Geosciences Research

Portfolio Description

This activity supports basic experimental and theoretical research in geochemistry and geophysics. Geochemical research emphasizes fundamental understanding of geochemical processes and reaction rates, focusing on aqueous solution chemistry, mineral-fluid interactions, and isotopic distributions and migration in natural systems. Geophysical research focuses on new approaches to understand the subsurface physical properties of fluids, rocks, and minerals and develops techniques for determining such properties at a distance; it seeks fundamental understanding of wave propagation physics in complex media and the fluid dynamics of complex fluids through porous and fractured subsurface rock units. Application of x-ray and neutron scattering using BES facilities plays an important role in the geochemical and geophysical studies within this activity. The activity also emphasizes incorporating physical and chemical understanding of geological processes into multiscale computational modeling.

Unique Aspects

Society and industry rely on the earth to provide energy resources, or the materials to synthesize energy systems, and to be the ultimate repository of energy wastes safely and cost effectively. The activity contributes to the solution of Earth Science-related problems in multiple DOE mission areas by providing a foundation of scientific understanding for them. Examples of these applications include (but are not limited to): the potential for geophysical imaging of permeability; reactive fluid flow studies to better understand hydrocarbon transport, contaminant transport and remediation, and geothermal energy production; and coupled hydrologic-thermal-mechanical-reactive transport modeling to predict geological repository performance. The DOE technology programs activities tend to focus on solutions to existing problems in the nearer-term. This activity seeks fundamental research results that can serve as the foundation for the technology programs directed research and development efforts in the longer-term, both from the national laboratories and from the university community. In particular, the BES Geosciences activity provides funding for long-term cross-cutting research efforts at national laboratories, which are directly and immediately transferred to the applied programs as needed.

Relationship to Other Programs

- DOE user facilities in geosciences, particularly synchrotron x-ray beamlines, are available to all of the geosciences community within the United States. BES research activities focus primarily upon the physical and chemical properties of geo-systems with a cognizance of critical biological interactions.
- The BES Geosciences activity is closely coordinated with applied programs focused on geological CO_2 sequestration within the Office of Fossil Energy (FE) and on geothermal energy within the Office of Energy Efficiency and Renewable Energy (EERE). It provides fundamental support in improving understanding of geochemical reactivity, subsurface flow and high resolution geophysical imaging to other DOE mission programs such as Environmental Management and Legacy Management.
- The BES Geosciences program also supports the National Research Council's Board on Earth Sciences and Resources and its study committees.

Significant Accomplishments
BES Geosciences has pioneered the use of synchrotron science and neutron science applications in the Earth sciences at the NSLS, APS, ALS, SSRL and SNS since their inception.

- The GSECARS beamline has been built and commissioned (in collaboration with NSF) as a center for high-resolution analytical geochemistry for the whole Earth sciences community, including multiple DOE applied program users. The Geosciences activity currently also supports other beamline activities at the Advanced Photon Source (APS) and at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory.
- Geosciences-supported investigators are significantly involved in plans for several new beamlines at the NSLS-II facility, and the program has provided seed funding for beamline transitions from NSLS I to NSLS II.
- Geosciences research projects, unique BES supported laboratory facilities, and BES funded workshops on Basic Research Needs for Geosciences and in topical areas are the foundations for identifying research opportunities for research and development integration activities between the Office of Science and the applied program offices. These workshops have also produced broadly applicable publications pertinent to geosciences topics of current interest.

Mission Relevance
This activity provides the basic research in geosciences that underpins the nation's strategy for understanding and mitigating the terrestrial impacts of energy technologies and thus is relevant to the DOE mission in a number of ways. Performance assessments of energy and environmental systems can't be tested with any usual engineering approach. They have to rely upon conceptual and computational predictions of those systems over geological periods of time (decades to centuries to millennia), and over technological spatial scales (kilometers), based on geological observations. This activity develops the fundamental understanding of geological processes relevant to energy materials production and for geological disposal options for byproducts from multiple energy technologies. This new knowledge will be critical to developing robust monitoring, verification and accounting metrics for regulatory approaches to new energy technologies, and as the foundation for consent-based waste disposal approaches. Knowledge of subsurface geochemical processes is essential to determining the fate and transport properties of harmful elements from possible nuclear or other waste releases. Geophysical imaging methods are needed to measure and monitor subsurface reservoirs for hydrocarbon production, or for carbon dioxide storage resulting from large-scale carbon sequestration schemes.

Scientific Challenges
Understanding the natural heterogeneity of geochemical and geophysical properties, processes, and rate laws is critical to managing improved production of the Earth's energy resources and safe disposal of energy-related wastes. Improved imaging and tracking of geochemical processes at the atomic (angstrom) scale using synchrotron x-rays and neutrons is critical for progress in understanding geochemical systems. New investigations are needed at the smallest scales to study electronic properties, geochemical reactivity, solute properties, and isotopic distributions in both inorganic and organic systems. Understanding pristine natural systems and DOE-specific sites requires improving our capabilities to make and understand high-resolution geochemical and geophysical measurements experimentally and in the field, and to model them. Understanding mineral surface-particle-fluid interactions is key to predicting the fates of contaminants in the environment or predicting nuclear waste-site performance. Improved high-

resolution geophysical imaging will underlie new resource recovery, tracking of contaminants, and predicting and tracking repository performance, whether for nuclear or energy-related wastes (such as CO_2). Even with new improved analytical equipment, technical challenges will continue in mastering data-fusion approaches to multiple-technique measurements, such as combined x-ray and neutron analyses or combined seismic-electromagnetic measurements. New computational capabilities enabled by new high performance computing architectures will be important contributors to optimization of geological modeling approaches for individual molecular, seismic, electromagnetic, geomechanical, and hydrologic modeling techniques and provide unique support to experimental analysis.

Projected Evolution

In the near term, geosciences research continues its basic activity in fundamental rock physics, fluid flow, and analytical, theoretical and experimental geochemistry. It continues national laboratory and university projects focusing on understanding the significance of fluid-rock-particle interactions including natural nanophases and nanoparticles in shallow earth systems and how they contribute to mineral-fluid reactivity. The activity continues working with various groups on investigating uses of synchrotron and neutron imaging in geosciences.

In the mid-term, the activity initiates new research efforts on imaging of earth processes with attention devoted both to improved small-scale imaging (geochemistry focus) using x-ray sources, neutron sources, and scanning microscopy, and large-scale imaging (geophysics focus) of physical properties through understanding intrinsic attenuation within seismic and electromagnetic imaging. GSECARS and other BES Geosciences supported synchrotron beamlines begin their second decade as the premier synchrotron user facilities for the earth sciences community, including bringing their expertise to new end stations at NSLS-II. The activity will expand research efforts in nanogeosciences to understand the role of nanophases in geological systems and efforts on understanding the geophysical and geochemical challenges of predicting the fate and transport of CO_2 as sequestration in deep geological formations is tested as a technology option to mitigate greenhouse gas emissions.

In the longer term, Geosciences activities will link analytical capabilities with computational capabilities at the nano-, micro- and macro-scales to provide understanding of geochemical processes occurring at natural time and length scales. Geosciences activities will provide robust understanding of what can be measured remotely at depth by geophysical means and will increase both the depth of current resolution and the resolution at any depths of interest.