GEOLOGICAL & ENVIRONMENTAL SYSTEMS ON-SITE RESEARCH

R&D073, November 2024

NATIONAL ENERGY TECHNOLOGY LABORATORY

OVERVIEW

NETL's Geological & Environmental Systems (GES) Directorate is internationally recognized for its ability to monitor, analyze and predict the physical, chemical and biological structures and functions of complex subsurface environments from the field-scale down to the molecular level. This capability enables accurate assessments of the occurrence and distribution of in-situ resources and predictions of the performance of engineered and natural systems over a range of time- and space-scales to produce decision-ready science.

By leveraging world-class facilities and longstanding expertise in geomaterials science, fluid flow in geologic media, multi-scale assessments, geospatial data management and analyses, and monitoring technologies, the GES Directorate's three teams investigate ways to investigate the physical, chemical and biological characteristics of complex surface, subsurface and offshore environments. GES research spans field scale to molecular levels, and microseconds to centuries. The research also focuses on preventing and remediating environmental challenges from fossil energy resource development, both legacy and future.

Our research teams focus on carbon and hydrogen storage; critical minerals; multi-scale, multiphase flow in fractured formations and hydrates; natural system behavior monitoring; geophysical and geochemical materials science; produced water geochemistry and geomicrobiology; well integrity; geospatial data management and risk assessment; and methane emissions detection and mitigation.

GEOCHEMISTRY TEAM

The GES Geochemistry Team studies the physical effects of developing energy-related natural resources and environmental mitigation strategies on natural and engineered geologic systems, such as those used for storing carbon dioxide and hydrogen underground.

Researchers address challenges for assessing and recovering critical minerals, helping create a reliable, domestic critical mineral supply chain. Our expertise spans subsurface geochemistry and geomicrobiology, mineralogy, resource assessment, fluid-rock interactions monitoring, and experimental assessment and modeling of fluids as they move through the Earth's crust.

NETL is developing new tools and processes to evaluate biological, chemical and physical processes in geologic settings, ensuring a more sustainable energy future. Leveraging the Lab's world-class resources, the GES Geochemistry Team conducts fluid chemistry analysis, isotope analysis, microbiological DNA sequencing, subsurface process analysis, geomaterials characterization, cement and wellbore integrity investigations, and studies under simulated subsurface conditions

The Geochemistry Team has extensive research experience in geochemical surface science, mineralogy, metagenomics, electrochemistry, isotope analysis, techniques to monitor fluid-rock interactions, reactive transport processes, water quality monitoring and mitigation. In the laboratory, the team employs world-class NETL facilities for fluid chemistry analysis, isotope analysis, microbiological DNA sequencing, subsurface process analysis, geomaterials characterization, cement and wellbore integrity investigations, and location and potential for recovery of critical minerals. Additionally, the team relies on in-house ingenuity to develop new tools and processes to evaluate biological, chemical and physical processes in geologic environments.

Figure 1. NETL researchers utilize synchrotron user facilities for advanced analyses of the chemical properties of geologic samples.

GEO-ANALYSIS & MONITORING TEAM

The GES Geo-Analysis and Monitoring Team supports and mitigates the environmental impact of extracting resources for energy, evaluating both subsurface conditions and environmental emissions during and after resource extraction. The team provides a critical link between researchers, regulators, and industry professionals responsible for the safe, efficient development of subsurface resources.

Additionally, the team performs characterization and modeling through a combination of geospatial and geotemporal approaches to data that are displayed using state-of-the-art visualization methods.

Figure 2. Airborne and ground-based techniques are used in field studies to locate and test legacy wells for methane emissions.

The Geo-Analysis and Monitoring Team employs geospatial and geotemporal analysis using a range of expertise and capabilities to accomplish these goals:

- Uses on-site and mobile laboratories to develop and secure characterization data at a variety of scales (from pore scale to regional scale) and develops subsurface maps and models of earth systems that can inform further research efforts.
- Assesses impacts and risk and reduces the uncertainty of data sets and modeling results through detailed analysis of engineered-natural systems.
- Possesses cumulative decades of expertise in the characterization, analysis and interpretation of geologic systems—including subsurface mapping and model development.

Research expertise includes airborne, ground-based and field detection and monitoring investigations of subsurface features and infrastructure; data mining and analysis; monitoring and modeling of air quality; methane emissions quantification; geophysics research; spectral imaging and remote sensing; tracers; geospatial mapping, analysis, and interpretation; and data analysis using statistical methods, artificial intelligence, and machine learning (AI/ML). Characterization and modeling activities, including using AI/ML and state-of-the-art data visualization, support resource extraction and geothermal development through a combination of geospatial and geotemporal approaches to data.

The team uses a three-pronged approach to realize its goals:

- Works closely with industry contacts to design and implement field experiments that answer key questions about the safety, efficiency and environmental performance of emerging energy development methods.
- Develops monitoring technologies that provide early warning of unwanted migration of fluid and gas from the subsurface to help identify and potentially mitigate environmental contamination.
- Collaborates with industry to assist in the identification of potential environmental and operational vulnerabilities prior to the implementation of energy extraction operations or or large-scale storage operations.

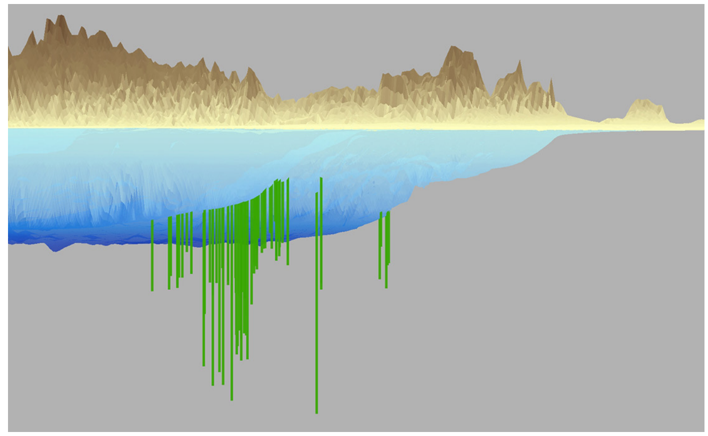
The team also developed and continues to contribute to NETL's Energy Data Exchange (EDX). EDX is a unique tool for effectively managing and sharing large quantities of data to enhance collaborative research efforts and data analysis.

RESERVOIR ENGINEERING TEAM

The GES Reservoir Engineering Team seeks to better understand underground subsurface fluid flow and deformation of reservoir components. With this knowledge, researchers provide an enhanced capability to predict the behavior of reservoir responses under coupled hydrologic, geomechanical, geophysical and geothermal processes initiated for resource development and utilization.

The Reservoir Engineering Team applies an array of capabilities to pursue research goals effectively:

- Characterize geophyscial, geomechanical and hyrological properties of subsurface system to support developing coupled processes models at reservoir scale using both in-house and external software.
- Non-destructive elemental, property and structural scanning of cores from the subsurface to characterize fluid behavior and matrix responses inside natural rocks under various temperature and pressure conditions at the micro to macro scales with world-class digital rock imaging facilities.



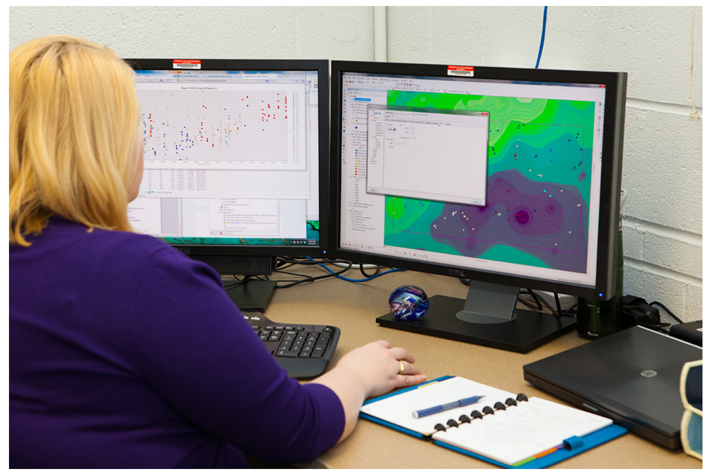


Figure 3. A geospatial researcher develops computer models to understand conditions in deep offshore oil and gas wells in the Gulf of Mexico.

- Combines data science, machine learning and numerical modeling to characterize the risks and potential of subsurface energy operations.
- Develop physics-informed and data-driven computation models to predict and simulate reservoir behavior for subsurface system-level analysis.
- Novel laser-based sensor design, testing, fabrication and validation for real-time elemental and temperature measurements on energy systems in harsh condition and other geoscience applications.
- Characterizes methane hydrate-bearing pressure cores for hydrological and geomechanical properties at in-situ conditions (approximately 4,500 psi and 4° C) and develops new applications of gas hydrate technologies.

The GES Reservoir Engineering Team specializes in characterizing subsurface fluid flow and impacts to underground reservoirs. With this knowledge, researchers can predict the behavior of reservoir responses under coupled hydrologic, geomechanical, geophysical and geothermal processes initiated for resource development and utilization.

We excel in visualization and characterization of hydrologic and geomechanical properties on natural or human-made specimens under single and multiphase flow situations with varying in-situ temperature and stress conditions. Researchers develop and demonstrate various models of reservoir response to fluid-flow through porous and fractured media to simulate responsive behavior of reservoirs, seals and other subsurface systems upon resource utilization and exploitation. Fluid behavior and matrix response is characterized at the micro to macro scales using world-class digital rock imaging facilities.

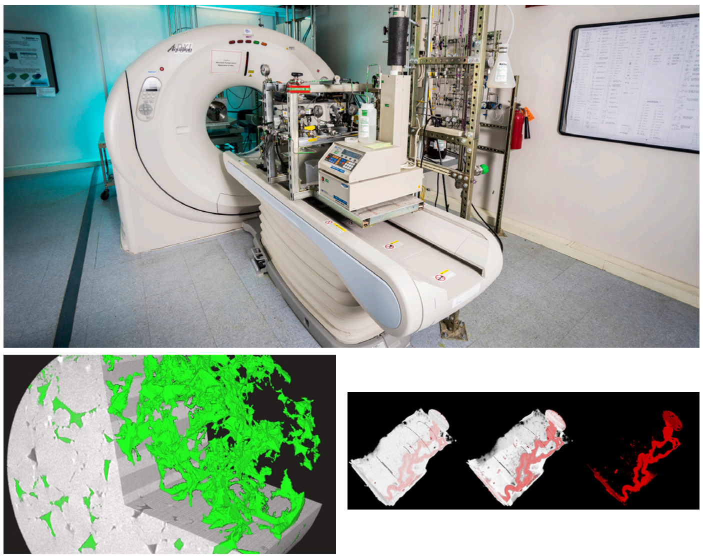


Figure 4. NETL's CT scanners are used to image geomaterials and understand interactions with fluids. Two examples—3D structures of CO_2 reacted zones in cement fractures, and pore space in reservoir rock—illustrate these capabilities.

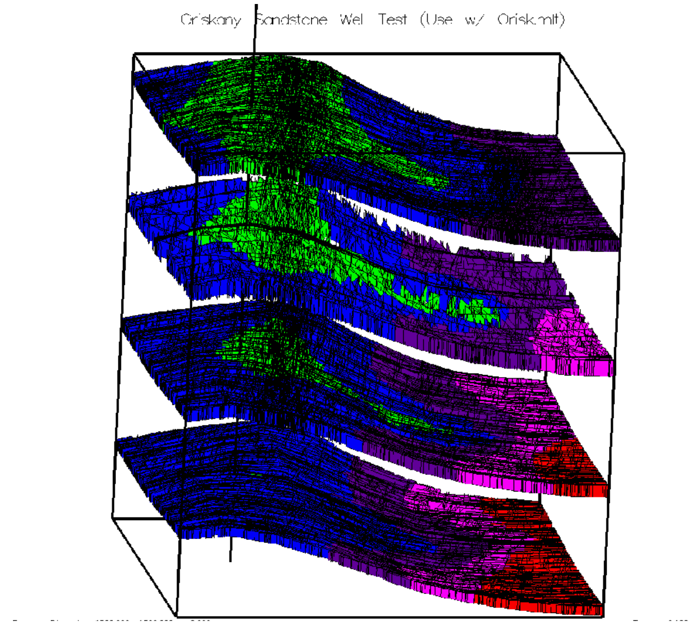


Figure 5. Reservoir simulation output shows pressures in four layers of a naturally fractured and folded sandstone. Simulation of the injection of carbon dioxide for storage.

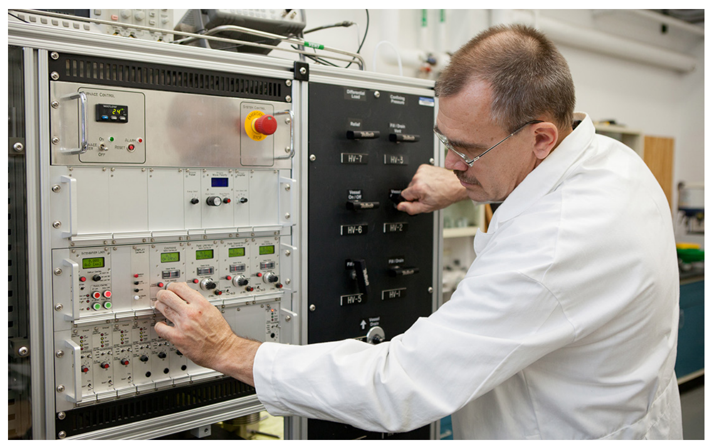


Figure 6. Scientist uses multipurpose lab instrument to analyze geomechanical rock properties.

NETL is a U.S. Department of Energy (DOE) national laboratory dedicated to advancing the nation's energy future by creating innovative solutions that strengthen the security, affordability and reliability of energy systems and natural resources. With laboratories and computational capabilities at research facilities in Albany, Oregon; Morgantown, West Virginia; and Pittsburgh, Pennsylvania, NETL addresses energy challenges through implementing DOE programs across the nation and advancing energy technologies related to fossil fuels. By fostering collaborations and conducting world-class research, NETL strives to strengthen national energy security through energy technology development.

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