Subsurface Control for a Safe and Effective Energy Future

U.S. Department of Energy Subsurface Technology and Engineering RD&D Crosscutting Team

Introduction

While subsurface sources constitute the Nation's primary source of energy (providing more than 80 percent of total U.S. energy needs today), they are also critical to the Nation's low-carbon and secure energy future. Next generation advances in subsurface technologies will enable access to more than 100 gigawatt-electric (GWe) of clean, renewable geothermal energy, as well as safer development of domestic natural gas supplies. The subsurface provides hundreds of years of safe storage capacity for carbon dioxide (CO_2) and opportunities for environmentally responsible management and disposal of hazardous materials and other energy waste streams. The subsurface can also serve as a reservoir for energy storage for power produced from intermittent generation sources, such as wind and solar. These opportunities are directly linked to Administration priorities and to broader societal needs. Clean energy deployment and CO_2 storage are critical components of the President's Climate Action Plan and are necessary to meet the 2050 greenhouse gas (GHG) emissions reduction target of 83 percent below 2005 levels. Increasing domestic hydrocarbon resource recovery in a sustainable and environmentally sound manner is also an Administration goal that enhances national security and fuels economic growth. Thus, discovering and effectively harnessing subsurface resources while mitigating impacts of their development and use are critical pieces of the Nation's energy strategy moving forward.

The Subsurface Technology and Engineering RD&D (SubTER) Crosscutting Team, in collaboration with the National Laboratories, has identified *Adaptive Control of Subsurface Fractures and Fluid Flow* as a key crosscutting theme. The ability to have real-time control or "mastery" of the subsurface can have a transformative effect on numerous industries and sectors, impacting the strategies deployed for subsurface energy production and storage. Mastery of the subsurface requires efforts to address the following key challenges to optimize energy production, energy/CO_2 storage, and waste storage/disposal:

- *Discovering, characterizing, and predicting*: Efficiently and accurately locating target subsurface geologic environments; quantitatively inferring their evolution under future engineered conditions; and characterizing the subsurface at a relevant scale;
- *Accessing*: Safe and cost-effective drilling or mining with properly managed reservoir integrity;
- *Engineering*: Creating the desired conditions in challenging high-pressure/high-temperature environments;
- *Sustaining*: Maintaining these conditions over long time frames throughout complex system evolution; and
- *Monitoring*: Improving observational methods and advancing understanding of the microscopic basis of macroscopic complexity throughout system lifetimes.

In response to these challenges, SubTER proposes initiatives for planning and implementing jointly-funded targeted research, development, and field demonstrations (RD&D) emphasizing the following four topic areas (see Fig. 1):

- Intelligent wellbore systems
- Subsurface stress and induced seismicity
- Permeability manipulation
- New subsurface signals

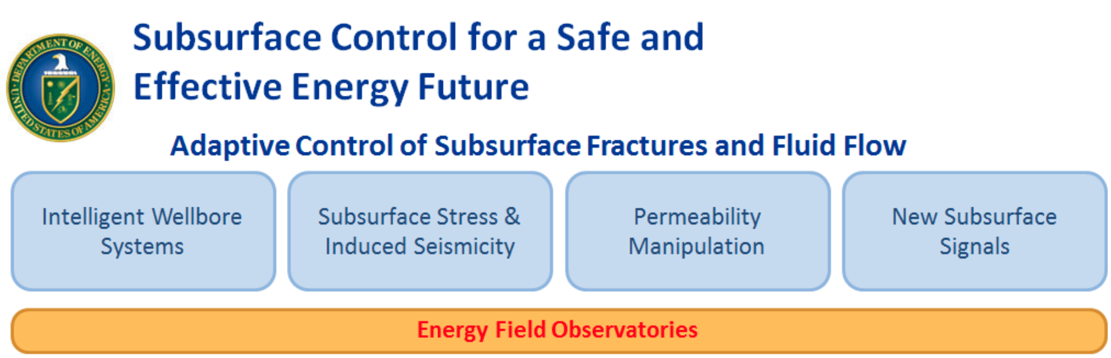

Figure 1: Proposed subsurface crosscut program.

This coupled RD&D program presents a phased schedule of R&D in conjunction with testing at a network of energy field observatories for validation of fundamentally new and timely capabilities. Field activities are essential to advance the state-of-the-art in subsurface technology and engineering. In order to extrapolate insights gained in the laboratory through experiments, theory, and simulation to the scale of field observations, heavily instrumented sites generating streams of high-fidelity data that industry either does not routinely collect or make publicly available are critical. The SubTER proposal is rooted in a coordinated approach to strategically leverage a wide variety of new and ongoing field operations to support the four proposed technical thrusts. Sequenced approaches for progressive laboratory, modeling, and pilot-scale R&D to support targeted field demonstrations are presented below.

Structure and Outreach

SubTER is a crosscutting technology team that encompasses DOE offices involved in subsurface activities. Activities are aligned with energy production/extraction (FE-Oil and Gas, EERE/Geothermal Technologies Office (GTO), ARPA-E), subsurface storage of energy (OE, ARPA-E) and CO_2 (FE-CO_2 Storage), subsurface waste disposal and environmental remediation (FE-Oil and Gas, EM, NE), and policy or analysis associated with the subsurface (EPSA, EIA). The Office of Science (SC) supports a broad spectrum of fundamental research in subsurface science, focusing on topics including geology, geophysics, and biogeochemistry, among others. In the context of the current initiative, SC has extensive expertise in subsurface chemistry, research approaches to monitoring and characterization, and complex fluid flow.

SubTER provides a collaborative structure to quickly identify scientific and technology challenges and efficiently leverage funding and expertise through multi-office collaborations. Functions of the DOE SubTER Team include:

- Exchange details on current subsurface RD&D portfolios across DOE offices;
- Identify subsurface challenges and recommend and implement solutions;
- Assess adequacy of DOE RD&D budgets, plans and priorities, and identify potential cross-cutting initiatives;
- Providing the necessary technical data and analyses in support of relevant legislative or regulatory requirements;
- Facilitate intra-departmental and interagency collaboration of cross-cutting subsurface RD&D activities; and
- Establish partnerships with industry stakeholders operating in the subsurface.

During FY14 the SubTER Crosscutting Team became a chartered organization with regular meetings and a focus on stakeholder engagement. In January, SubTER held an internal summit in which program offices shared work from existing portfolios, program strategy, and key goals for future initiatives. In March 2014, SubTER held a workshop with National Lab partners in association with the DOE National Lab “Big Ideas” Summit. SubTER has coordinated closely with Lab partners in developing the core technical pillars proposed here. SubTER has also gathered input from industry and other stakeholders through various forms of outreach and engagement. A request for information published in May 2014 received broad feedback. SubTER held well-attended public briefings hosted by the U.S. Energy Association in July and October. The crosscut was discussed in a dedicated portion of the National Academy of Sciences Committee on Geological and Geotechnical Engineering meeting on May 29, 2014, and that engagement continued at the next committee meeting on Oct. 23, 2014. In December 2014, SubTER will host a Town Hall meeting at the American Geophysical Union annual meeting.

Participating program offices have engaged in joint funding efforts in FY14 that will continue into FY15. Eight offices contributed to funding a JASON letter report on the “State of Stress in Engineered Subsurface Systems” completed in September 2014. The independent JASON advisory group recommends that “DOE take a leadership role in the science and technology for improved measurement, characterization, and understanding of the state of stress of engineered subsurface systems in order to address major energy and security challenges of the nation.” JASON recommends coordinated research and technology development at dedicated field sites to connect insights from laboratory scales and models to operational environments. Additionally, the EERE Geothermal Technologies Office and Office of Fossil Energy have jointly awarded approximately $1.6M to National Laboratory teams to begin work on crosscutting topics. These projects are envisioned to feed into broader program efforts in upcoming years.

Participating DOE offices will further these efforts through continued collaboration with diverse participant groups from industry, academia, non-governmental organizations, and the National Laboratories; as well as cooperation with international organizations and other Federal partners such as DOI (e.g., USGS, BLM), EPA, DOD, and NSF.

Federal Role

DOE's subsurface engineering investments focus on solving high-impact challenges that are not sufficiently addressed by the private sector (see Fig. 2). For many sectors operating in the subsurface, markets do not drive private R&D investment. In some cases, the barrier to private-sector uptake is a lack of funding for high risk activities necessary to advance the state of the art (e.g., geothermal). In other cases, the federal role is driven by a need to develop technologies and supportive national policy to meet GHG emission reduction targets where no market driver currently exists (e.g., carbon capture and storage), or to meet Federal obligations (e.g., nuclear and other high-level waste storage/disposal). DOE has a strong history of funding transformative R&D to enable private sector adoption and deployment—a notable example is DOE's original pathfinding investment in oil and gas rock stimulation, coupled with R&D into innovative drilling-related technologies. DOE also has the unique ability to pull together a consortium execution model involving data sharing between multiple Labs, industry, and academic partners to tackle the identified subsurface challenges holistically across a variety of subsurface geologies. These technology advancements with the potential to revolutionize the global energy landscape do not arise from the short-term profit-driven private sector R&D that is typically focused on current company assets rather than exploratory research. Whereas the private sector tends to pursue incremental efficiency gains in existing technologies (version 1.2 and 1.3 R&D), the Department is an appropriate catalyst in the pursuit of game-changing technologies (version 3.0 R&D) or to serve emerging public needs outside of industry's scope and purview. Consistent with DOE's mission, these investments drive U.S. energy leadership, competitiveness, and independence; environmental responsibility, sustainability, and safety; and economic prosperity through cost reduction and job creation.

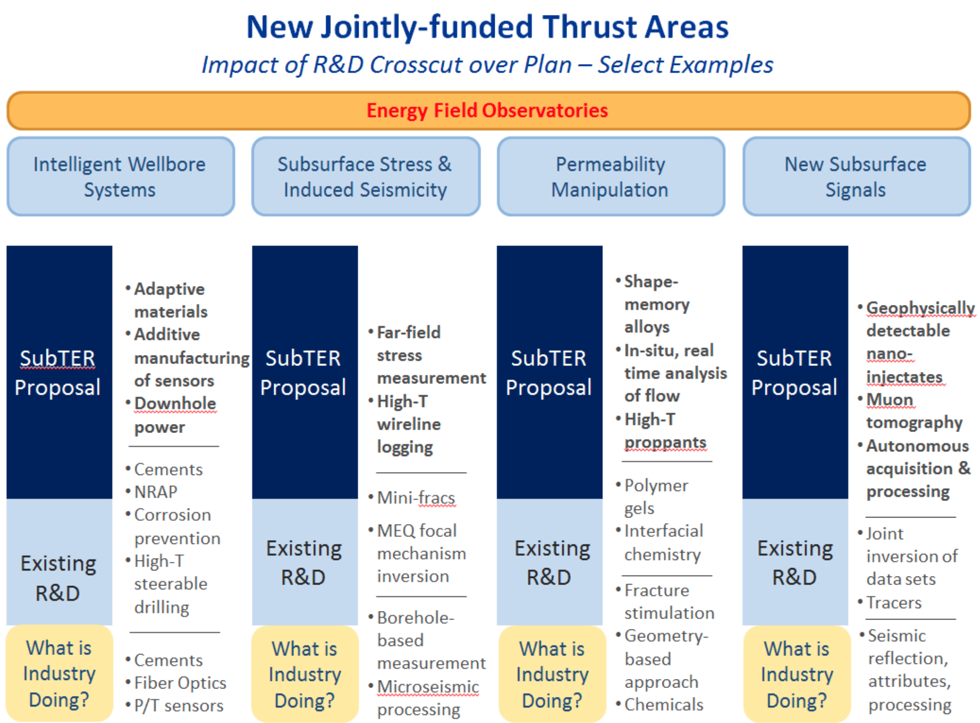

Figure 2: New program objectives relative to base and industry activities.

Proposal

Participating DOE offices are committed to SubTER's focus on *Adaptive Control of Subsurface Fractures and Fluid Flow*. The SubTER Crosscutting Team recommends an approach that includes subsurface technology and engineering R&D on the four identified technical topics, and energy field observatories for both soft rock and hard rock applications (or sedimentary rock and crystalline rock, respectively), which appropriately frame the varied subsurface conditions expected across the breadth of the targeted energy applications.

Field tests are critical to the validation of new results and approaches at commercial scale. There is no substitute for real-world testing to confirm and validate tools, technologies, and methodologies and to measure fundamental progress. The field test site(s) will require strong industry engagement for project development, implementation, and operations. This includes safety and environmental permitting, as well as cost share. Additionally, technical skills such as site characterization, modeling and simulation, drilling, monitoring, data management and control, field operation and management, and fluid injection are other key components where industry has decades of experience and expertise. Project partnerships will be critical to success of the field sites. A recent SubTER request for information (RFI) has elicited indications that industry partners will be willing to participate, co-fund, and supply datasets, cores and sites.

For each of the four thrust areas, SubTER has developed multi-year concepts for both core R&D and associated activities at field observatories (including both physical and virtual sites). Field sites will serve as dedicated testing platforms for technologies or methodologies across all of the technical thrust areas. The expectation is that sites will have already had a high degree of characterization, so funds will initially focus on infrastructure development (i.e., wells and instrumentation) followed by funding to support operations, maintenance, testing, and ultimately the transfer of sites to other entities.

Intelligent wellbore systems

Wellbore integrity is critical across all DOE programs focused on subsurface extraction of resources, energy storage, disposition of civilian and defense waste streams, and the remediation of sites contaminated from past endeavors. The need to reduce the risk of uncontrolled release of formation fluid throughout the lifecycle of a wellbore extends across a wide range of geologic environments and time-scales from weeks to eons. Well integrity is regarded as the single most important consideration for protecting groundwater resources that co-exist with oil and gas production. As hydrocarbon reservoirs are increasingly found in deeper and hotter locations, chances of seal integrity failure increase considerably. It is known that hydraulic fracturing can compromise the local cement/formation seal around casing perforations, but the effect of hydraulic fracturing on macro-scale seal performance has not been comprehensively examined. Wellbore integrity issues have been identified in 45% of the fleet of wellbores in the Gulf of Mexico. Legacy wells also present considerable potential for unwanted CO_2 migration in large-scale CCS operations. Additionally, a better understanding is desired of several technical issues relevant to potential disposal of high-level waste in boreholes in crystalline rock environments, including borehole stability under in situ stresses at 5km depth, as well as additional stresses caused by heat from the disposed waste. Better understanding of the interaction between seals and the deforming borehole under the in-situ and applied stresses is also desired.

While advances in seal materials (e.g. cements) will help address some of these challenges, transient (logging) and real-time in-situ sensor systems that can monitor the health of seals and barriers would provide operators with the high-fidelity data required to make intelligent decisions about environmental stewardship and production performance. Improvement in imaging technologies for external casing surfaces and the casing-cement bond are possible. Ultrasonic imaging logs are a well-established means of characterizing the quality of a cement bonds, but it is difficult to differentiate unwanted micro-annuli from the natural porosity of the cement material. Current remediation techniques require the destruction of a portion of casing and are successful less than 50% of the time. Non-invasive remediation techniques are needed and have a high-value proposition. Technology that allows the driller to anticipate rock properties meters ahead of the bit is in its infancy. Such technologies would significantly aid in identifying and avoiding unwanted fluid migration into the borehole, which if left uncontrolled, can lead to catastrophic well failure and blowout.

R&D activities will focus on developing adaptive and self-healing cement materials, next-generation diagnostic (e.g. logging) tools, and downhole in-situ sensors. The goal for next-generation logging tools is to increase the resolution and ability to image radially from the borehole. While wireless data telemetry methods are mature, robust sensors to measure formation properties, fluid migration, and mechanical properties of casing are needed. Additive manufacturing represents a new opportunity to fully integrate sensors into casing elements. SubTER efforts would leverage existing DOE investment in this space. R&D will begin on harvesting and converting downhole energy sources into usable power for electronic systems. This effort would drive toward field deployment of self-healing cements and downhole in-situ sensors. R&D activities will also advance anticipative drilling systems with field trials at field sites. Full integration of transducer elements and sensors into downhole materials would be first-of-its-kind and enable an unprecedented level of intelligence in the management and monitoring of subsurface energy operations.

Another component of SubTER will be drilling for NE's Deep Borehole Field Test (DBFT) at a volunteer site yet to be determined. The DBFT is designed to advance the technical basis for consideration of a deep borehole disposal facility. The DBFT will be used to validate proof of concept, but will not involve the disposal of actual radioactive waste. The

DBFT has three purposes: evaluation of the capability for drilling and construction of deep, large-diameter boreholes; downhole scientific analyses to assess hydrogeochemical conditions that control waste stability and containment; and engineering analysis to assess the viability and safety of deep borehole canister emplacement.

The DBFT consists of drilling two 4-5 km deep boreholes into crystalline basement rock in a geologically stable continental location. First, a characterization borehole with approximately an 8.5-in (0.216 m) bottom-hole diameter will be drilled and completed to facilitate downhole scientific testing (e.g., examination of hydrogeologic, geochemical, and geomechanical characteristics of the near-borehole host rock). The scientific testing and analysis activities will identify the critical downhole measurements that must be made to determine if conditions favorable to long-term isolation of radioactive waste exist at depth. Then, a full-scale field test borehole with approximately a 17-in (0.432 m) bottom-hole diameter will be drilled and completed to facilitate proof-of-concept of engineering activities using surrogate waste canisters. The engineering analysis will evaluate the feasibility of canister emplacement operations by determining performance envelopes for drilling, canister handling, and canister retrieval during emplacement. In addition, borehole sealing materials and designs will be examined through above-ground testing.

In addition, a comprehensive program of field studies on seal performance of legacy wells and existing enhanced oil/gas wells will be initiatied. This will be complemented by laboratory studies on material fatigue and response to radiation exposure. Data and information from this suite of field studies will serve as a baseline for comparison to out-year field studies that will utilize new diagnostic technology developed through the SubTER Crosscutting Team. Remediation techniques will follow a similar logic; baseline field studies using existing state-of-the-art technologies will be conducted while next-generation systems are matured through the R&D stages. These next-generation prototypes will then be fielded to quantitatively assess the advantages of these new methods. SubTER plans to emphasize R&D funding in the early years of the effort, followed by a switch to field observatory funding.

Anticipated outcomes that continue to be refined include: (1) the ability to monitor the near-wellbore environment for multiple decades at sufficient resolution to identify cracks >1 cm long, (2) self-healing casing materials that limit crack growth to <2 cm, (3) cost-effective wellbore remediation techniques, and (4) initiating drilling of a deep borehole field test.

Subsurface stress and induced seismicity

Knowledge of the subsurface stress state is required to predict and control the growth of hydraulically-induced fractures, re-opening of faults, and induced seismicity potentially associated with subsurface energy production, storage and waste disposal applications. Current capabilities to directly measure or infer the in-situ stress are woefully inadequate to serve many public needs. This limitation leads to significant uncertainties and lost opportunities to take advantage of the subsurface for energy production and waste storage, as well as public distrust of the subsurface energy sector.

To guide and optimize sustainable energy strategies while simultaneously reducing the environmental risk of subsurface injection, new approaches are needed to quantify the subsurface stress regime. New methods are needed to characterize the local and regional geology (lithology, tectonics, and seismic activity), the local and regional stress regime, the nature and presence of faults, the pressure and properties of existing fluids, and the mechanical properties of the rocks – over large spatial extents and with sufficient time/space resolution. Acquiring this knowledge at each site requires major improvements in interrogating stress state beyond the borehole and development of a fracture control risk assessment framework. Adaptive control of subsurface fractures and flow requires pairing capabilities gained through this thrust area with new abilities to manipulate and predict subsurface responses to perturbations (as are described under the Permeability Manipulation and Fit-for-Purpose Modeling themes). It is important to highlight the ongoing research portfolio and leadership of USGS in better understanding naturally-occurring subsurface stress and seismic activity. The SubTER proposal complements the USGS research mission and focuses on the substantial gaps in our understanding of the interaction of engineered systems with the subsurface environment.

Proposed activities include R&D efforts to establish baselines for assessing the state of stress at key length scales and developing new tools and methodologies to push the boundaries of dynamic stress characterization in the wellbore and to the far field. Example opportunities include high-temperature wireline logging for continuous stress measurements in deep settings, methodologies for extracting improved source mechanisms from microseismic events and stress changes from ambient noise seismic interferometry, and advanced methods for monitoring and interpreting aseismic slip. Investments will also lay foundations for multi-faceted seismic field observatories. Respondents to the recent SubTER RFI indicated a need for improved seismic monitoring and production data in areas where induced seismicity related to operations in the subsurface has been observed. The SubTER team proposes to address this data gap by developing data-sharing agreements with industry and developing a mobile seismic array that can be deployed at operational sites. An industry data partnership will be established to create an Induced Seismicity Virtual Site. This site can build on the existing DOE-USGS-EPA consortium effort to partner with industry to make key field and laboratory data accessible to the broader scientific community. In addition, SubTER will launch a design and build phase for an ultra-high density deployable surface and borehole seismometer array, building on existing academic-industry efforts to design and deploy large (on the order of 1000 sensors) seismic networks. These deployments will continue into the out years of the program, adding to data stores of the Virtual Site.

After deployment of the array, R&D emphases will turn to advanced data processing and adapting risk assessment frameworks (e.g., FE's National Risk Assessment Partnership) to reflect new insights and capabilities. SubTER also proposes the design of a controlled source demonstration site. The objective of this site will be to implement purposeful perturbation tests, where the target reservoir can be critically stressed in a highly-predictable manner to validate theories of fracture initiation and propagation.

Anticipated outcomes that continue to be refined include: (1) real-time data acquisition and modeling tools for seismic risk assessment and mitigation for the engineered subsurface that include constraints from events below magnitude 0.0, (2) new techniques to measure stress at an accuracy of +/- 5 MPa in the near wellbore environment and +/- 15 MPa in the far-field, and (3) new models to integrate stress measurements and geological structures to develop a quantitative risk assessment framework.

Permeability manipulation

The ability to adaptively manipulate permeability in the subsurface is a critical scientific and technical challenge. Respondents to the SubTER RFI from industry and academia indicated that their current mathematical models for multi-phase flow in high permeability sandstones do not work for the nano-scale pores in low permeability rocks (i.e., shales). If a marked improvement in mastery could be achieved beyond what has been developed up to this time after a century of drilling and fluid production/injection experience, there is the potential to radically transform multiple subsurface energy applications. At a time when the subsurface is being called upon to provide primary energy resources and storage and disposal solutions for energy and energy wastes, the benefits of addressing this challenge now are potentially enormous. The current lack of precise control over fracturing and fluid flow despite decades of industrial practice is testimony to the huge challenges involved, primarily related to the difficulty of characterizing the heterogeneous deep subsurface and incomplete understanding of the coupled processes related to fluid flow, geomechanics and geochemistry over scales from nanometers to kilometers.

Activities proposed for this thrust emphasize lab R&D to (1) develop new technologies for enhancing, reducing, and eliminating fluid flow, (2) develop new methods for remotely characterizing flow in the subsurface, and (3) improve our fundamental understanding of physicochemical processes during fluid-rock interactions. Current industry-led efforts for enhancing permeability tend to rely on drilling longer wells and injecting water at higher pressure. SubTER seeks to investigate new paradigms of "breaking rock" more intelligently that dramatically reduce the need for water, and that are effective in the high-temperature environments suitable for geothermal development. The need to selectively reduce and eliminate flow also needs to be extended into increasingly harsh environments. These barriers to flow are needed for both short-term applications for engineering geothermal reservoirs and long-term applications to ensure containment of CO_2 and to eliminate groundwater interaction with nuclear waste. SubTER will also initiate planning and site selection for well-characterized sites with willing partners to test technologies in the field in later years.

In later years, SubTER will seek to support crystalline rock and sedimentary rock field sites where novel stimulation and permeability reduction technologies can be tested. The emphasis of R&D funds will move from remote characterization of fluids to the ability to control fluids remotely (i.e., using phased arrays of seismic sources to generate local regions of high strain to manipulate the permeability structure of the subsurface). Work directed at this area will leverage the deployment of the array and the controlled source demo (described in the subsurface stress and induced seismicity thrust) to test concepts associated with remotely manipulating permeability.

Anticipated outcomes that continue to be refined include: (1) New stimulation techniques that reduce water consumption by >50% compared to current technology, and (2) new technologies to eliminate flow through specific fractures that can operate at temperatures >250 °C.

New subsurface signals

A major obstacle to adaptive control of subsurface fractures, reactions and flow is our inability to clearly characterize and monitor critical subsurface features. Although the energy industry has developed sophisticated tools to characterize the subsurface using both surface and wellbore methods, an entirely new class of capabilities are needed to characterize fractures and associated processes at sufficiently high spatial resolution and over large enough volumes to guide subsurface operations. The challenge is complicated by the range of relevant scales and the coupled nature of relevant thermal-hydrological-mechanical-chemical (THMC) processes. The 'New Subsurface Signals' theme seeks to transform our ability to characterize subsurface systems by focusing on four areas of research: new signals, integration of multiple datasets, identification of critical system transitions, and automation. A focus is on co-characterization of physical, geochemical, and mechanical properties using multiple datasets and on leveraging advancements in materials science, nano-manufacturing, and high-performance computing. Success in addressing this challenge is needed to master the subsurface for identification and characterization of ideal sites for energy operations.

Proposed activities will focus on advancing state-of-the-art technologies for subsurface interrogation both from the wellbore and from the surface. The R&D emphasis will be on the development of cheap, small, high-performance sensors for broad scale deployment in subsurface reservoirs. The work will also focus on developing methods for autonomous acquisition, processing and assimilation, which is a central component of the unifying "big idea" of achieving adaptive control of the subsurface.

SubTER also seeks to support field testing of technologies to identify and validate new subsurface signals. In addition to the theme of sensors noted above, testing on methods to engineer proppants, waste fluids, stimulation fluids, and other injectates to be geophysically visible will be carried out at the field site(s). This thrust area will also leverage all of the data collected in the various thrust areas to advance (1) next generation integration approaches and (2) diagnostic signatures of critical transitions. Drawing upon scenario analysis of critical transitions such as carbon sequestration caprock failure, connection of an induced fracture with a fault, or abrupt chemical dissolution/precipitation processes, this work will analyze the key set of observations needed and the ideal integration methods for various scenarios. A coordinated field campaign will be conducted at all operating field sites to validate the practices developed from case studies and scenario analysis.

Anticipated outcomes that continue to be refined include: (1) technologies to image the presence and orientation of fractures at least 10 cm long within 3 m from a borehole, (2) techniques to image from the surface the approximate dimensions and orientations of fractures at least 5 m long, and (3) reduced risk associated with exploratory drilling due to improved remote characterization of the subsurface.

Fit-for-purpose modeling and simulation capabilities

A portion of the funding in each thrust will be dedicated to advanced computing technologies as applied to the subsurface. Advanced modeling and simulation that is fit-for-purpose, or targeted at the most important aspects of the problems, is essential for tuning how the subsurface is engineered for both energy production, storage and waste disposal. Adaptive control of the subsurface requires rapidly assimilating, processing and interpreting large data streams; and then representing the governing processes and responses at appropriate scales to provide decision support for real-time operational changes for enhanced production and risk reduction. Achieving mastery of the subsurface will require new scaling techniques that utilize the full suite of signatures from geophysical, geochemical, and hydrologic observations. Some of the capabilities required in this workflow exist, but currently lack integration, whereas others need to be developed or significantly improved.

Other Program Activities
All of the SubTER offices also have significant ongoing investment in other activities not described above that directly address critical challenges related to subsurface engineering. The SubTER Crosscutting Team will provide a valuable forum in which to share information regarding ongoing RD&D efforts so that accomplishments of each office can be leveraged by the entire subsurface community. Below are summaries of the related program office activities:

EERE-GTO: Frontier Observatory for Geothermal Research (FORGE) baseline characterization, drilling and O&M; Hydrothermal and Resource Confirmation AOP and slim drilling confirmation efforts; and associated targeted RD&D.

FE-CO_2 Storage and Oil and Gas: The Carbon Storage Program will continue activities through core RD&D and injection tests in different storage formations/depositional environments to support the goal of developing a suite of tools for safe, permanent storage of CO_2. The Oil and Gas Program will continue RD&D activities that address and mitigate the risks associated with safe and environmentally sustainable shale gas development.

EM: Design, fabrication and performance testing of a universal canister within which a variety of radioactive waste types could be encased for deep borehole disposal. Design, fabrication, and licensing/permitting of associated packaging and transportation/conveyance containers. Development and demonstration of specialized sensors, detectors, imaging devices, and measurement devices for the inspection and monitoring of canister and borehole performance and integrity.

NE: RD&D on characterization and performance of generic mined geologic repository media and concepts for disposal of high-level radioactive waste and spent nuclear fuel.

SC: The Office of Science supports a broad spectrum of fundamental research in subsurface science, including geology, geophysics, hydrology, geochemistry and biogeochemistry.

Policy Implications and Challenges
Science-based policy as a basis for national energy strategy can mitigate threats to domestic production, improve public confidence in the energy sector, and bolster the nation's ability to adequately steward our natural resources. There is also significant need for effective communication with stakeholders, to provide science-based education regarding the true benefits and risks of subsurface activities. This diverse group includes the public, regulatory bodies and decision makers, non-governmental organizations (NGOs), and the larger scientific and technical community.

Policy Wins. In many cases, there is no viable pathway to address subsurface challenges through regulatory or statutory action alone; advances in technology and engineering can provide policy options.

- A major Administration priority is to reduce GHG emissions, and successful subsurface CO_2 storage enabled by technology development and demonstration directly addresses this challenge.
- Deployment of renewable energy production is another means of achieving reductions in GHG emissions. Geothermal development advances the Administration's goal of doubling renewable energy in the U.S. by 2020 from 2012 levels.
- Environmental, health, and safety issues are a major concern for subsurface activity. Technological advances can lead to environmentally sustainable energy use, and in some cases new technology can obviate the need for regulatory action.
- The subsurface is also an asset for continued and increasing reliance on nuclear power generation to meet growing energy demands in a carbon-constrained future. Success in creating sustainable nuclear waste disposal addresses current challenges in meeting regulatory requirements for the U.S. to responsibly manage this sector.

Policy Risks. Failure to sufficiently advance subsurface engineering and related technologies also carries costs and risks.

- Fossil fuels will underpin our energy supply for decades to come. Business as usual exposes the industry to continued challenges related to energy-water co-management, sub-optimal recovery, adverse environmental impacts due to inefficient capture of methane, and other challenges for which federal investment and leadership is necessary.
- Failure to invest, advance, validate, and demonstrate key subsurface demonstration projects for all energy sectors could result in a lost opportunity to leverage our nation's leadership in subsurface engineering. Policy risks include insufficient funding, and employing appropriate regulatory frameworks for the intended activities.

Policy Tools. The following are examples of policy levers that would facilitate advancements in the subsurface.

- Permitting and regulatory timelines for all subsurface activities need to be improved through interagency collaboration and coordination with state and local governments. For example, the permitting process for geothermal is lengthy and time consuming, and does not benefit from the broad streamlining and categorical exclusions afforded to oil and gas.
- Policy and regulatory guidance that supports the implementation of advanced technology that will reduce and mitigate the risk of freshwater aquifer impairment, address emissions standards, develop water management plans, and overall minimize or mitigate the impact of subsurface activities.
- The deployment of CO_2 storage requires an effective and robust market for CO_2 to incentivize project development. Consistent emissions accounting schemes are necessary along with policies that incentivize CO_2 capture and storage.
- Ongoing cooperation among DOE, EPA, and states is needed to provide the scientific and technical information to continue to inform the regulatory development process for geologic storage of CO_2.
- Continued discussions with EPA and DOJ regarding long-term stewardship issues for injected CO_2 are necessary.

Participating Offices

Energy Efficiency and Renewable Energy-Geothermal Technologies
Fossil Energy-Carbon Storage, Oil and Natural Gas
Nuclear Energy
Environmental Management
Science, Energy Policy and Systems Analysis
Electricity Delivery and Energy Reliability
Chief Financial Officer
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