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

2015 Annual Report Geothermal Technologies Office

April 2016

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Steam, West Flank of Coso, NV

The 2015 Annual Report of the Geothermal Technologies Office is a product of the United States Department of Energy, Office of Energy Efficiency and Renewable Energy.

DOE/EERE-1160 • April 2016. This report spans calendar year 2015. Photographs have been accredited herein.

2015 Achievements Geothermal Technologies Office

Director's Message

Susan Hamm, Office Director

Year in Review

Over the past year, the U.S. Department of Energy's (DOE's) Geothermal Technologies Office (GTO) supported a number of exciting initiatives and research and development (R&D) activities! The GTO budget was increased in Fiscal Years (FY) 2015-2016, providing the opportunity to invest in new technologies and initiatives, such as the DOE-wide Subsurface Crosscut Initiative, and the Small Business Vouchers (SBV) Program, which is focused on growing our small business and national laboratory partnerships. These efforts will continue to advance geothermal as an economically competitive renewable energy.

In FY 2015, GTO also saw the launch of Phase I of the Frontier Observatory Research in Geothermal Energy (FORGE), a first-of-its-kind geothermal field observatory initiative. FORGE will build on the technical success of GTO's Enhanced Geothermal Systems demonstration portfolio, which promotes transformative science and engineering through collaboration centered on a fully equipped, permitted, and characterized field site. This is truly innovation in the works!

GTO also launched the GeoVision Study in 2015. This initiative will develop a clear strategy for geothermal growth between now and 2050 to help stakeholders advance geothermal energy. The analysis is a robust, data-driven vision study that will articulate clear strategies across multiple sectors. It will provide a cohesive plan to attain geothermal growth scenarios for 2020, 2030, and 2050, with projections backed by robust data, modeling, and analysis. Through this study, GTO will demonstrate the benefits of geothermal energy as a renewable power and show that advances in geothermal technologies can greatly contribute to our nation's all-of-the-above energy strategy.

GTO continued its work on Play Fairway Analysis (PFA), an initiative to reduce uncertainty for drilling targets by defining the most promising areas for geothermal exploration. Play Fairway Analysis Phase I was completed this year for all 11 awardees. Phase I involved constructing risk analysis, uncertainty models, and maps to highlight areas for future geothermal resource exploration. This initiative will help reduce cost and increase production of geothermal systems, making geothermal a more viable economic option for power generation.

Further, we continue to be excited about the potential of co-production and low-temperature resources, funding research that will add value to geothermal projects through concurrent extraction of valuable strategic materials. The Mineral Recovery Phase II initiative was announced this year—an activity that continues our push to demonstrate additional value from geothermal energy and provide materials utilized by other industries. New information on potential financial benefits of geothermal gained through this research may result in enhanced economics of planned or existing power production plants. That, in turn, may encourage new U.S. geographic areas to develop geothermal processes to recover strategic materials resources.

However, we have not been entirely focused on technology R&D. This year marked an important milestone for the Energy Department's Geothermal Data Repository; the online geoscience tool received its 500th submission since its launch in March 2012. GTO deployed the Repository to store all data collected from office-funded projects and to help accelerate geothermal energy resource R&D by providing researchers, academia, and industry with access to this project information. The Repository is a critical component of the National Geothermal Data System (NGDS), a DOE-initiated resource that provides free access to millions of geothermal research and site demonstration records.

A Look Ahead

As GTO kicks off 2016, we will be working closely with other DOE program offices to advance complementary crosscutting subsurface R&D through the Subsurface Tech Team, known as the SubTER initiative, allowing us to better leverage internal resources and expertise. Subsurface energy sources currently satisfy more than 80% of total U.S. energy needs. Next generation advances in subsurface technologies will enable increases up to 100-plus gigawatts-electric (GWe) of clean, renewable geothermal energy—meeting roughly one-tenth of America's energy demand. With initial funding, DOE has launched nine laboratory projects on crosscutting, subsurface topics. These projects are envisioned to feed into broader program efforts in upcoming years. We are excited about the new direction of these initiatives, the expected impact on geothermal opportunities, as well as the potential to add more geothermal power to the national grid.

PFA will enter Phase II in 2016. The selected awardees' projects will gather additional geophysical data to further validate their Play Fairway exploration methodology. GTO will also ramp up work on the GeoVision Study in 2016, illustrating the geothermal potential and impacts in 2020, 2030, and 2050.

Finally, GTO continues efforts to develop near-term exploration tools to lower the upfront risk of exploration, and establish reproducible methods for commercially developing, and sustaining, geological heat reservoirs. This will allow geothermal energy to compete on an equal footing with conventional electricity sources. Further work will demonstrate the capability to create and sustain a greenfield 5 megawatts (MW) Enhanced Geothermal System (EGS) reservoir by 2020 and lower the levelized cost of electricity (LCOE) from newly developed geothermal systems to $0.06 kilowatt hours (kWh) by 2030.

GTO welcomes your questions, ideas, and recommendations on program activities. Please contact us at geothermal@ee.doe.gov.

Geothermal Technologies Office FY 2016 Budget at a Glance

GTO has witnessed incredible growth over the past two years, and expects to reach new heights in 2016. The program experienced 18% budget growth from FY 2014 to FY 2015, and 25% growth from FY 2015 to FY 2016. Notably, GTO's requested 33% budget increase in FY 2017 has received positive support. GTO is committed to developing and deploying a portfolio of innovative technologies that enable clean, domestic power generation. To accelerate the growth of geothermal energy, GTO continues to utilize its budget to support groundbreaking technologies that reduce the risks and costs of bringing geothermal power online. As a key component of the U.S. clean energy mix, geothermal is a renewable energy that generates power around the clock.

Enhanced Geothermal System

Geothermal piping, Fallon, NV

EGS has the potential to be an important contributor to the U.S. energy portfolio as a source of clean, renewable energy.

Overview

A naturally occurring geothermal system is defined by three key elements: heat, fluid, and permeability at depth. An Enhanced Geothermal System (EGS) is a man-made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. In an EGS, fluid is injected into the subsurface under carefully controlled conditions, which causes pre-existing fractures to re-open, creating permeability. EGS technology has the potential to help meet the energy needs of the United States by accessing the Earth's vast heat resource, an estimated 100 GWe, located at depth. GTO actively pursues EGS R&D and demonstration projects to facilitate technology validation and deployment, reduce cost, and improve performance. Near-term, R&D and demonstration projects will move industry along the learning curve toward technological readiness.

Demonstration

AltaRock Newberry EGS: Accelerating EGS Deployment

The AltaRock EGS demonstration project, at Newberry Volcano near Bend, Oregon, is the site of cutting-edge research on EGS development. AltaRock, one of five EGS demonstration projects in the GTO portfolio, was funded by DOE through the American Recovery and Reinvestment Act (ARRA) in 2009. The project, which was completed in 2015, achieved numerous technical "firsts" during its operational lifetime. The AltaRock team demonstrated the first multi-zone EGS stimulation, increasing the volume of rock that is available for fluid circulation and, ultimately, heat extraction. Five years of field work culminated in the confirmed creation of a new EGS reservoir in the low permeability rock surrounding the injection well. Additionally, AltaRock developed and utilized a first-of-its-kind pumping system using custom-made Baker Hughes pumps to allow a wide range of injection rates and pressures during stimulation. Finally, in order to monitor the evolution of their reservoir and seismic impacts, AltaRock deployed the most sensitive telemetered seismic array of any project in the GTO portfolio. The wealth of data collected from this robust seismic array facilitated collaborative analysis from three separate teams of seismologists to resolve complex location issues. The researchers, in partnership with AltaRock, made cutting-edge discoveries surrounding the limits of data extraction of even the most advanced seismic monitoring systems. These successes, along with many other "firsts," have significantly advanced our knowledge of EGS reservoir creation and technologies.

Raft River Demonstrates an Increase in Well Injectivity

Another GTO EGS demonstration project is taking place at U.S. Geothermal's Raft River Field in Idaho. At the site, partner University of Utah is demonstrating stimulation techniques to create an EGS reservoir adjacent to an existing well.

Following initial thermal and hydraulic stimulation operations, geothermal brine has been continuously injected into the well since April 2014. In October 2015, the team observed an incredible 370% increase in well injectivity! The increased injectivity has several important implications:

- The EGS well has since been converted into a commercial injection well and the project team has met their target flow rate of 500 gallons per minute (gpm) at plant exit pressure. This has allowed U.S. Geothermal to stop injection into another nearby well, translating to an additional $1.4 million of Net Present Value that results from increased revenue over the life of the project, per U.S. Geothermal.
- The increased injectivity of the EGS well will allow for expansion of the field and capital savings, yielding an estimated additional 2.5 megawatts-electric (MWe) without the cost associated with drilling another $3-4 million injection well.
- The team's success at the Raft River EGS demonstration shows the importance of low pressure thermal stimulation as the primary mechanism for improving the injectivity of the EGS well. Since injection began in June 2013, more than 404 million gallons of water have been injected and only 180 microseismic events have been recorded field-wide, some of which appear to be related to injection into other wells.

Broad collaboration on this EGS demonstration project has contributed significantly to its success to date. Lawrence Berkeley National Laboratory's (LBNL) Distributed Temperature Sensor (DTS) array, deployed in the wellbore during injection activities, was instrumental to the monitoring efforts and analysis associated with the stimulation. Also, Idaho National Laboratory (INL) is providing critical insight to the evolution of the geothermal reservoir via modeling of the thermal and hydraulic behavior of the reservoir in response to the well stimulation. Breakthrough techniques in this field are advancing the field of well injectivity, ultimately contributing to the adoption and large-scale deployment of EGS.

R&D

Enhancing Monitoring Systems for Geothermal Reservoirs

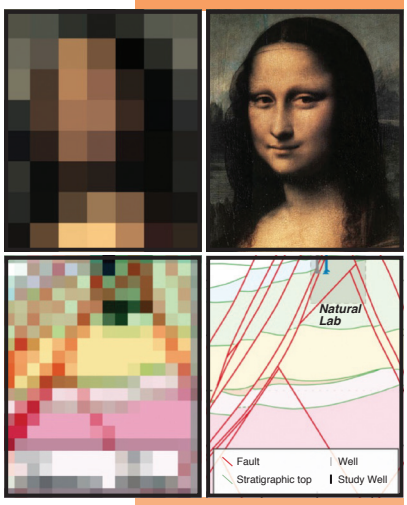
The images and behavior of geothermal reservoirs are often blurry, making it difficult for scientists and engineers to see what is going on far below the Earth's surface. The dynamic nature and intrinsic complexity of EGS and geothermal reservoirs create a need for data-rich analysis to produce a clear image.

University of Wisconsin-Madison geoscientists and engineers are working with industry partners and GTO to address this problem and significantly improve image resolution. The team is working to integrate several data-gathering approaches, including a new combination of satellite imaging techniques and fiber-optic cables, into a highly detailed monitoring system for geothermal reservoirs. Currently, the team is testing out this system at Brady's Hot Springs in Nevada, although it will ideally be scaled up to larger fields in the future.

Enhanced Geothermal System

The development of this highly detailed monitoring system requires the investigation of fundamental geoscience, including rock fractures and deformation. It also explores the usefulness of fiber optic cables to measure rock properties in a geothermal field—a common approach in mining operations and oil exploration, but rare in this setting. Recent advances in fiber optic technology allow for the collection of detailed seismic and temperature data. This technology produces data approximately 500 times per second, or a terabyte per day.

Armed with a wealth of data and the team's new data analysis and integration techniques, images of the subsurface are becoming clearer. With improved vision, scientists and researchers have the opportunity to create better and more efficient reservoirs, which could contribute to the deployment of EGS on a broader scale.



Lab R&D Successes

Correlation of Neutron Imaging Based Particle Image Velocimetry with Simulation of Fluid Flow through Fractures

The continued viability of EGS depends on developing and improving technologies essential to a geothermal reservoir, including permeability. Characterizing flow through fractures is critical to understanding processes before, during, and after stimulation of an EGS reservoir. Directly measuring fluid flow through fractures, however, has proved difficult for commercial and research organizations alike.

Researchers from Oak Ridge National Laboratory (ORNL) have developed a breakthrough methodology for direct imaging of fluid through fractures by leveraging the extensive neutron imaging research experience and facilities at the laboratory.

Tracking actual flow paths involves more than simply capturing images while flowing water through rock samples under reservoir pressures. The ORNL researchers first focused on the development of a specialized apparatus to facilitate testing at conditions comparable to the high-pressure, high-temperature environment, up to 350 degrees Celsius (350°C) where EGS reservoirs are created. The team created a custom pressure cell that allows fluid to flow through 1.5 by 6 inch cylindrical rock samples, while pressure is applied in three directions—mimicking conditions in an EGS reservoir—and neutron imaging is performed. To date, the focus of the team's research effort is developing neutron imaging techniques that utilize a contrast agent. These are tracked and captured in neutron radiographs that measure flow parameters, such as fluid speed and direction within the fracture.

Through this research effort, ORNL used direct neutron imaging—a first-of-its-kind achievement to quantify fluid flow velocities, gradients, and regimes for a variety of engineered fractures in metallic and geological samples inside a pressure vessel. Automated processing techniques that examine sequential images were developed and used to quantify the motion of the contrast agent in the fractures. The results identified different types of flow regimes within the sample.

The ORNL team successfully accomplished a major project goal by demonstrating the utility of neutron radiography at reservoir conditions as a means to capture high resolution images of fracture flow that can correlate with computational fluid models. This achievement will help to bridge the gap between understanding flow in the laboratory and flow in the Earth's subsurface. Building on these successes, ORNL will focus on advancing the imaging capabilities by conducting fractured EGS-type reservoir rock sample flow through experiments in FY 2016.

PNNL Breakthrough in Reservoir Stimulation Optimization has Exciting Potential for EGS Creation

GTO is providing funding to Pacific Northwest National Laboratory (PNNL) to develop stimuli-responsive fracturing fluid with engineered, reversible physical properties. PNNL researchers have developed a new stimulation solution, subjecting reservoir rocks to a wide range of pressure and temperature settings. The stimulation solution is comprised of a polymer that can expand up to 250% of its original volume and is triggered by a pH drop associated with the presence of carbon dioxide (CO_2).

The volume expansion introduces significant stresses to the reservoir rock, without inducing extremely high pressures. This represents a potentially important difference over traditional hydraulic fracturing operations that rely primarily on exceeding formation fracture pressures for stimulation. For one particular experiment, results show that the stimulation material was capable of inducing fractures in rock with a force nearly 70% below traditional stimulation techniques. An advantage that the team will continue to explore is the polymer's potential to change and reverse its physical properties, allowing for the stimulation materials to potentially be recycled via flowback.

The PNNL team's research highlights include a patent application, interest in collaboration from a number of private companies, and most notably, receiving the prestigious 2015 Global Award from The Institution of Chemical Engineers.

In 2016, the project team plans to fully identify the mechanisms enabling their successful induced fractures via polymer expansion. Additionally, the team seeks to understand how far the fractures can continue to propagate beyond the initial reacted fluid and volume expansion. Answering such questions is critical for understanding how PNNL's research could help optimize reservoir creation in EGS.

EGS could facilitate geothermal development outside of traditional hydrothermal areas in the western U.S., thereby extending geothermal energy production nationwide.

Salt Wells Geothermal Plant, Fallon, NV

FORGE
U.S. Department of Energy

FORGE

FORGE Kick-Off: Launch of Phase I

GTO awarded a total of $2 million to five projects for the first stage of the multi-phase Frontier Observatory for Research in Geothermal Energy (FORGE). This field laboratory, dedicated to cutting-edge research on enhanced geothermal systems, could unlock access to a domestic, geographically diverse, and carbon-free source of clean energy. The activity could potentially supply power to 100 million homes in the United States.

The FORGE initiative consists of three phases. The first two phases, which will be conducted over the next two years, will focus on selecting a site and operations team, then preparing and fully characterizing the site. Selected teams will receive up to $31 million during the first two phases.

The five selected teams that were announced earlier this year represent projects in California, Idaho, Nevada, Oregon, and Utah. In Phase 1, the teams will spend nine months completing mission-critical technical and logistical tasks. These will demonstrate site viability and show the teams' ability to meet FORGE objectives and develop robust plans for Phase 2. Phase 1 tasks will include conceptual geologic modeling and the creation of comprehensive plans for data dissemination; intellectual property; environmental, health and safety information; communications and outreach; stakeholder engagement; R&D implementation; and environmental management.

In early September and mid-October the GTO staff visited the selected sites, met with teams and stakeholders, learned more about the individual locations, and checked in with each of the teams on their progress. GTO staff had an opportunity to learn about the sites' geology, geochemistry, and characteristics, and take inventory on the most promising locations for new EGS wells and developing conceptual geologic models.

FORGE Teams

Idaho National Laboratory

- Location: Snake River Plain, Idaho
- The field site is located along the Yellowstone Hotspot—an area with potentially high subsurface temperatures and mechanical rock characteristics favorable for EGS reservoir stimulation.

Pacific Northwest National Laboratory

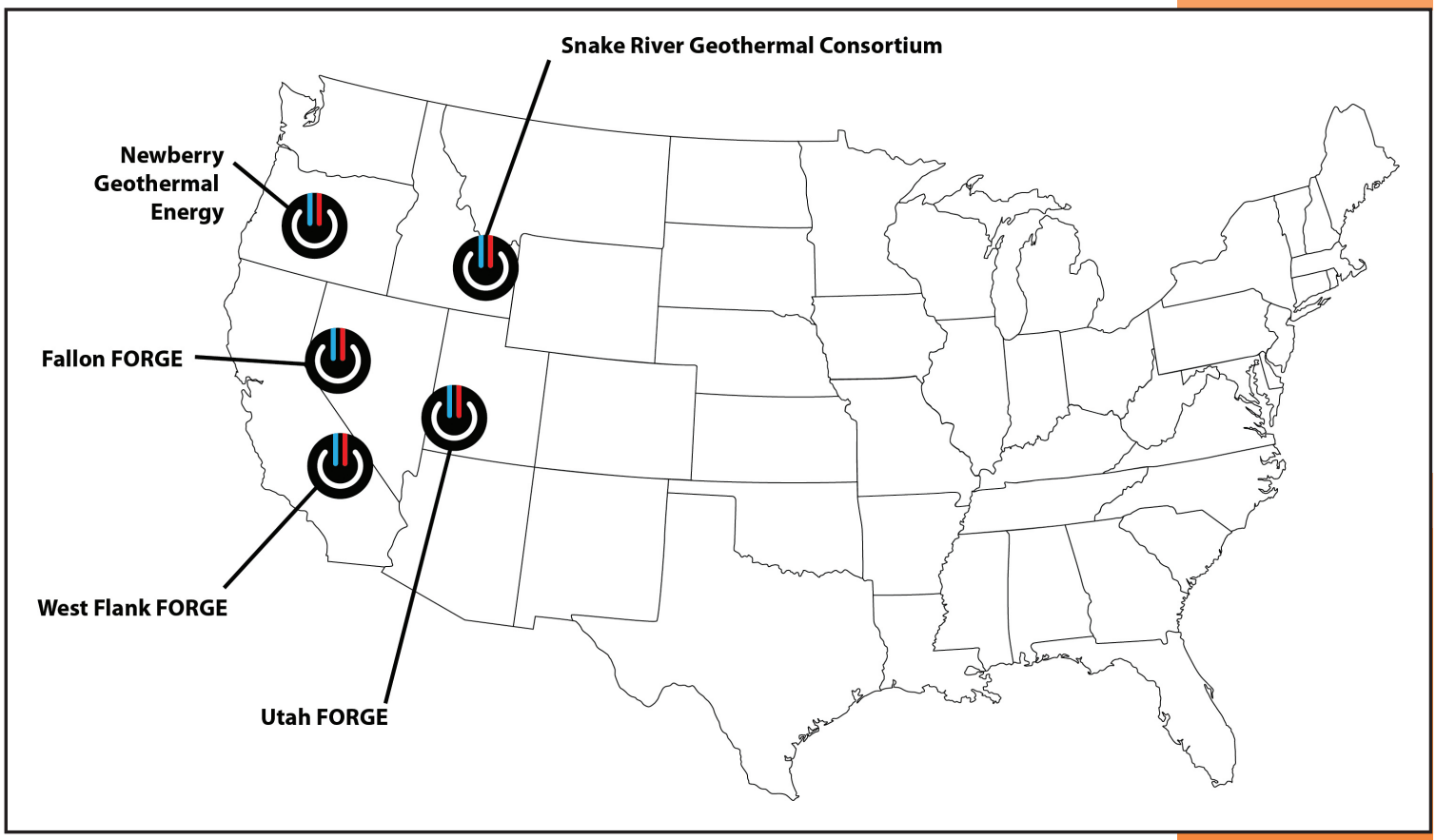
- Location: Newberry Volcano, Oregon
- Newberry Volcano may be one of the largest geothermal heat reservoirs in the western United States. AltaRock Energy has developed and applied EGS technologies at this site for the last four years.

Sandia National Laboratories

- Location: Coso, California
- The field site is located near the Coso geothermal production field within the Naval Air Weapons Station China Lake. Data suggests the potential presence of a high subsurface temperature with little fluid and permeable rock at depth.

Sandia National Laboratories

- Location: Fallon, Nevada
- This site is located on the Naval Air Station Fallon. A previous analysis has revealed its suitability for EGS reservoir R&D. The team will also develop additional scientific data and generate a 3-D model and plan for potential development of the Fallon site for the FORGE EGS demonstration.



University of Utah

- Location: Milford City, Utah
- This field site may have large underground volumes of high-temperature granite, potentially conducive to EGS development.

Next year, as many as three teams will be selected to move to FORGE Phase 2. These teams will receive up to $29 million in funding. During Phase 2, selected teams will further characterize the proposed sites and complete all environmental and permitting requirements. Pending appropriations, Phase 3 is anticipated to fully fund implementation of FORGE at a single site, managed by one operations team.

The GTO team took in the sights while making visits to all five FORGE sites this fall.

Hydrothermal Program

The GTO team on a site visit, Coso, CA

Develop advanced exploration tools and technologies to accurately identify potential geothermal resources.

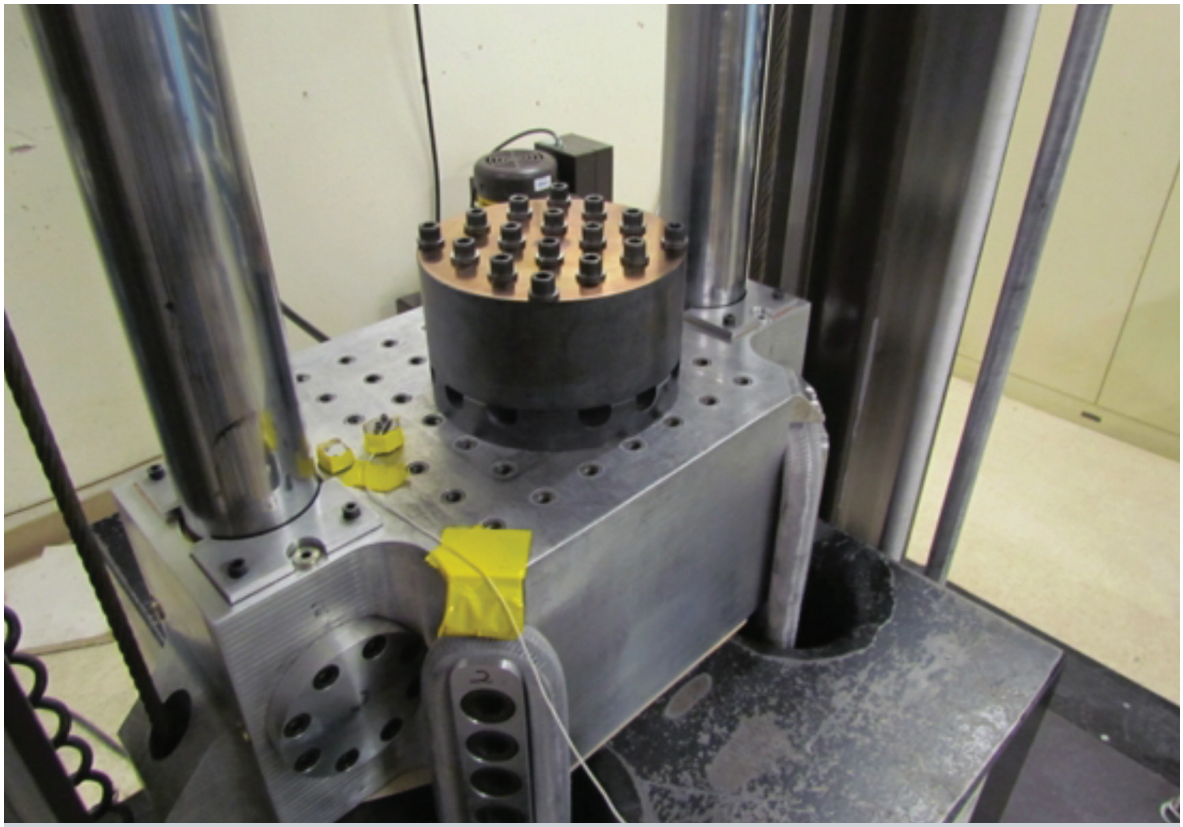
Overview

Conventional hydrothermal resources naturally contain all three components that a geothermal resource requires to generate electricity: fluid, heat, and permeability. These geothermal systems can occur in widely diverse geologic settings, sometimes without clear surface manifestations of the underlying resource. The Hydrothermal Program is focused on reducing the cost of exploration and development of geothermal resources. The development of advanced exploration tools and technologies will accelerate the discovery and utilization of the U.S. Geological Survey's estimated 30,000 MWe of undiscovered hydrothermal resources in the western United States by increasing exploration and confirmation of well success rates.

Percussive Hammer Enables High-Temperature Geothermal Drilling

In 2015, Sandia National Laboratories (SNL) and industry partner Atlas Copco successfully developed and tested a down-the-hole (DTH) percussive hammer capable of operating at elevated temperatures. A high-operating temperature drilling facility was developed at SNL to simulate downhole soak conditions up to 300°C. A 190 kilowatt (kW) process gas heater pre-heats the inlet air to simulate cross-flow heat exchange that would occur at depth. The facility is remotely operated and automated to provide a safe and consistent testbed for developing the high-temperature DTH. Percussive hammers are a promising advanced exploratory drilling technology for geothermal since they rely upon rock reduction mechanisms that are well-suited for use in the hard, brittle rock characteristic of geothermal formations. Down hole hammers are also compatible with low-density fluids that are often used for geothermal drilling. Experience in mining, and oil and gas drilling has demonstrated their utility for penetrating hard rock. Percussive hammers have the potential to reduce overall well construction costs by significantly improving the penetration rate capability of geothermal drilling in the hot, hard, abrasive environment typical of geothermal drilling.

Although existing pneumatic hammer product lines may be able to penetrate typical geothermal formations, the



Through Energy Department funding, Atlas Copco and partner Sandia National Laboratories refined a percussive hammer tool for harsh geothermal applications. Source: Sandia National Laboratories

downhole temperatures of geothermal wells (100–300°C) can challenge the elastomeric and polymer-based components that presently comprise conventional percussive hammer componentry. Hence, they are unable to survive the "soak temperatures" encountered in a geothermal well. Additionally, the metal alloy components comprising a percussive hammer may potentially be compromised with reduced strength and fatigue life at elevated temperatures.

The DTH is the result of a multi-phase development process. Phase 1 focused on proof-of-concept and demonstrating the viability of a high-temperature design. Activities in Phase 1 included modeling and simulation of hammer performance, coupon-level testing of materials and coatings, and prototype hammer design and limited lab testing.

High-Operating Temperature (HOT) test facility and bit close-up. Source: Sandia National Laboratories

Phase II commercial operation of Ormat's McGinnis Hills Geothermal Power Plant—which came online in February 2015—doubled the plant's generating capacity in less than three years, thanks to the Energy Department's Loan Guarantee Program. The plant now generates a combined total of 70 megawatts (MW). Through early DOE investment, Ormat improved efficiency of energy extraction from geothermal brines at that plant by 10%.

U.S. Energy Increase Derived from Geothermal Sources

Geothermal energy accounted for more than half of the new U.S. generating capacity brought online in February 2015, according to the latest Federal Energy Regulatory Commission (FERC) infrastructure report, issued March 19, 2015. The new geothermal capacity consists of a 45 MW expansion that was added to the McGinness Hills geothermal site in Lander County, Nevada. The power generated is sold to Nevada Power under long-term contract. The FERC document can be found at: www.ferc.gov. For more information on the geothermal expansion project, view the Ormat Technologies press release entitled, "McGinness Hills Phase 2 Geothermal Power Plant Begins Commercial Operation," available at www.ormat.com.

Conventional cement
After 1 thermal shock cycle

New BNL cement
After 7 thermal shock cycles

Cement-casing bonding after thermal shock tests 350°C heat - 25°C water. Photo source: Brookhaven National Laboratory

Multifunctional Corrosion-resistant Foamed Cement Developed

With annual operating plan (AOP) funding from GTO, Brookhaven National Laboratory (BNL) developed thermal shock-resistant cements able to withstand harsh 600°C/25°C rapid quench cycles for new geothermal applications. Cements were composed of calcium aluminate, calcium silicate, Class F fly ash, and sodium metasilicate. Modifications of cement formulations with specific additives (high-temperature inorganic corrosion inhibitor, micro-carbon fiber, and a set-controller) allowed the BNL team to create cost-effective multifunctional cements providing excellent protection of carbon steel casing against brine-caused corrosion and great chemical bonding to casing. As a result, compared with the conventional well cements, including Class G and previously developed BNL calcium aluminate phosphate (CaP), this new cement technology provides the following five benefits for hydrothermal and EGS wellbores: 1) Extension of carbon steel casing lifecycle; 2) reduction of capital investment by replacing very expensive corrosion-resistant titanium and zirconium alloys with stainless steel or clad materials; 3) decrease in well operation and maintenance (O&M) costs; 4) reduction of substantial expenditures for abandoning, re-drilling, re-cementing, reconstructing, or repairing wells brought about by the failure of well cement; and 5) reduction of capital investments by using cost-effective cements.

Such new-type, super high-temperature cements with multifunctional properties inspired the world's largest oilfield services company, Schlumberger Limited, to initiate a collaboration with BNL to develop field-applicable cement formulations and assess potential commercialization in geothermal and oil and gas fields. Agreements have been reached on a Cooperative Research and Development Agreement (CRADA) between DOE/BNL and Schlumberger to share data and evaluate this new technology. In addition, at the 2015 Geothermal Resources Council Annual Meeting, a presentation involving this project was selected for the Best Presentation Award.

Play Fairway Analysis

Play = A set of geological conditions, i.e. heat + permeability + fluid

Fairway = Smaller geographic area inside a basin/region that contains the play and usually a number of prospects to follow up on

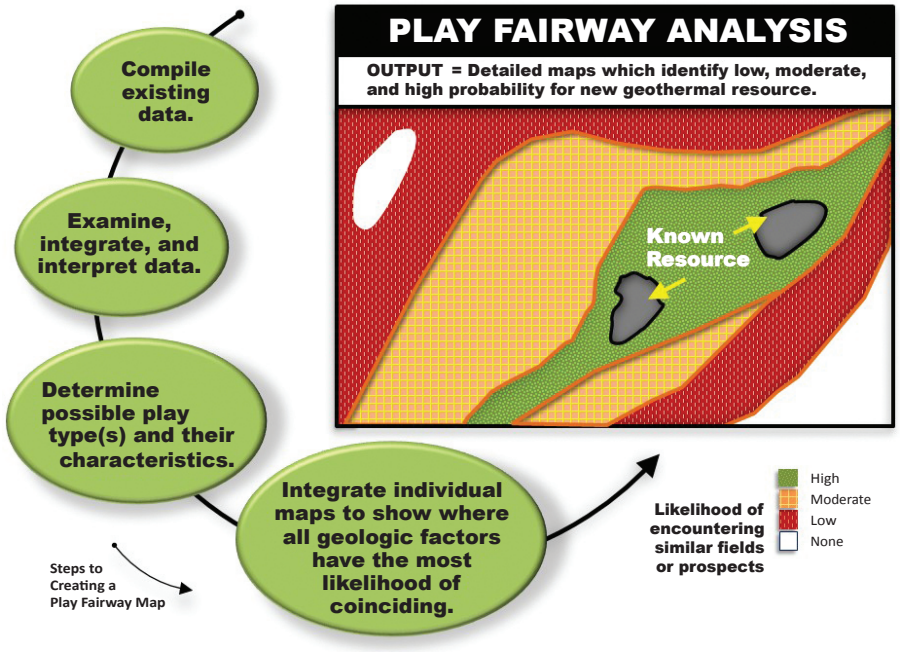
Large to small: Region, basin, play, fairway, prospect, viable geothermal resource

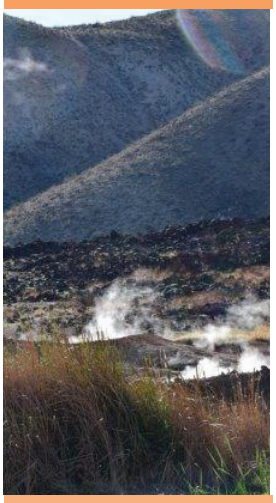
PFA Phase I Completed

GTO has wrapped up Phase I of its Play Fairway Analysis effort, with promising results. The concept of the PFA has been used to identify potential locations of blind hydrothermal systems—areas warranting future exploration—and also to describe geothermal opportunities in rift-zone settings. This tool incorporates the regional or basin-wide distribution of known geologic factors besides heat flow that control the occurrence of a particular example of a geothermal system. Conducting PFA in unexplored or underexplored basins or regions or using new play concepts in basins with known geothermal potential is central to this effort. This year saw the completion of Phase I of the PFA. The 11 awardees presented their work to GTO and the technical monitoring team at the end of October 2015.

Highlights and accomplishments of Phase I include:

- Teams framed scenarios of heat, permeability, and fluid, defining one or more plays in each study area (fairway)
- Teams mapped, evaluated, and weighted indicators of heat, permeability, and fluid (the play, as defined in each project) in existing datasets
- Teams quantified the uncertainty inherent in existing datasets, including data quantity and coverage, quality, spatial accuracy, and time of data collection
- Teams have generated Favorability Maps (called different things by different teams, but this is the language GTO supports) that highlight areas of high prospectivity for future research



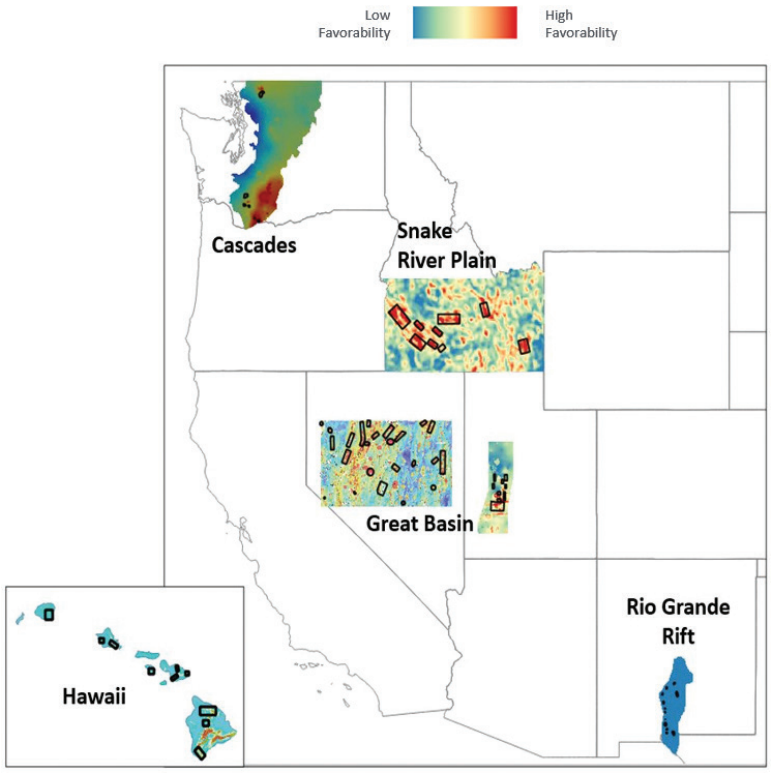


Hot springs, Coso, CA

- Teams have also considered socio-economic and technical factors, such as land position, permitting timelines, and industry partnerships in prospective areas, and have quantified (loosely, at least) the potential economic impact of future R&D.

PFA Phase II Selections Announced

In December 2015, GTO announced six teams selected to continue with PFA Phase II. The projects selected for Phase II (data collection, updating maps, and methodology) will begin work in early 2016 and will have just over a year to complete Phase II activities. GTO will award $4.5 million in additional funding to the six projects from the 2014 PFA Funding Opportunity Announcement (FOA). The projects selected for additional funding will continue to address the overarching theme of uncertainty quantification and reduction.



GTO's Sam Shiffman and Lauren Boyd

Advance a higher drilling success rate, decrease risk, and lower costs.

Subsurface Technical and Engineering RD&D (SubTER)

SubTER Background

Energy sources originating from beneath the Earth's surface satisfy more than 80% of total U.S. energy needs. Finding and effectively exploiting these resources while mitigating impacts of their use constitute major technical and socio-political challenges and opportunities.

The Energy Department's SubTER team is an integrated platform across DOE subsurface interests to address crosscutting grand challenges associated with the use of the subsurface for energy extraction and storage purposes. This team includes representatives of all DOE applied technology offices, as well as several other DOE offices focused on policy, research, and development. Through this coordinated approach, DOE can more quickly identify scientific and technology challenges and more effectively leverage funding through multi-office collaborations.

Next generation advances in subsurface technologies will enable increases in domestic natural gas supplies, as well as more than 100 gigawatts (GW) of clean, renewable geothermal energy. The subsurface can also serve as a reservoir for energy storage for power produced from intermittent generation sources.

These opportunities have immediate connection to societal needs and administration priorities. Clean energy deployment and CO_2 storage are critical components of the President's Climate Action Plan, necessary to meet the 2050 greenhouse gas (GHG) emissions-reduction target. Increasing domestic energy supply from greater hydrocarbon resource recovery, conducted in a sustainable and environmentally sound manner, is another Administration goal that will enhance national security and fuel economic growth.

Mastering the subsurface for energy production and storage, and to facilitate management, DOE is implementing a new collaborative model to address the following common subsurface challenges:

1. Discovering, characterizing, and accurately predicting the subsurface using integrated geophysical and geochemical technologies
2. Quantitatively inferring subsurface evolution under current and future engineered conditions
3. Finding viable, low-risk resources
4. Accessing safe, cost-effective drilling and completions with properly managed wellbore integrity
5. Engineering, creating, and constructing desired subsurface conditions in challenging high-pressure/high-temperature environments
6. Sustaining optimal subsurface conditions over multi-decadal or longer time frames through complex system evolution
7. Monitoring and improving observational methods to advance the understanding of multi-scale complexities through system lifetimes

SubTER Pillars

Through ongoing engagement with key stakeholders to help identify high priority technology areas for federal advancement, DOE has developed a comprehensive research, development, and deployment (RD&D) strategy focused around four core pillars:

1. Wellbore Integrity – New sensors and adaptive materials are needed to ensure sustained integrity of the wellbore environment.
2. Subsurface Stress and Induced Seismicity – Radically new approaches are needed to guide and optimize sustainable energy strategies and reduce the risks associated with subsurface injection.

Who's Involved?

Representing the geosciences, research, modeling, technology development, policy, and stakeholders, the participating DOE program offices include:

Fossil Energy
Energy Efficiency & Renewable Energy
Nuclear Energy
Environmental Management
Science

3. Permeability Manipulation – Greater knowledge of coupled processes will lead to improved methods of enhancing, impeding, and eliminating fluid flow.

4. New Subsurface Signals – DOE seeks to transform our ability to characterize subsurface systems by focusing on four areas of research: new signals, integration of multiple data sets, identification of critical system transitions, and automation.

A critical component of all pillars will be R&D testing at Energy Field Observatories. Field tests are critical to the validation of new results and approaches at commercial scale to validate tools, technologies, and methodologies and measure progress.

National Laboratory Early-Phase Research

Approximately $9 million has been jointly awarded by GTO and the Office of Fossil Energy to national laboratory teams to begin work on crosscutting topics. These projects are envisioned to feed into broader program efforts in upcoming years. The following lists the nine selected projects with the primary lab awardee:

- *Lawrence Berkeley National Laboratory*: Hydraulic Fracture and Stimulation in a Deep Mine Investigation. PILLAR: Permeability Manipulation, Subsurface Stress and Induced Seismicity
- *Lawrence Livermore National Laboratory*: Development of microBayesloc Location Method. PILLAR: Subsurface Stress and Induced Seismicity
- *Los Alamos National Laboratory*: Development of Novel 3D Acoustic Borehole Integrity Monitoring System. PILLAR: Wellbore Integrity
- *Los Alamos National Laboratory*: Multi Variate Examination of the Cause of Increasing Induced Seismicity. PILLAR: Subsurface Stress and Induced Seismicity
- *National Energy Technology Laboratory*: Big Data and Analytics for Induced Seismicity. PILLAR: Subsurface Stress and Induced Seismicity
- *Oak Ridge National Laboratory*: Photo-stimulated Luminescence Spectroscopy Stress Sensor for In-situ Stress Measurement. PILLAR: Subsurface Stress and Induced Seismicity
- *Oak Ridge National Laboratory*: Ultrasonic Phased Arrays and Interactive Reflectivity Tomography. PILLAR: Wellbore Integrity
- *Pacific Northwest National Laboratory*: Borehole Muon Detector for 4D Density Tomography of Subsurface Reservoirs, Geophysics, Hydrology, Geochemistry, and Biochemistry. PILLAR: New Subsurface Signals
- *Sandia National Laboratories*: Imaging Fracture Networks Using Joint Seismic and Electrical Change Detection Techniques. PILLAR: Permeability Manipulation

Grand Challenge Workshop

In May 2015, DOE held a Grand Challenge workshop to discuss imaging geophysical and geochemical signals in the subsurface. The success and synergy of the workshop lead to a follow-up roundtable in July 2015. These two events convened national laboratory, university, and industry experts to brainstorm research areas that underpin the SubTER Pillars. The outcome of these meetings resulted in the identification of prioritized research questions that will help inform future research directions.

The workshop participants identified a number of key subtopics under the Grand Challenge that are considered essential to making fundamental progress on imaging the subsurface. These subtopics include:

- Imaging Subsurface Fractures and Flow
- Resolving and Interpreting Changes in Fluid Composition
- Characterization of Reservoirs
- Physical and Chemical Changes in Rock-Fluid Systems
- Subsurface Stress Distribution and Dependent Seismicity

The panel determined that now is a very good time to undertake a serious, concerted effort regarding the Grand Challenge topic. Advances in materials science, manufacturing, scientific instrumentation, data processing, and computing power have reached a point where substantial progress is possible. The Grand Challenge Report can be found at the SubTER website: www.energy.gov/subsurface-tech-team-subter

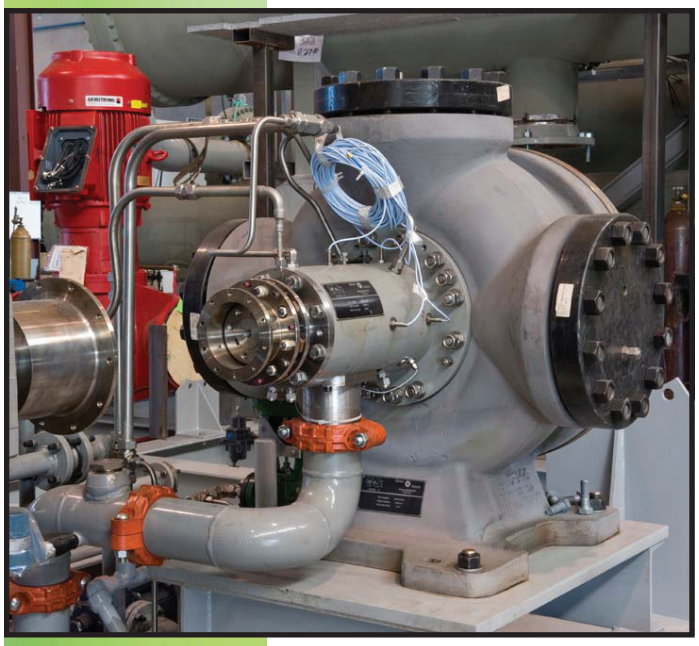
SubTER Exhibits with the National Labs

GTO and the national laboratories exhibited SubTER at two conferences in 2015: the Geological Society of America (GSA) Annual Meeting and the American Geophysical Union Fall Meeting. Representatives were on hand to answer SubTER questions and provide informative materials. Attendees were most interested in future plans for the crosscut initiative, technology improvement and development, and initial laboratory projects. DOE and the national laboratories have also established a social media presence (see *Resources* section) and were able to post and share throughout the conferences.

Learn more about GTO investments in hydrothermal power at www.energy.gov/eere/geothermal/hydrothermal.

Geothermal piping, Steamboat Springs, NV

Low-Temperature and Coproduced Resources



LT Manufactured Turbine

Overview

Low-temperature and coproduced resources represent a small, but growing, sector of geothermal development in resources below 150°C (300°F). Considered non-conventional hydrothermal resources, these technologies are bringing valuable returns on investment in the near-term, using unique power production methods. GTO works with industry, academia, and national laboratories to develop and deploy new low-temperature and co-production technologies that will help the geothermal community achieve widespread adoption of under-utilized, low-temperature resources.

GTO is working toward a goal of achieving widespread production of low-temperature power by 2020 through surface and down-hole technology advances, improved education and outreach, and increased collaboration between government and industry.

Validated methods will provide a pathway to added revenue streams that may be significantly beneficial to improved value proposition.

Extracting Critical Materials from Geothermal Brines

GTO is investing in RD&D innovations to extract critical or other high value materials found in geothermal brines. Geothermal fluids could be a key pathway for supplying a growing domestic demand for these materials, which are predominantly imported today. In addition, unlocking cost-effective and accurate processes for extracting such materials from geothermal brines can create a new revenue stream for geothermal developers.

In May 2015, GTO issued a Request for Information (RFI) that sought input on innovations to extract critical materials found in geothermal brines. The RFI addressed the following: potential approaches that could be adapted from existing extraction processes in oil and gas, mining, and other industries; commercialization concepts and approaches that leverage geothermal and mining methods already in use; and ideas for combined drilling technologies, rock stimulation technologies—such as those used in enhanced geothermal systems, and mineral extraction technologies currently applied in solution mining.

Based on the RFI responses, GTO released a FOA for Phase II on December 1, 2015. The FOA explores the potential of extracting and purifying high value materials from fluids produced by geothermal power operations or prospective geothermal projects. This FOA seeks to improve the economic and production benefits of geothermal energy projects, making them more economically competitive at a wide range of locations. It is also possible that these minerals could be found in fluids produced by oil, gas, or mining operations.

The work initiated under the Phase I FOA continued into 2015. The Phase I awardees are: Carnegie Mellon University, LBNL, PNNL (two awards), Southern Research Institute, SRI International, Tusaar Corp, and University of California-Davis (UC Davis). All eight of the awards have passed, or are expected to pass, the first budget period and have begun the second period of research. Seven of the projects are evaluating a range of novel approaches for recovering rare earth elements or high value materials, such as lithium from chemically complex geothermal brines at elevated temperatures. Research ranges from new selective resins, to a new class of selective nano-particles, to bioengineered microorganisms—all designed to selectively bind with valuable materials in the geothermal fluids. To support this work, DOE is funding INL to develop standardized synthetic brines that approximate some basic geothermal fluids. These brines will assist the research teams in verifying the effectiveness of their extraction approaches. The University of California team is focused on refining methods to characterize a range of geothermal fluids correlated to the source of the fluids to better understand potential predictors for valuable materials in the geothermal fluids.

Low-Temperature and Coproduced Resources

The Stillwater geothermal plant is the first hybrid solar-geothermal facility in the nation. In 2014, Enel Green Power added 2 MW of concentrating solar power to the existing geothermal plant and solar photovoltaic field, for a total installed capacity of ~60 MW. Source: Enel Green Power North America

Optimizing Geothermal with Geo-Solar Hybrid Systems

DOE is exploring the potential of using hybrid applications to raise power plant outputs at low cost. During 2014, industry partner Enel Green Power—in collaboration with INL and National Renewable Energy Laboratory (NREL)—began work to quantify the potential benefits of combining geothermal and solar thermal systems. Positive results could enhance deployment of these clean, renewable energy technologies in regions where the resources overlap. The research team is evaluating both the technical and economic aspects of hybrid power generation by combining geothermal energy with concentrating solar power (CSP) technology. The work utilizes data from the operating Stillwater geothermal-photovoltaic hybrid plant in Fallon, Nevada, where CSP was installed this year.

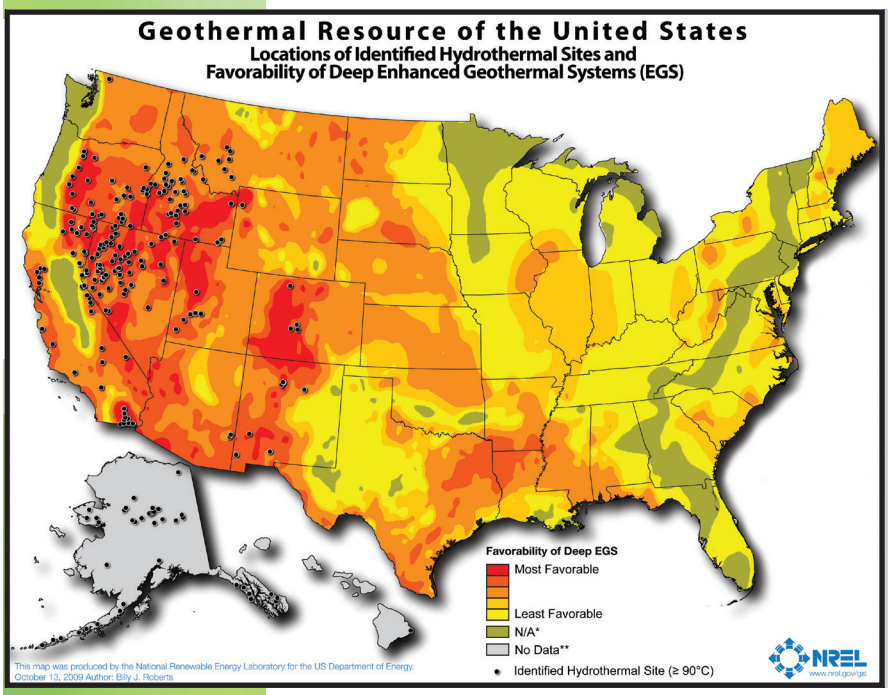
Modeled results achieved a 5% reduction in the LCOE by using a retrofit geothermal-solar hybrid plant. The magnitude of the results is highly dependent on resource productivity, power purchase agreement (PPA) penalties, solar collector array costs, and solar array installation parameters. The results also indicate that further LCOE savings are possible if reduced risk associated with the solar heat source translates to more favorable pre-operation project financing terms. Federal and state renewable energy incentives or tax credits could further decrease LCOE. Hybrid systems are subject to any PPA penalties on the economics of the hybrid plant relative to the base CSP power plant. Additional work is underway to evaluate commercial opportunities and best alternatives for geothermal/hybrid systems.

Award-winning Research Looks at Geothermal to Balance U.S. Energy Supply

At this year's National Geothermal Summit on June 3, 2015, the Geothermal Energy Association (GEA) honored Tom Edmunds and Pedro Sotorrio at Lawrence Livermore National Laboratory (LLNL) for innovative research that contributes to the geothermal industry's understanding of future energy markets and showcases the benefits of geothermal within the broader context of renewable energy sources. GTO commissioned the study to explore economic incentives that would motivate geothermal plant operators to consider a more flexible geothermal energy supply.

Energy scientists predict that high penetration levels of intermittent wind and solar generation in the western United States will increase the uncertainty and variability in energy generation and its delivery to consumers. Geothermal power plant operators could help balance this variability and reduce uncertainty by operating plants in a more flexible manner to respond to sudden changes in energy use. In the report, LLNL details how plant operators could financially benefit from providing more flexibility to the grid in the form of ancillary services.

The LLNL team found that if ancillary service prices increase significantly above current levels for a sufficient number of hours during the year, geothermal power plant operators could capture additional revenue by operating plants in a flexible manner to meet consumer demand. Energy prices in the year 2020 are expected to be significantly higher due to an aggressive 33% renewable portfolio standard in California and the retirement of more than 2,000 MW of flexible generation capacity. Geothermal plant operators could step up to fill the gap left by this retired capacity, and those that secure flexible contracts would benefit from additional revenue streams. Ancillary services, for instance, could add 8% revenue annually under a flexible contract with an energy price of $70 per megawatt hour (MWh).



Geothermal energy, traditionally a baseload power source among renewables, is now poised to emerge as a flexible power source, balancing intermittent wind and solar power production and reducing variability in energy prices. Source: NREL

GTO Doubles Down on Desalination

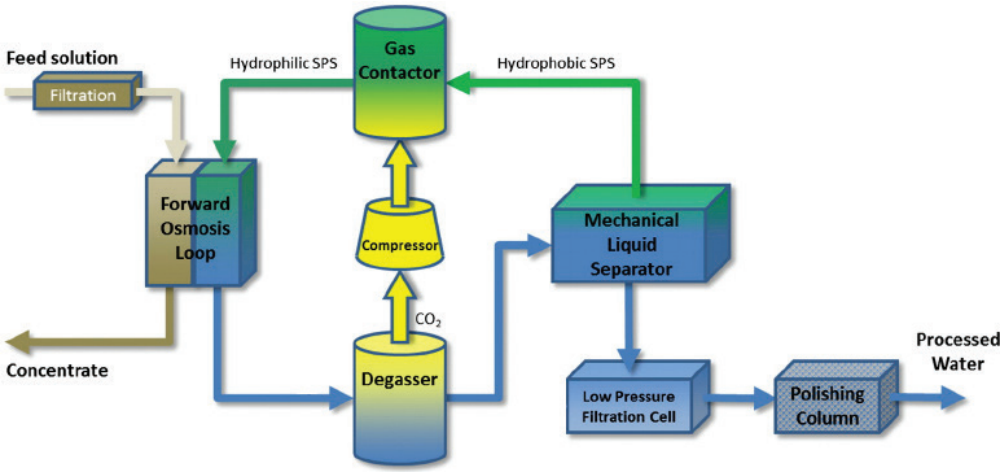
GTO has continued to invest in developing technologies that use thermal energy for desalination of impaired waters.

Over the past year, GTO has continued to invest in developing technologies that use thermal energy for desalination of impaired waters. These technologies have the potential to allow for geothermal heat to be used directly in cleaning produced waters, which will provide additional water supply for stressed regions and mitigate the hazards from induced seismicity. Reverse osmosis, which is the current standard for desalination technology, uses electricity to create a pressure difference that drives water across a membrane to remove dissolved salts. Both Forward Osmosis (FO) and Membrane Distillation (MD), the two technologies that GTO is currently funding, also drive water across a membrane, but they do so by making use of a low-grade temperature difference, which reduces the overall operating expenses when it comes from a geothermal resource.

During 2015, both of GTO's two desalination projects increased their scope from proof of concept to prototype development, with plans for field testing at a geothermal site in 2017–2018. INL is leading a project with LBNL to develop a FO system that uses a switchable polarity solvent (SPS) as its draw solute (see Figure below). When the SPS is heated, it has a lower pressure, which draws water across a membrane leaving the dissolved salts behind in concentrated brine. The polarity on the draw solute can then be switched to extract the fresh water where the SPS is recycled to continue to process.

NREL has teamed with SNL, Colorado School of Mines, and University of California at Riverside to develop an MD process that is driven by low-grade heat from geothermal energy. Like FO, the MD process also uses the heat to drive water across a membrane, but instead of a draw solute it uses a vacuum, and evaporation and condensation of the water to remove the dissolved salts.

This past November, researchers from both the FO and MD projects participated in the DOE-hosted Energy Optimized Desalination Technology Workshop in San Francisco to understand how advancements in renewable energy and energy efficiency can reduce the economic and environmental costs for sustainable water clean-up. GTO is excited about the impact of these promising desalination technologies, not only to enable a new use of geothermal resources, but also for the broader societal benefits they can provide.



The proposed Switchable Polarity Solvent - Forward Osmosis system being developed by Idaho National Laboratory

Deep Direct Use

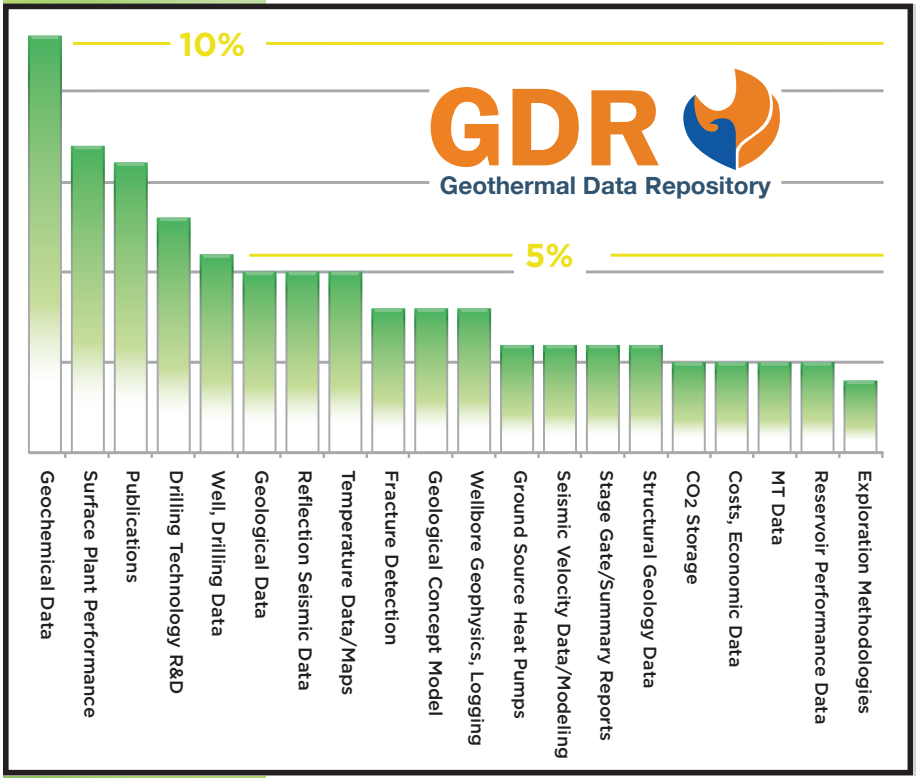
Deep Direct Use (DDU) geothermal applications utilize geothermal fluid for a wide range of cascading uses, including district heating and cooling, commercial and residential applications, industrial processes, and agricultural uses. As the demand for net-zero energy campuses, military installations, and offices increases, DDU offers great opportunities to significantly expand the impact and reach of geothermal energy to a much wider swath of the country. These systems could provide a large fraction of the space conditioning and low-end thermal energy demand currently supplied by high-grade fossil fuels.

DDU promotes large-scale, commercially viable systems that optimize the value stream of lower-temperature resources for campus or installation-sized applications.

GTO is working toward a goal of achieving widespread production of low-temperature energy by 2020 through surface and down-hole technology advances, improved education and outreach, and increased collaboration between government and industry.

As part of an eastern U.S. workshop, GTO staff toured the Frick Park Environmental Center, which is slated to meet the "Living Building Challenge" through use of geothermal heating and cooling. The challenge requires stringent use of water and net-zero energy.

NRG Energy's District Energy CEO and Plant Manager gave workshop participants a tour of the utilities' Northside District Energy Plant. The tour focused on potential methods to integrate geothermal energy.



The GDR accepts many different types of data useful to the geothermal community, as illustrated by the data categories in the image. Credit: Jon Weers, NREL.

Overview

GTO's Systems Analysis Subprogram supports projects that solve non-technical barriers to geothermal deployment. The program is primarily focused on environmental issues; policy, regulatory, and financing; economic analysis and validation; and data and tools that support geothermal exploration and development.

Geothermal Data Repository Reaches 500 Submissions

July 15, 2015, marked an important milestone for the Energy Department's Geothermal Data Repository (GDR)—the online geoscience tool received its 500th submission since its launch in March 2012. GTO deployed the GDR to store all of the data collected from office-funded projects, but also to help accelerate the research and development of geothermal energy resources by providing researchers, academia, and industry with access to this project information. The GDR is a node of the Energy Department's National Geothermal Data System, which provides free access to millions of records of geothermal research and site demonstration data.

The GDR's 500th submission came from Carnegie Mellon University and consists of a structured, high-quality data set containing the results of experiments on the effectiveness of materials to separate rare earth metals from geothermal brine—the mixture of water and dissolved minerals extracted from geothermal sites. Close on its heels was the 501st submission from the private company, SRI International, with data showing the effectiveness of polymers to do the same with lithium and manganese. Both the Carnegie Mellon and SRI International research projects received funding from GTO's Mineral Recovery FOA. If successful, these methods will not only help make geothermal a source of sustainable energy, but also a source of rare earth elements and other minerals crucial to today's technology.

All projects receiving GTO funding upload their raw data—ranging from well and drilling data to tested exploration methodologies—to the GDR. Ensuring access to the data is not just about uploading it to a data repository; it's about making the data useful to others in ways that will foster innovation and promote further scientific discovery. This practice not only complies with the White House's open data policy, but also goes a step further by making the data part of the NGDS and other data catalogs, such as OpenEI and Data.gov, providing a resource that is useful for the broader geothermal industry and scientific community. The 500th submission is also unique because it was formatted to fit an NGDS Data Exchange Model, which makes it interoperable with other data in the repository. This formatting is highly recommended by the GDR, and submissions that meet these interoperability requirements are categorized as Tier III. Additional information pertaining to the data quality and format used for the 500th submission may be found on the Mineral Recovery Brines page of the NGDS.

On its own, the GDR had 1,038 direct downloads between July 1, 2014–June 30, 2015. However, files hosted on the GDR were downloaded more than 11,300 times during that period by users accessing the data through GDR's open data partner sites. Members of the geothermal industry are not only contributing to the GDR, but the contributed data is providing tangible value to the entire geothermal community. For example, Schlumberger, a global industry leader serving the oil and gas sectors, was able to make better drilling decisions because of raw temperature data supplied to the NGDS.

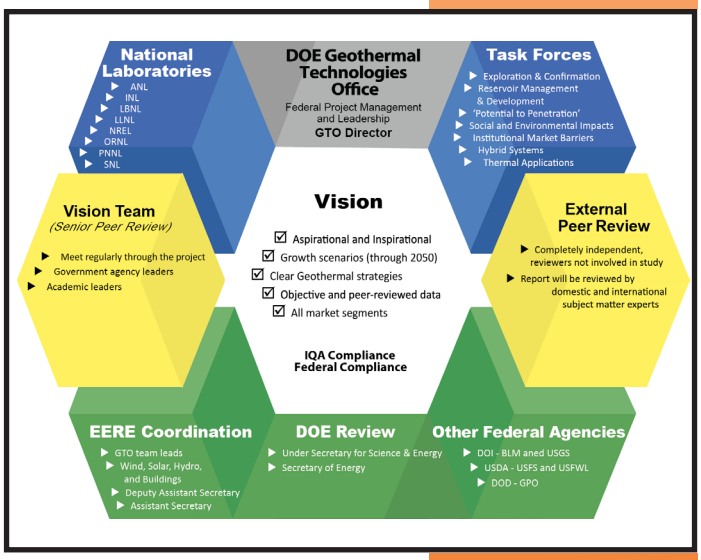
The GDR, along with the NGDS and other open source databases, are helping increase the deployment of geothermal energy in the United States, which will play a vital role in reaching the goals outlined in the recently announced U.S. Environmental Protection Agency clean power plan.

GeoVision Study Kicks Off

In summer 2015, GTO launched a massive effort to produce an analytical report outlining a vision for the future of the geothermal industry in the coming decades. This "GeoVision" report will highlight the potential economic, environmental, and social benefits of geothermal energy. Stakeholders and visionaries from academia, national laboratories, and the private sector have come together to conduct the study that will produce this report.

GTO initiated this vision study with a meeting of industry experts in August 2014, and again in January 2015. The key objectives of the study are to provide a rigorous analysis-driven assessment of the future for a full continuum of geothermal energy technologies, and to further advocate for the continued RD&D efforts by DOE in this space. By engaging the geothermal industry in this dialogue, GTO anticipates a product that will benefit the entire industry and unify it moving into the future.

Market sectors will include existing and potential opportunities for geothermal electric generation, thermal applications, and other additive value streams. The study will be based on robust data, modeling, and analysis, and will be reviewed by a diverse group of industry peers (the "Visionary Team") throughout the effort. Results of the study will identify the potential for geothermal energy to play an important role in national energy and climate change priorities, and articulate a clear GTO investment strategy across the different sectors to achieve this outcome.



Multiple Labs Work to Assess the Potential for Deep Direct Use

In 2015, GTO launched a multi-lab analysis of the potential for DDU [see the Low-Temperature section for more information on the concept of DDU.] GTO is also working closely with ORNL, National Energy Technology Laboratory (NETL), and NREL to assess the potential for distributed geothermal resources, including DDU and geothermal heat pump (GHP) systems.

In March 2015, NREL and the Colorado School of Mines co-sponsored a Direct Use Geothermal Workshop in Golden, Colorado. Keynote Speaker Michael McReynolds of the Colorado Energy Office referred to the direct use of geothermal technology as an "emerging technology." Although aimed at the western United States, geothermal experts from across the country addressed thermal load demand; the importance of shifting exploration models; bounding parameters for direct use; sharing resources with distributed energy systems; district heating; GHP systems; desalination; building the future grid; industrial applications; renewable thermal energy policy; direct-use profitability; business models employed through community partnerships; and cascading uses and technology coupling.

In August 2015, the NETL Morgantown staff sponsored the Geothermal Direct Use Technology & Marketplace Workshop in Canonsburg, Pennsylvania. Similar to the workshop in the western United States, the eastern U.S. workshop included more than 65 participants. Participants primarily represented three sectors (private industry/consultant, academics, and government/contractors), with roughly a third of attendees coming from each group.

The workshop leveraged the DOE (NETL) 21st Century Infrastructure Memorandum of Understanding (MOU) with the City of Pittsburgh by exposing energy and green buildings stakeholders to the potential for Geothermal Direct Use in key MOU localities within the Appalachian Basin. The City of Pittsburgh's Chief Resilience Officer presented emerging opportunities to develop district energy in cities like Pittsburgh that are experiencing growth and re-development. An Icelandic consultant discussed geothermal district heating with an established geothermal resource, and provided insights into different heating and cooling needs and approaches that would be relevant to Pittsburgh.

George Richards hosts the Geothermal Direct Use Technology & Marketplace Workshop in Canonsburg, PA.

Thermal Task Force Analysis to Include Geothermal Heat Pump Systems

The GTO Systems Analysis and Low Temperature (SALT) team members are excited to kick off work with ORNL ground source heat pump (GSHP) expert Xiaobing Liu and Visionary Team members from the International GSHP Association and GeoExchange. As 2015 came to a close, Dr. Liu provided an overview of thermal loads and energy consumption for space conditioning and water heating in U.S. buildings, and an assessment of existing GSHP installations. In addition, Kate Young, from NREL, is completing an overview of available geothermal resources in the United States for direct use applications. SALT team member, Arlene Anderson, looks forward to working with industry members who are validating the concept that distributed geothermal energy results in more energy being exported than is consumed. Stay tuned!

The GTO team at the GRC Annual Meeting September 20-23, 2015.

Engaging Industry to Commercialize Innovative Technologies

Over the past year, GTO has continued to make an effort to deploy new technologies in geothermal, using some innovative methods to engage with industry. Three of these methods are the Small Business Vouchers (SBV) pilot program, the Small Business Innovation Research (SBIR)/Small Business Technology Transfer program (STTR), and national laboratory Tech-to-Market (T2M) activities. Through these activities, GTO hopes to continue to make an impact on the cost reduction and further deployment of geothermal energy.

SBV is a $20 million Energy Efficiency and Renewable Energy (EERE) pilot program that was announced by the White House on July 9, 2015. Through the SBV pilot, national laboratories provide technical assistance, and collaborative research and development support to small businesses working in the clean energy sector. Each voucher equates to a $50,000 to $300,000 national laboratory project of up to 12 months in duration. GTO is participating in the SBV pilot by making $1.5 million available for vouchers in the areas of Enhanced Geothermal Systems, Low-Temperature and Coproduced resources, and Systems Analysis.

September 2015 marked the opening of the program's first round, of small businesses submitting requests to work with the national laboratories. Over the following month, small businesses with great ideas for geothermal innovations submitted 25 requests for assistance. Two of these requests were selected for vouchers to work with the experts at national laboratories to commercialize their ideas. There are two more rounds of SBV, the second one opens in March 2016 and the third is planned for June 2016. There is also a possibility of subsequent rounds in FY 2017. If your organization is a small business with a geothermal innovation, consider participating in this exciting new pilot by submitting a request for assistance to SBV.org. The SBV pilot is a great way for small businesses with limited resources to access the world-class technical experts and facilities of the national laboratories.

GTO also continues to engage with industry through the SBIR/STTR program. In 2015, GTO awarded three new phase I SBIR projects under the topic of "Innovative Products or Technologies that Develop New Markets or Revenue Streams for Geothermal Energy." For FY 2016, DOE will not have a geothermal-specific SBIR topic, but instead, has a SubTER crosscut collaborative topic. The solicitation containing the SubTER SBIR topic closed in October 2015 and received 19 proposals. Awards are expected to be announced in January 2016. GTO plans to sponsor its own SBIR topic in FY 2017—that solicitation will be released in the fall 2016.

GTO's third approach to industry engagement is sponsorship of national laboratory Tech-to-Market activities. Through T2M, SNL researchers visited private industry in 2015 to discuss opportunities to license national laboratory technologies. The researchers also provided technical support to businesses for commercializing new technologies. Future activities include plans to hold industry meetings in summer 2016. These events will showcase lab-developed technologies that are available to industry for licensing. Additionally, GTO will provide information on industry "intake points," describing how to work with the national laboratories on licensing, technical assistance, or cooperative research and development.

GTO is excited about how these efforts have helped industry to commercialize new technologies and looks forward to another year of new engagements. For questions about SBV, SBIR/STTR, T2M, or related activities, please contact Josh Mengers at joshua.mengers@ee.doe.gov.

2015 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY GEOTHERMAL TECHNOLOGIES OFFICE

On May 11–14, 2015, GTO conducted its bi-annual program peer review in Westminster, Colorado. In addition to providing independent, expert evaluation of the technical progress and merit of GTO-funded projects, the review was a forum to gather feedback and recommendations on future GTO strategic planning. Further, this event provided an opportunity for the geothermal community to share ideas and solutions to address the challenges facing the geothermal industry.

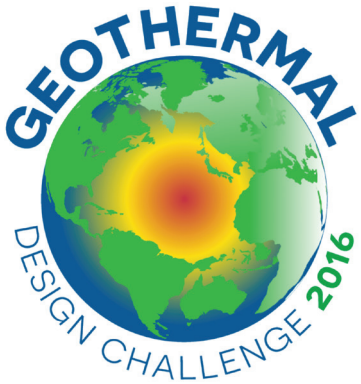
During the course of the peer review, GTO-funded projects were evaluated for: (1) the impact of their research, accomplishments, results, and progress; and, (2) their scientific/technical approach. Projects were also evaluated qualitatively on their strengths, weaknesses, and opportunities for improvement. Principal Investigators (PIs) came together in sessions organized by topic "tracks" to present the progress and results-to-date of their projects to a panel of independent experts, as well as attendees. Dr. Kate Baker served as the overall chairperson, providing guidance to reviewers to ensure consistency, transparency, and independence throughout the review process. Her career has spanned the geoscience and engineering disciplines, including geotechnical, drilling, and reservoir engineering; geology; geophysics; and formation evaluation. Dr. Baker also served as the overall chairperson for the GTO peer reviews in 2012 and 2013, and is well-versed in the EERE peer review process.

The GTO peer review provides a forum for independent, expert evaluation of the technical progress and merit of GTO-funded projects. The event attracts a national and international audience in this burgeoning sector, and opens a dialogue with other respected experts in geophysics, geochemistry, modeling, down-hole tools, and more. The four-day event brought together nearly 300 participants from eight countries, industry, national laboratories, and academia. Projects were presented by 110 GTO awardees, and an additional 21 individuals shared posters on GTO-funded research.

GTO Launches New Student Competition – Design Challenge 2016

In partnership with the Center for Advanced Energy Studies and INL, GTO invited high school and university (undergraduate and graduate) students to explore the future of geothermal energy and literally "draw the heat beneath your feet." Teams of two to three members each will collect and interpret geothermal data in order to design an infographic that tells a compelling story about the future of geothermal energy. For the 2016 Challenge, GTO and its partners selected the theme, "What is the Future of Geothermal Energy? How Will It Impact You?"

The competition launched December 16, 2015, and will accept applications until March 1, 2016. The winning teams in each category will receive $2,500. The grand prize winner will receive $2,500 and a trip to the Geothermal Resource Council 40th Annual Meeting on October 23–26, 2016, in Sacramento, California, to showcase their designs.



GTO's Enhanced Geothermal Systems Program Manager, Lauren Boyd, presented at the GRC Conference Opening Session, sharing an overview of the GTO current outlook, as well as DOE funding opportunities and highlights from the U.S. Environmental Protection Agency's clean power plan. The plan demonstrates true commitment across government and from the Administration to promote and facilitate clean energy technology development. The presentation can be found on the GTO website at: energy.gov/eere/geothermal/presentations

GTO Honored for Inroads in Geothermal Energy

GTO R&D investments garnered five awards at the Geothermal Energy Association's National Geothermal Summit on June 3, 2015. The GTO awards were recognized amidst a celebrated list of 12 sector trailblazers and industry standouts, including Ormat Technologies, Enel Green Power of North America, and Cyrq Energy. The 2015 GEA Honors mentioned four GTO-funded awards managed by DOE national laboratories for their transformative work in diminishing the risks of geothermal energy adoption.

Further, GEA honored Ernie Majer from LBNL for his efforts to advance the understanding of induced seismicity in EGS systems. Majer's instrumental work with the Energy Department on a novel seismicity protocol—recognized as a best practice by the National Academy of Sciences—set the standard in the subsurface community for safe and responsible drilling. His body of research continues to help geothermal scientists monitor the behavior and benefits of microseismicity in EGS.

Thomas Edmunds and Pedro Sotorrio, from LLNL, took home a special recognition award for advancing the understanding of flexible and ancillary geothermal services. These services will be needed to balance the renewable energy grid, along with conventional baseload power. Research published by Edmunds and Sotorrio provides a potential first look at our energy future and a critical analysis for defining the new flexible paradigm.

Dan Getman, from NREL, was honored for pioneering the Geothermal Prospector mapping tool, which provides an excellent data resource for visual exploration of geothermal resources. By drawing on tools and datasets from the GTO project portfolio and industry data, Getman's mapping capabilities enable better access to both exploration gap analysis and EGS planning.

In tandem with an Energy Department project conducted by Argonne National Laboratory (ANL) on water efficiency issues, Jordan Macknick, at NREL, was recognized for his work improving the understanding of geothermal water use in a water-constrained West.

In addition to our national laboratory partners, former director of the GTO, Douglas Hollett—now Deputy Assistant Secretary for Renewable Power at the Energy Department—was honored for his leadership and vision in support of the office. Hollett secured unprecedented support and funding to advance and grow GTO's technical portfolio with new initiatives such as FORGE, Play Fairway Analysis, and the GeoVision Study.

Geothermal Resource Council Annual Meeting

The Geothermal Resource Council (GRC) Annual Meeting is the premier gathering to discuss the latest developments in geothermal energy. The 2015 meeting and Geothermal Energy Association Expo took place from September 20–23, 2015, in Reno, Nevada, and attracted more than 1,400 participants from 39 countries and six continents. The GRC meeting offered technical, policy, and market conference sessions, educational seminars, and tours of geothermal and renewable energy projects.

Also at this year's GRC Annual Meeting and GEA Expo, GTO staff were awarded "Best in Show for Educational Materials" for their new, attractive infographics and accompanying first-class guide to agency programs. The dynamic booth provided up-to-date information on GTO's latest projects and was staffed by their knowledgeable subject matter experts.

EERE Releases a 2016-2020 Strategic Plan

In December 2015, EERE released its *2016-2020 Strategic Plan and Implementing Framework*. The report is a blueprint for promoting the nation's leadership in the global clean energy economy. The document will guide the organization over a five-year period, building on decades of progress in developing clean, affordable, and secure energy. Through its renewable power portfolio, EERE seeks to explore opportunities and challenges involved with making geothermal power generation technologies directly cost competitive with conventional sources of electricity, and address the wide range of related market issues to facilitate nation-wide technology deployment.

Plan highlights include:

- Seven strategic goal sections aligned with EERE's core technology sectors and crosscutting areas
- EERE's Investment Approach and Core Questions to prioritize work and deliver value
- Success indicators to ensure EERE stays on track or adjusts its strategies as needed
- Continued efforts to leverage partnerships with industry, national laboratories, and other agencies to conduct demonstrations of next-generation renewable energy technologies, such as FORGE
- A strategy to reduce the modeled cost of geothermal power from currently undiscovered hydrothermal resources to $0.10/kWh by 2020.

The EERE Strategic Plan can be downloaded at http://energy.gov/eere/downloads/eere-strategic-plan.

GTO's Chris Richard, Josh Menger, and Elisabet Metcalfe attend the 2015 GRC Annual Meeting.

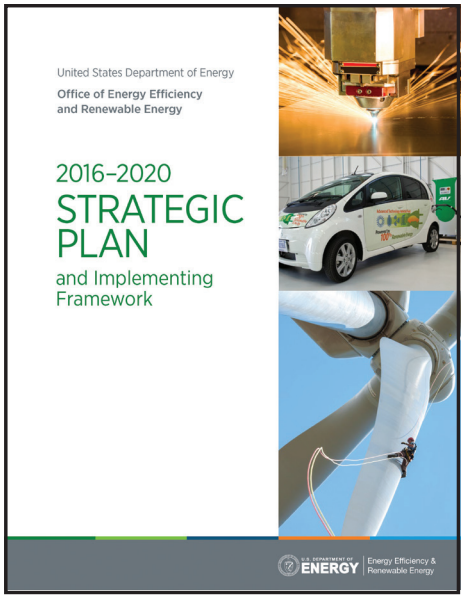
Quadrennial Technology Review

The DOE released the Department's second *Quadrennial Technology Review* (QTR) in 2015. The QTR examines the most promising research, development, demonstration, and deployment (RDD&D) opportunities across energy technologies to effectively address the nation's energy needs. Specifically, this analysis identifies critical technology RDD&D opportunities across energy supply and end use that can help facilitate development of a clean energy economy in the United States. The insight gained from this analysis provides essential information for decision-makers as they make funding decisions, and develop approaches to public-private partnerships and other strategic actions over the next five years.

Geothermal technologies are profiled in Chapter 6 of the QTR, titled "Innovating Clean Energy Technologies in Advanced Manufacturing." The QTR outlines four opportunities in geothermal:

- Develop advanced remote resource characterization tools to identify geothermal opportunities without surface expression
- Achieve purposeful control of subsurface fracturing and flow
- Improve and lower $/MW subsurface access technologies
- Develop mineral recovery and hybrid systems to provide second stream of value

The QTR was written in response to a 2010 recommendation by the President's Council of Advisors on Science and Technology, which advised DOE to regularly complete technology reviews. Geothermal resources currently provide cost-competitive, low-carbon, and firm, but flexible, power generation in specific geographical regions. Removing technical barriers will promote increased capacity in these geographies with improved reservoir management tools and broaden the geographic footprint of geothermal power generation. The rapidly evolving nature of energy technology and scientific capability to address these challenges demands rigorous analysis to inform DOE's strategic decisions—a need that the QTR helps address.



GTO's Arlene Anderson Appointed IEA Direct Use Annex POC

GTO's Arlene Anderson was appointed to serve on the International Energy Agency (IEA) – Geothermal Implementing Agreement (GIA) Direct Use Annex VIII. This group is tasked with planning expanded roles for direct use of geothermal energy. In her new assignment, Arlene prepared a presentation detailing GTO's assessment of DDU and other GTO priorities, which was provided to attendees at the 2015 IEA Geothermal Workshop on "New Concepts – New and Innovative Applications of Geothermal Energy." Participating countries include Canada, France, Germany, Iceland, Japan, New Zealand, Republic of Korea, Switzerland, United Kingdom, and the United States.

Hellos

Susan Hamm
GTO welcomes Dr. Susan Hamm as its new acting Office Director. In this role, Dr. Hamm will lead the office's initiatives to accelerate geothermal development in the United States, as well as manage GTO's participation in the SubTER Crosscut Initiative. Dr. Hamm is on detail from the National Science Foundation (NSF), where she served as the Directorate Operations Officer for Mathematical and Physical Sciences. Prior to NSF, she worked at the U.S. Department of Homeland Security in the Science and Technology Directorate, advocated with professional science societies, and served as a legislative assistant on Capitol Hill. She holds a bachelor's degree in Geology from Amherst College, a master's degree in Geophysics, and a doctorate in Material Sciences from the University of Minnesota.

Zach Frone
Zach joined GTO's EGS Program as an ORISE Science and Technology Policy Fellow in September 2015 after completing his Ph.D. at Southern Methodist University (SMU). His dissertation was titled "Heat Flow, Thermal Modeling and Whole Rock Geochemistry of Newberry Volcano Oregon and Heat Flow Modeling of the Appalachian Basin, West Virginia." The paper focused on geochemistry data from borehole cores and cutting from Newberry Volcano, and heat conduction modeling to estimate the size of intrusive bodies at Newberry and to evaluate heat flow within the Appalachian Basin of West Virginia. The goal of his work at Newberry was to characterize the stratigraphy, structure, and thermal resource present at both locations. While at SMU, he also worked on event relocation and analysis of earthquake sequences around the Dallas-Ft. Worth area.

Shane Harper
Shane Harper is GTO's Operations Manager, a new role in the office. Shane is responsible for leading and coordinating budget activities and will also be heavily engaged with all business operations, as well as international engagement. Prior to assuming his present role, Shane was located in DOE's Office of International Affairs, where his responsibilities included budget, procurement, policy development, and energy market analysis to support U.S. energy policy and security objectives in the Russian, Eurasian, African, and Middle Eastern regions. Prior to joining DOE, Shane was a member of the U.S. Air Force for ten years, serving in countries throughout the world, including Qatar, Kuwait, Germany, and Iraq.

Matt Kalmuk
Matt Kalmuk joins GTO as the new Operations Supervisor. Matt is responsible for overseeing and managing all business processes in the office, including budget, contracts, communications, legislative engagement, and Annual Operating Plan (AOP) development with the national laboratories. Matt previously supported business operations in EERE's Wind and Water Power Technologies Office.

Kevin McCarthy
Kevin joined GTO as an ORISE Science and Technology Policy Fellow in August 2015. Kevin spent the last several years working in the oil and gas industry for companies such as Schlumberger, BP, and Hess in various locations from Calgary to Houston. While in Canada, he provided research and technical support to clients for all geochemical issues related to heavy oil. In Houston, Kevin modelled unconventional shale petroleum systems in multiple basins across the United States. He graduated from the University of South Florida, where his dissertation focused on the geochemistry of shallow hydrothermal vent systems.

Erin Tulley
Erin Tulley joined GTO in fall 2015 as the Communications Lead, a contracted role with The Hannon Group. Erin has wide-ranging experience within the environmental field, including fieldwork, policy and scientific research, climate change advocacy, and renewable energy research. Prior to her current role, she worked for several non-profits, contributing to climate change campaigns and communications efforts. Most recently, Erin worked as a Communications and Outreach Fellow, a position in which she organized media, social media, and general public knowledge efforts for various environmental campaigns. Erin has a graduate degree in Conservation Biology and greatly enjoys educating and advocating for renewable power.

Goodbyes

Margaret Schaus
After three years as Operations Supervisor for GTO, Margaret will transition to a new role in EERE— Senior Advisor to the Deputy Assistant Secretary for Renewable Power. She looks forward to continued engagement with the Geothermal Technologies Office and the geothermal sector in this role.

Sharon Cosgrove
A fond farewell to Sharon, who helmed GTO Communications—and myriad green lights, success stories, web blasts, graphics, and blogs—along the way! Sharon served as Communications Lead for the office for three years, initiating creative products such as booth design, annual report, and vivid collateral and web content to amplify geothermal. In spring 2015, Sharon transitioned to the EERE Communications Office, where she writes and designs products on energy efficiency and renewable power.

Acronyms

ANL	Argonne National Laboratory
AOP	Annual Operating Plan
ARPA-E	Advanced Research Projects Agency - Energy
ARRA	American Recovery and Reinvestment Act of 2009 (Recovery Act)
BNL	Brookhaven National Laboratory
CaP	Calcium Aluminate Phosphate
CO_2	Carbon Dioxide
CRADA	Cooperative Research and Development Agreement
CSP	Concentrating Solar Power
DDU	Deep Direct Use
DOE	U.S. Department of Energy
DTH	Down The Hole
DTS	Distributed Temperature Sensor
FO	Forward Osmosis
GDR	Geothermal Data Repository (DOE's node on the NGDS)
EERE	Office of Energy Efficiency and Renewable Energy
EGS	Enhanced Geothermal System
FERC	Federal Energy Regulatory Commission
FOA	Funding Opportunity Announcement
FORGE	Frontier Observatory for Research in Geothermal Energy
FY	Fiscal Year (October 1 through September 30)
GEA	Geothermal Energy Association (industry association)
GHG	Greenhouse Gas
GHP	Geothermal Heat Pump
GPM	Gallons Per Minute
GRC	Geothermal Resources Council (industry association)
GSA	Geological Society of America (industry association)
GSHP	Ground Source Heat Pump
GTO	Geothermal Technologies Office
GW	Gigawatt
GWe	Gigawatt (electric)
INL	Idaho National Laboratory
JASON	A renowned group of scientists that performs independent analysis
kW	Kilowatt

Acronyms

DOE's EGS Demonstration at The Geysers in California was the first in the nation to prove a commercial scale 5 MW equivalent of steam. Source: Calpine Corporation

kWh	Kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
LCOE	Levelized Cost of Electricity
MD	Membrane Distillation
MW	Megawatt
MWe	Megawatt (electric)
MWh	Megawatt-hour
MOU	Memorandum of Understanding
NETL	National Energy Technology Laboratory
NGDS	National Geothermal Data System
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
ORISE	Oak Ridge Institute for Science and Education (DOE institute)
ORNL	Oak Ridge National Laboratory
PI	Principal Investigator
PLA	Play Fairway Analysis
PNNL	Pacific Northwest National Laboratory
QTR	Quadrennial Technology Review
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RDD&D	Research, Development, Demonstration, and Deployment
RFI	Request for Information
SALT	Systems Analysis and Low Temperature
SBIR	Small Business Innovation Research
SBV	Small Business Vouchers
SNL	Sandia National Laboratory
SPS	Switchable Polarity Solvent
STTR	Small Business Technology Transfer
SubTER	Subsurface Technology and Engineering Research, Development, and Demonstration (crosscutting initiative at DOE)
T2M	Tech to Market

Resources

GTO makes the following tools and resources available for free and public use. Click on the links below to learn more about these resources.

Reports

- **EERE Strategic Plan**—A blueprint for promoting the nation's leadershiop in the global clean energy economy: energy.gov/eere/downloads/eere-strategic-plan
- **EGS Roadmap**—A technology roadmap for strategic development of enhanced geothermal systems: eere.energy.gov/geothermal/pdfs/stanford_egs_technical_roadmap2013.pdf
- **Exploration Roadmap**—A roadmap for strategic development of geothermal exploration technologies: geothermal.energy.gov/pdfs/exploration_technical_roadmap2013.pdf
- **Low-Temperature, Coproduced, and Geopressured Geothermal Technologies Peer Review Presentations**—Complete collection of technical presentations from GTO's 2015 Peer Review: energy.gov/eere/geothermal/2015-peer-review-presentations-geothermal-energy
- **Geothermal Technologies Market Trends Report**—An updated snapshot of the geothermal market: energy.gov/geothermal/pdfs/market-report2013.pdf
- **GTO 2015 Peer Review Technical Report**—Comprehensive final report summarizing GTO's 2015 Peer Review: energy.gov/eere/geothermal/downloads/2015-peer-review-report-geothermal-technologies-office
- **Latest GTO presentations**: energy.gov/eere/geothermal/presentations
- **JASON Study on EGS**—A report conducted by the JASON group on EGS: eere.energy.gov/geothermal/pdfs/jason.final.pdf
- **JASON Study on Subsurface Technologies**—Findings from a study on subsurface technologies: energy.gov/articles/2014-jason-report-state-stress-engineered-subsurface-systems
- **Quadrennial Technology Review (QTR)**—energy.gov/quadrennial-technology-review-2015

Tools

- **Geothermal Prospector**—A mapping tool developed for the Geothermal Power industry. This tool is designed to help developers site large-scale geothermal plants by providing easy access to geothermal resource datasets and other data relevant to utility-scale geothermal power projects: nrel.gov/gt_prospector
- **Geothermal Regulatory Roadmap**—A centralized information resource on the permitting processes for geothermal development in Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, and Texas: en.openei.org/wiki/RAPID/Roadmap/Geo
- **The Geothermal Electricity Technology Evaluation Model (GETEM)**—A detailed model of the estimated performance and costs of currently available U.S. geothermal power systems: geothermal.energy.gov/geothermal_tools.html
- **The Jobs and Economic Development Impact (JEDI) Geothermal Model**—Allows users to estimate project costs and direct economic impacts for both hydrothermal and EGS power generation projects based on exploration and drilling activities, power plant construction, and ongoing operations: nrel.gov/analysis/jedi/about_jedi_geothermal.html
- **National Geothermal Data System**— geothermaldata.org
- **SubTER Twitter**—@SubTERCrosscut
- **SubTER LinkedIn**—linkedin.com/groups/7017263
- **SubTER websites**—subter.lbl.gov and energy.gov/subsurface-tech-team-subter

Find answers to the most frequently asked questions and more resources at http://energy.gov/eere/geothermal/geothermal-basics

Hot springs, Coso, CA

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

2015 Annual Report Geothermal Technologies Office

The 2015 Annual Report of the Geothermal Technologies Office is a product of the United States Department of Energy, Office of Energy Efficiency and Renewable Energy.

DOE/EERE-1160 • April 2016
This report spans calendar year 2015 achievements.
Photographs are accredited herein.