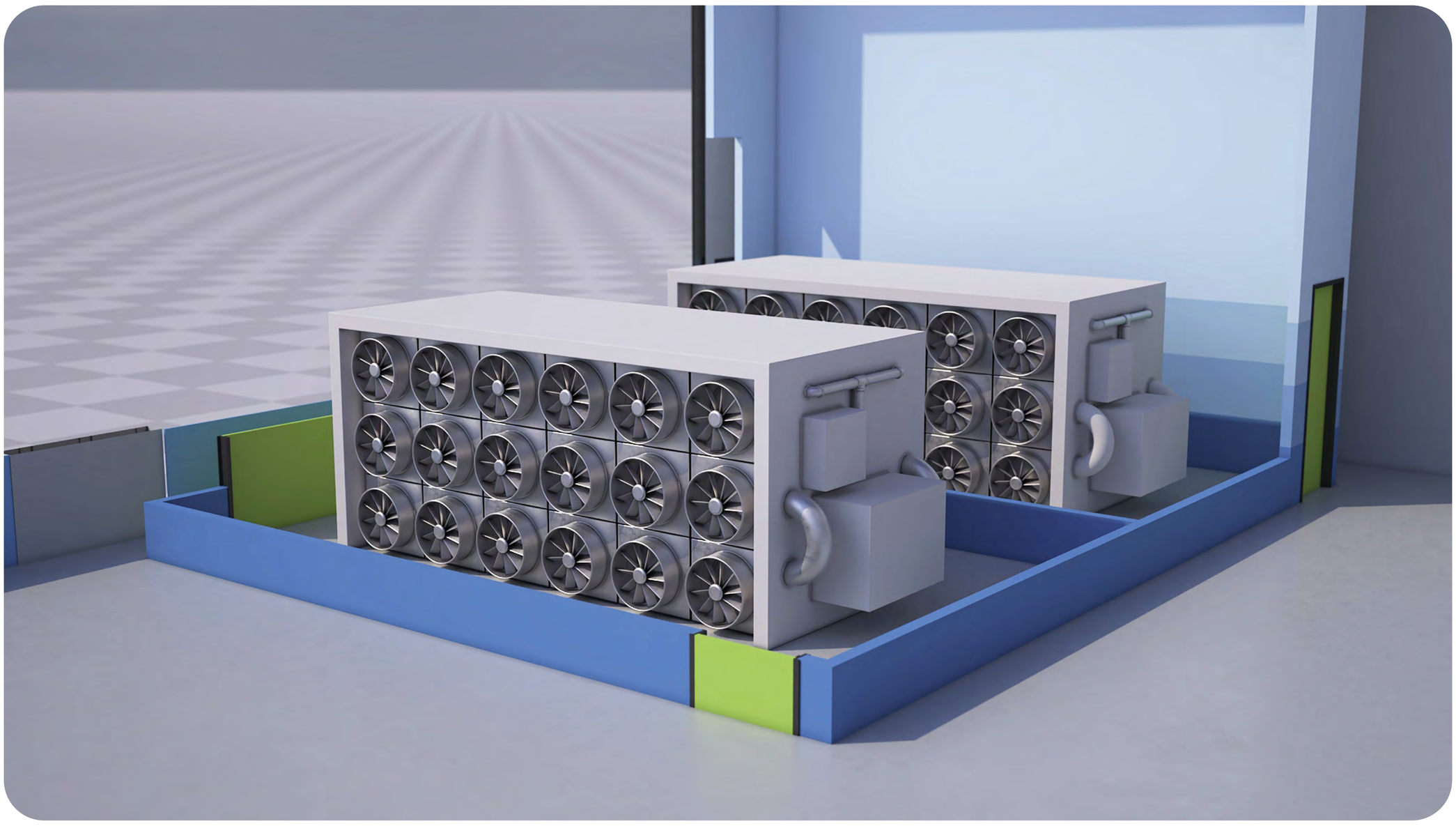
DOE Geothermal Technologies Office (GTO)

DOE Advanced Manufacturing Office (AMO)

DOE Industrial Efficiency & Decarbonization Office (IEDO)

The NETL DAC Center: Turning Ambitious Ideas into Technology Solutions

The NETL DAC Center provides testing facilities and expert support to accelerate DAC technologies toward commercialization to achieve our nation's goal of net-zero CO_2 emissions by 2050



Unique environmental chambers test DAC prototypes across a range of climates.

The NETL DAC Center supports the Carbon Negative Shot goal of reducing capture costs to $100/tonne by 2032.

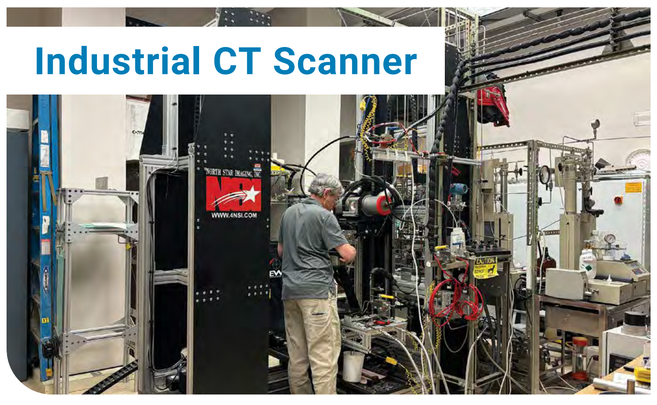
- One-of-a-kind facility dedicated to supporting private sector technology maturation.
- Reduces CapEx investment for scale-up in the Technology Readiness Level 3–6 range.
- Integrates experimental and modeling techniques to efficiently resolve scale-up issues.
- Tests capture materials and processes under conditions representative of a variety of climates.

NETL's Material Visualization and Evaluation Capabilities Tackle Subsurface Challenges

NETL's laboratory tools are providing insight into subsurface energy resources, aiding in developing more efficient exploration strategies and helping assure safe and permanent geologic CO_2 and hydrogen storage.

DynaTOM CT Scanner

GeoSpec NMR Core Analyzer



Industrial CT Scanner

LIBS System

Medical-grade CT Scanner

Variety of visualization and analytical technologies can be utilized in tandem to provide characteristic geologic and geophysical information on subsurface materials at multiple of scales.

NETL's imaging and evaluation technologies test, monitor, and characterize a variety of geomaterials from sandstones to fluids and cements. Complex energy system needs are investigated include caprock integrity and critical mineral characterization. Applications include geologic storage of CO_2 and hydrogen.

- Tools include computed tomography scanners for geomaterial imaging with micron-to-millimeter 3D resolution, controlled flow systems for core evaluation, multi-sensor geologic core loggers, fluid contact angle measurement system, nuclear magnetic resonance for detection and monitoring of fluids in porous media, and laser-induced breakdown spectroscopy for precise and cost-effective elemental composition analysis.
- Real-world applications can be examined in the lab using samples and fluids from specific project sites. Evaluation can occur under site-specific temperature, pressure, and saturation conditions.
- Resulting analytical data can be used to generate more realistic site models, economic valuations, resource maps, and field characterization efforts, and to inform operational decision making.

NETL PARTNERS

West Virginia University

WVGES
GEOLOGY UNDERLIES IT ALL

Pennsylvania Geological Survey Est. 1836

ExxonMobil

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U.S. DEPARTMENT OF ENERGY | NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL-COMP-GES-000015

Advanced Alloy Signature Center: A National Resource for Alloy Development

Forging the connection between laboratory-scale innovation and large-scale production.

Manufacturing capabilities bridging the gap from lab to production scale.

NETL develops affordable and durable alloys by combining computations and AI/ML with manufacturing at scale and assessment at condition

Capabilities:

- Induction Melting, Vacuum Induction Melting, Vacuum Arc Remelting, Electroslag Remelting furnaces (up to 500 pounds).
- Extrusion Press, Press Forge, Rolling Mills, Wire Drawing
- Electric Arc Furnaces (up to 1 ton) for steel manufacturing and pyrometallurgy.

Innovation and Impact:

- Computational design of homogenization heat-treatments for advanced superalloys.
- Developed system that improves ingot quality and reduces energy consumption during melting.
- NETL refractory (licensed to Harbison Walker) used in nearly every slagging gasifier worldwide.
- Improved GM's casting method for manufacturing complex aluminum engine components.
- Advanced a biodegradable medical alloy with BioGD and a world leading radiopaque stent alloy with Boston Scientific.
- Developed alloys and armor for the U.S. Army in use today.

NETL PARTNERS

ATI

FORT WAYNE METALS

BioDG, inc.

SPECIAL METALS

OMIC R&D

NAVAL NUCLEAR LABORATORY

HAYNES International

Pacific Northwest NATIONAL LABORATORY

OAK RIDGE National Laboratory

INL Idaho National Laboratory

Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

U.S.ARMY

Ampere Scientific

gm

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U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL-COMP-MEM-000020

Analytical Strategies for Reliable and Affordable Energy Transition and Beyond

NETL provides comprehensive integrated analyses of mitigation, capture, utilization, and storage of carbon emissions across the energy value chain.

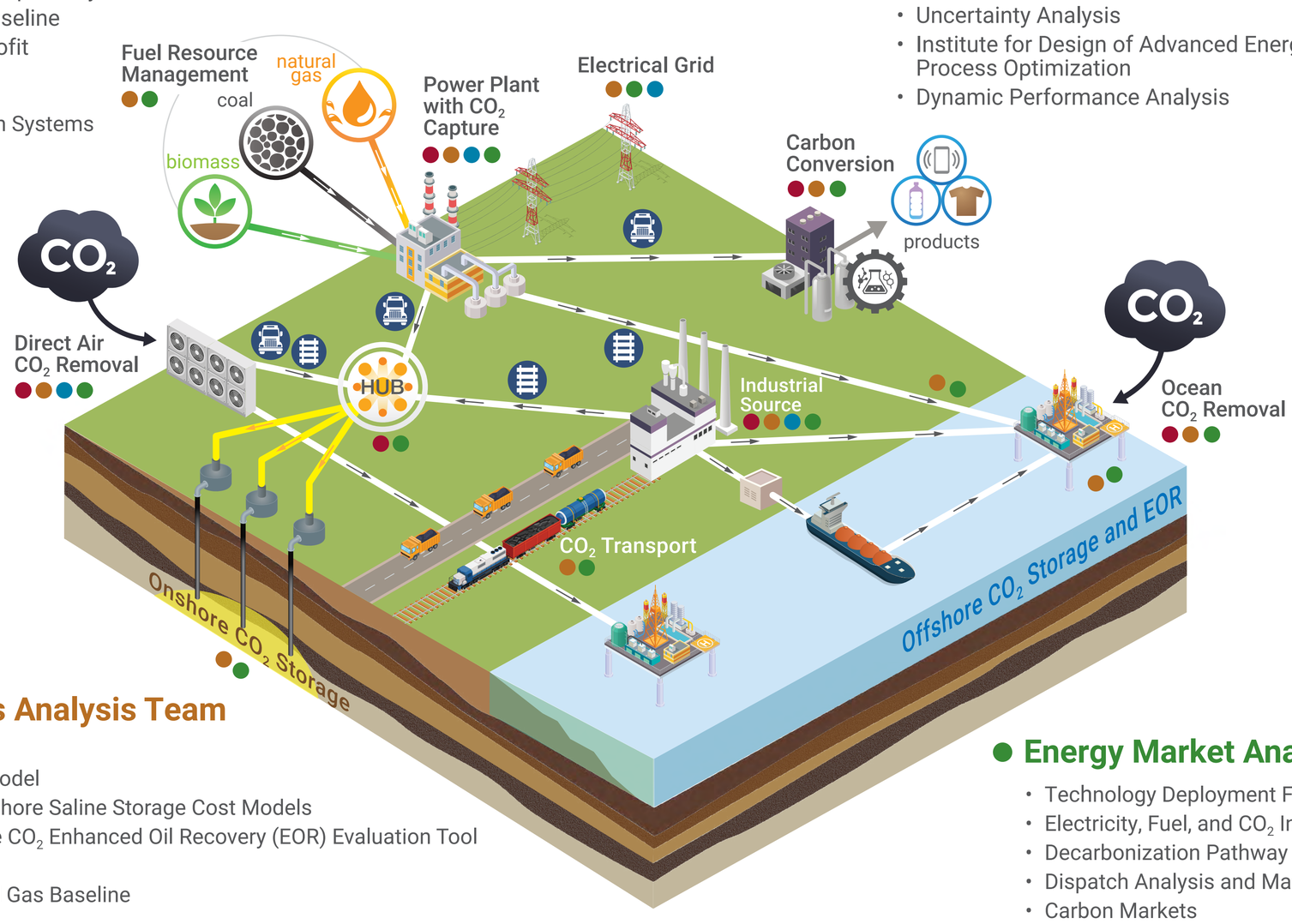
Energy Process Analysis Team

Performance and Cost Estimation

- Baseline Studies of Capture Systems
- Direct Air Capture Baseline
- Carbon Capture Retrofit Database (CCRD)
- Techno-economics of Carbon Conversion Systems

Process Systems Engineering Team

- Carbon Capture Simulation for Industry Impact ($CCSI^2$) Process Models and Tools
- Uncertainty Analysis
- Institute for Design of Advanced Energy Systems (IDAES) Process Optimization
- Dynamic Performance Analysis



Energy Systems Analysis Team

Subsurface Analysis

- CO_2 Transport Cost Model
- CO_2 Onshore and Offshore Saline Storage Cost Models
- Onshore and Offshore CO_2 Enhanced Oil Recovery (EOR) Evaluation Tool

Life Cycle Analysis

- Electricity and Natural Gas Baseline
- Carbon Accounting
- Methane Emissions
- Carbon Conversion Life Cycle Analysis
- CO_2 EOR Life Cycle (CELiC) Model

Energy Market Analysis Team

- Technology Deployment Forecasting
- Electricity, Fuel, and CO_2 Infrastructure Analysis
- Decarbonization Pathway Analysis
- Dispatch Analysis and Market Design
- Carbon Markets
- Economic Impacts
- Policies/Regulation Analysis
- Financial Analysis

Transport by Road Transport by Rail

NETL-SSAE Involved in All Parts of the Carbon Management Value Chain

NETL's Strategic Systems Analysis and Engineering (SSAE) boasts multidisciplinary teams specializing in the following:

- Process Cost Engineering Team evaluating the techno-economics of carbon capture and conversion technologies.
- Process Systems Engineering Team exploring advanced carbon capture processes and systems and developing open-source tools with cutting-edge optimization techniques.

Energy Systems Analysis:

- Subsurface Analysis Team investigating the transport and storage of captured carbon with pioneering cost models.
- Life Cycle Analysis Team specializing in cradle-to-grave emissions accounting and analysis.
- Energy Markets Team assessing the competitiveness of decarbonization technologies, contributing to the prestigious Energy Modeling Forum and the North American Electricity Reliability Council.

NETL SHOWCASE 2024

U.S. DEPARTMENT OF ENERGY | NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL-COMP-SSAE-000021

NETL SUPPORTS R&D OF AWARD-WINNING TECHNOLOGY TO DECREASE LITHIUM-ION BATTERY COSTS

This technology represents a domestic, abundant and inexpensive alternative to graphite.

Semplastics received Voltage Award from the Battery Innovation Center.

NETL supported Semplastics R&D of polymer-derived ceramic composite lithium-ion battery anodes that utilize coal as an alternative to graphite.

- The technology received the Voltage Award from the Battery Innovation Center that recognizes an emerging company and/or technology with the highest potential to make a difference in batteries and electrification.
- The technology addresses a growing demand for lithium-ion anode materials used in battery electric vehicles (BEVs), energy storage, and other products.
- If all BEVs utilized this technology, the total global annual BEV production could be addressed with less carbon than two months' operation of a single coal-fired power plant.
- The innovative technology also promotes remediation of existing coal waste sites throughout the U.S.

RESEARCH PRIORITY

DOMESTIC CRITICAL MINERALS PRODUCTION

PERFORMER

Semplastics

CLICK FOR MORE INFORMATION

NETL ANNUAL
ACCOMPLISHMENTS
2023

U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL DRIVES RESEARCH TO PRODUCE GRAPHITE FROM CARBON WASTE MATERIALS

Carbon waste materials are exceptional feedstocks for making high-quality graphite suitable for battery and other high-performance applications.

Demand for graphite is expected to soar as U.S. production of electric vehicles increases.

Research projects by NETL and ORNL are developing technologies to quickly and inexpensively produce graphite — an essential component for battery electric vehicles and other green technologies.

- A novel process developed by NETL lowers process temperatures from 3,000 °C down to 1,500 °C and reduces process times from several days to just a few hours.
- Graphite produced with the NETL process has been shown to outperform anodes made with commercially sourced graphite materials.
- Accompanying research at ORNL, supported by NETL, also significantly reduces process temperatures and time, which improves the overall carbon footprint of the graphite manufacturing process.
- The ORNL process allows low-value carbon feedstocks typically considered “non-graphitizable” to be converted directly into high-value graphite.

RESEARCH PRIORITY

DOMESTIC CRITICAL MINERALS PRODUCTION

PERFORMERS

NATIONAL ENERGY TECHNOLOGY LABORATORY

OAK RIDGE National Laboratory

CLICK FOR MORE INFORMATION

NETL ANNUAL ACCOMPLISHMENTS 2023

U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

NATIONAL ENERGY TECHNOLOGY LABORATORY

Deploying a New AI Software Tool for Rapid Characterization & Quantification of Unconventional Sources of Critical Minerals

Creason, C.G.,[1] Rose, K.,[1] Montross, S.,[1] Maymi, N.,[2] Jackson, Z.,[2] O'Barr, S.,[2] Bishop, E.,[2] Wingo, P.[1], Hazle, G.,[3] Skipwith, S.,[3] Moyes, A.,[3] Lindemann, G.,[3] Atkins, C.,[3] Hird, J.,[4] Taglia, F.[4]

1 National Energy Technology Laboratory
2 NETL Site Support Contractor
3 Ramaco Carbon
4 Weir International

NATIONAL ENERGY TECHNOLOGY LABORATORY
Research & Innovation Center

Project Summary

The effort will accelerate application and commercial utilization of an NETL-developed technology to rapidly characterize critical mineral occurrences within secondary and/or unconventional feedstocks, such as coal refuse or waste impoundments.

The project involves deploying a 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. This 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.

Industry Partners

Ramaco Carbon: *Ramaco Carbon, LLC is a subsidiary of Ramaco Resources, Inc. (NASDAQ: METC). Ramaco Carbon focuses on higher value uses for carbon ore and the development of critical minerals at the Brook Mine located just north of Sheridan, WY.*

Weir International: *Since 1936, WEIR has been providing professional, independent and objective consulting services to the United States and international engineering, geology, mining operations, and energy industries.*

Conventional vs. Unconventional

Conventional critical mineral resources *refer to known deposits that are presently part of the global resource base, with known geologic controls and enrichment processes that produced these occurrences.*

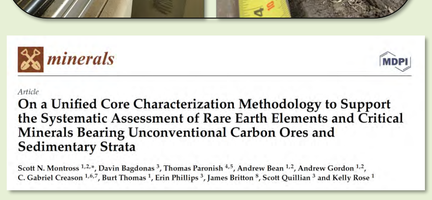
Unconventional critical mineral resources *refer to any resource from a geologic or secondary byproduct host that is distinctive from the mechanisms resulting in conventional, established deposits. These require revised or new methods and models to characterize and assess that focus on the unique source and temporal controls resulting in these deposits. (Source: Yesenchak et al., 2022)*

Background & Motivation

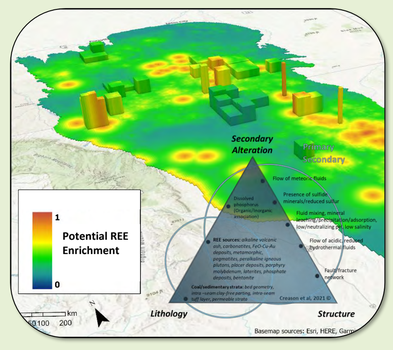
Current approaches for detecting the quantity and/or form of critical minerals (e.g., ICP-MS, LIBS, XRD) are costly and time-intensive. Handheld x-ray fluorescence is a quick, non-destructive method to characterize elemental composition, but challenges with interference and sensitivity limit its applicability for resource characterization.

This project will leverage 7+ years of FECM/NETL-RIC applied R&D (blue text figures below) to enable rapid and cost-effective detection of critical minerals from unconventional sources. These combined tools and approaches 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.

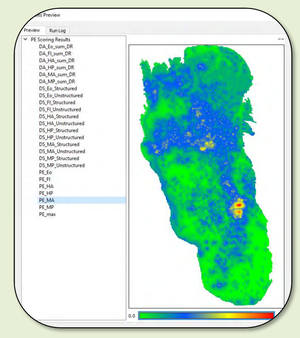
Systematic Methods & Data to Find & Quantify *in situ* Critical Minerals



AI-Informed Unconventional CM Resource Assessment



Streamlined User-Friendly Software Tool



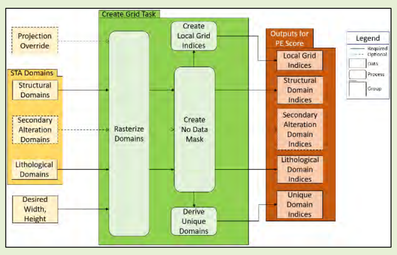
Project Outline

This project will field-demonstrate the commercial potential of a prototype software technology involving advanced x-ray-based elemental and mineralogical characterization and science-based, data-driven modeling methods pioneered by NETL to rapidly detect and quantify critical mineral resources from secondary and/or unconventional feedstocks.

Key project tasks are outlined below:

1. Software Development	• Modify existing URC resource assessment tool, GUI • Incorporate additional machine learning capabilities
2. Searchable Database	• Elemental-mineral assemblages (e.g., XRF, ICP-MS, XRD) • Lithologic characterization, geophysical measurements
3. Sample Recoverability Index	• Index dataset for software tool module • Recoverability benchtop extractions
4. Software Demonstration	• Software field demonstration (pXRF sampling) • Predictive ML training of mineral (chemical) form
5. Software Validation	• Validated software ML predictions using ICP-MS, LIBS, XRD, and or SEM
6. Deployment of Downhole Capabilities	• Downhole XRF and ML software field deployment and testing
7. Resource Reserves Modeling	• Estimate resource reserves using field-based software output
8. Market Readiness & Alignment	• Solicit external user feedback on software user-friendliness • Perform TEA to inform strategy for technology distribution
9. DEIA Engagements	• Workforce development for underrepresented and minority STEM students (local rural and tribal communities)

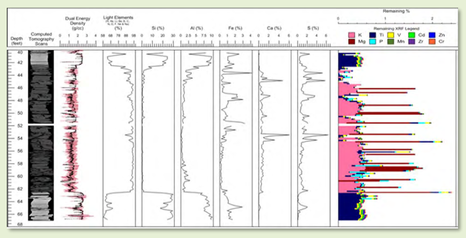
Software Development



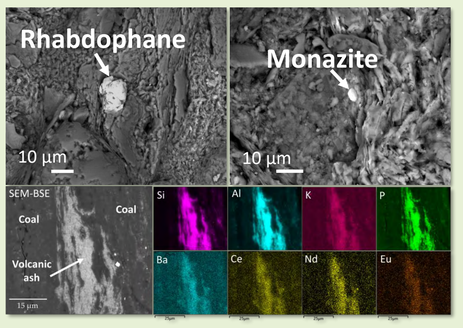
Handheld XRF

Core Characterization

Multi-Sensor Core Logging



Mineralogy



Downhole Deployment

Outcome

This 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. Demonstrating this technology in field applications with industry partners at an active site with high resource potential will increase the visibility and realization of critical mineral production potential from domestic unconventional sources.

The key outcome will be an inexpensive, portable, user-friendly software package for characterizing critical mineral in unconventional feedstocks. The ML-informed software system will support rapid, quantitative evaluation and assessment of critical mineral potential in coal refuse materials at the surface, and, where boreholes are available, from downhole scans as well. Within the software package will be a database that calibrates elemental XRF measurements to minerals and mineral assemblages, specifically tailored to secondary and unconventional critical mineral feedstocks.

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