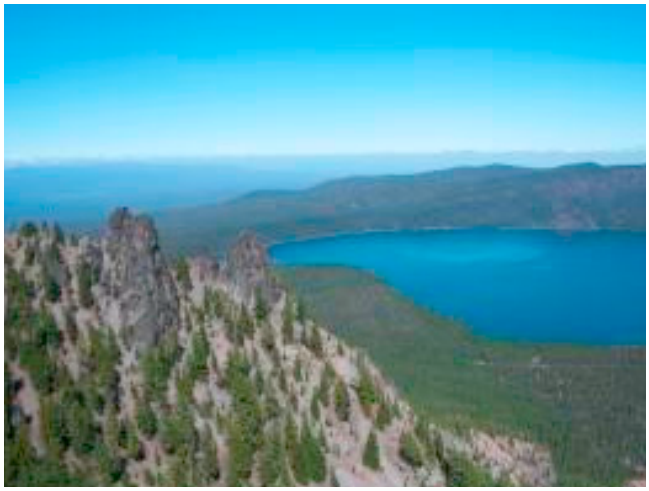
Annual Report 2012

YEAR IN REVIEW



GEOTHERMAL TECHNOLOGIES OFFICE

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

Contents

Program Updates

www.geothermal.energy.gov / email **geothermal@ee.doe.gov**

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The Geothermal Technologies Office Annual Report spans
Fiscal Year (FY) 12: October 1, 2011 through September 30, 2012

For more information about the Geothermal Technologies Office, visit www. geothermal. energy.gov.

Message from the Director

Douglas Hollett
Director, Geothermal Technologies Office

Year in Review

This is our first Annual Report in many years, and it marks an important milestone for both the Geothermal Technologies Office (GTO) and for DOE, as we work to advance the broader deployment of geothermal energy in the United States. Through our research and development portfolio of over 200 projects, we partner with industry, academia, and our national laboratories to research, develop, and demonstrate innovative technologies that will lower both risk and costs for the geothermal sector. In 2012, the United States met the administration goal of doubling renewable energy generation from 2008 levels, and GTO is proud to have played a key role in advancing this achievement.

Our focus is on those geothermal technologies that can have a significant and measureable impact in facilitating the growth of installed electrical generation capacity. Our priorities include low-temperature and co-produced resources for the near to intermediate term, identifying new hydrothermal resources and lowering the cost and risk of developing these opportunities, and advancing Enhanced Geothermal Systems (EGS) for the longer term. We are also committed to addressing critical non-technical and market barriers.

This past year has seen key achievements within the Office's portfolio. There is our first EGS demonstration success at the Geysers Field in California, the discovery of significant new hydrothermal resources, and key technology advances which impact both EGS and Hydrothermal systems. The extraction of strategic materials such as lithium from geothermal brines is close to becoming a commercial reality. The Regulatory Roadmap project, a collaborative effort with many state and federal partners, also received strong support from industry and continues to move us towards the goal of optimizing geothermal timelines. Finally, we saw the rapid advancement of the National Geothermal Data System (NGDS), which is an extraordinary example of the power and impact of making technical data more broadly available.

The year also saw a number of personnel changes as we both added staff and bid farewell to colleagues. Josh Mengers and Dan King joined as PMF and AAAS Fellows, respectively. Greg Stillman left for a temporary detail at Sandia National Lab, and will return in early 2013. The Hydrothermal Program Supervisor, Hidda Thorsteinsson, moved on in December to take an executive position as Director of R&D with the utility in Reykjavik, Iceland, and while she will be missed, we're very proud to have helped advance her career. Eric Hass, previously EGS Supervisor, has replaced Hidda, and Lauren Boyd is now the Acting EGS Supervisor. Jay Nathwani, previously Systems Analysis Supervisor, will be moving to a new responsibility as Chief Engineer for the Office. Margaret Schaus joined as our new Operations Supervisor and will ensure that the Office is more efficient and streamlined. GTO also added a number of excellent contract staff in key areas. Finally, Caroline Mann has joined the team on detail and is working on NEPA and regulatory issues. Further, we have now posted for a series of full-time positions and look forward to adding skilled professionals in the near future.

In this 2012 Annual Report, you will find a round-up of the Office's key activities and accomplishments spanning the fiscal year. Special thanks to our partners at the national labs, in academia, and in the private sector, whose efforts and innovation are foundational to sector growth. By pushing technical boundaries, they strive to make geothermal an economically competitive, major contributor to the nation's energy portfolio.

A Look Ahead

What lies ahead in the coming year? We look forward to successful deployment of several binary units into working oil and gas field operations, to better illustrate the technical and operating conditions where this is economically attractive. We expect to see groundbreaking for the first lithium-from-geothermal plant in California; more exciting results in our EGS demos and R&D; initial output from the geo-thermal play fairway analysis; and major progress on our EGS test project initiative, which will be the key program component in making EGS a large-scale reality. Since these successes will rely on your collective efforts, I look forward to a fun, collaborative, and productive 2013 working with you.

Sincerely,

PROGRAM HIGHLIGHTS

Hydrothermal

The Geysers, courtesy of Calpine Corporation

US Leads the World in Geothermal Production

The Geysers geothermal field in northern California is the largest complex of geothermal power plants in the world, generating about 875 MW of electricity to the national grid—enough to power about 875,000 homes.

Research & Development Kick-offs

The Geothermal Technologies Office (GTO) started FY12 by kicking off 14 research and development (R&D) projects focused on novel geochemical and geophysical methods. The projects have progressed well this year, and many will reach the end of Phase 1 in early FY13. These projects are working on important advancements in geothermometry, joint inversion, drilling systems, remote sensing, and seismic techniques that will help lower upfront exploration risk in geothermal development.

Exploration Analysis

A significant amount of information on exploration techniques, geothermal regions, and related publications has been made available through the National Renewable Energy Laboratory's (NREL) OpenEI website, **http://en.openei.org/wiki/Gateway:Geothermal**. The OpenEI system is a wiki-based platform that allows users to view, edit, and add their own information and download data for free. Visitors to the geothermal gateway on OpenEI can now look up geothermal regions and see what exploration techniques have been used there. The database also includes resource estimates for each area based on the United States Geological Survey's (USGS) 2008 assessment. NREL will continue to upgrade the website in 2013 to further enhance the user experience. GTO anticipates that the geothermal gateway on OpenEI will prove to be a valuable tool for the geothermal community going forward.

Play Fairway Mapping

Play fairway mapping is a common and extremely useful tool in the oil and gas industry to find candidate sites for exploration. The methodology reduces risk by integrating geologic and technical factors to identify areas that are more highly prospective for certain types of resource. Since exploration risk remains a major barrier to furthering geothermal development in the United States, developing an analogous geothermal analysis tool along with initial play fairway mapping for high-potential regions will be a major step in reducing that risk.

In FY12, the hydrothermal program initiated the geothermal play fairway effort. A data gap analysis was performed for the western United States with the help of NREL. Data coverage maps were created using current and pending data from the National Geothermal Data System (NGDS), as well as industry, university, laboratory, and agency personnel. The maps were compared with USGS resource potential maps to identify high potential geothermal areas where critical data are needed. The program is also reviewing current literature on geothermal occurrence models—characteristics that together imply favorable heat flow, fluid flow, and permeability—and looking to apply those occurrence models in play fairway analysis. Data gap analysis and the program's review of geothermal occurrence models will be presented at the Stanford Geothermal Workshop in February 2013. The geothermal play fairway analysis work is expected to be completed in FY14.

Drilling Technologies

DOE invests in innovative drilling technologies with the goal of increasing their productivity and efficiency—and ultimately lowering the cost of drilling.

New Capacity Added

In FY12, DOE investments yielded approximately 25 MW of additional nameplate capacity and identified an additional 57 MW of new resources. Geothermal accounts for 3,187 MW or about 2% of the installed renewable energy nationwide.

Exploration Technologies

Through funding provided by the American Recovery and Reinvestment Act (ARRA) of 2009, GTO funded 24 innovative exploration projects designed to validate novel techniques and confirm 400 MW of new geothermal resources by 2014. In FY12, six projects successfully drilled exploration wells, and nearly half of all projects successfully deployed innovative resource characterization techniques, including vertical seismic profiling, soil gas surveys, and LiDAR remote sensing. To date, DOE investments have identified a total of 170 MW and drilled over 20 wells across California, Nevada, and Idaho. The effort is ongoing with eight more projects expected to drill in 2013-14.

Navy Collaboration

GTO previously signed an agreement with the Defense Department (DoD) to accelerate activities that further geothermal development in the United States. Since then, the Navy Geothermal Program Office and Department of Energy (DOE) are working to share data, technologies, expertise, and resources and identify opportunities to test new techniques and technologies while concurrently advancing the goals of renewable energy deployment and energy security on DoD lands. In FY12, the Navy and DOE conducted a joint site visit to DoD lands, and an in-depth analysis is underway to identify potential Navy sites for research, development, and demonstration activities.

Small Beginning for Something Big

The Surprise Valley Electrification Corporation (SVEC) project has developed a geothermal resource to benefit the Surprise Valley Electric member-owners and promote the creation of cascaded businesses and benefits within the community. SVEC is establishing a replicable model that other Rural Electric Cooperatives (RECs) can follow to develop small geothermal resources in their service territories. The project, funded by a GTO ARRA award in 2009, will develop geothermal electric power from a producing low-temperature resource located on an operating ranch. A feasibility assessment concluded that the resource was viable for both electric production and aquaculture operations. In 2012, all significant subsurface work was completed and a third injection well drilled. Based on fluid rates and temperatures, the site is estimated to produce 3.1 MW with an estimated plant life of 20 years, an encouraging find that may prove to be the catalyst for a much bigger development of small, low-temperature resources throughout the region.

Stillwater Geothermal Power Plant, courtesy Enel Green Power

PROGRAM HIGHLIGHTS

Hydrothermal

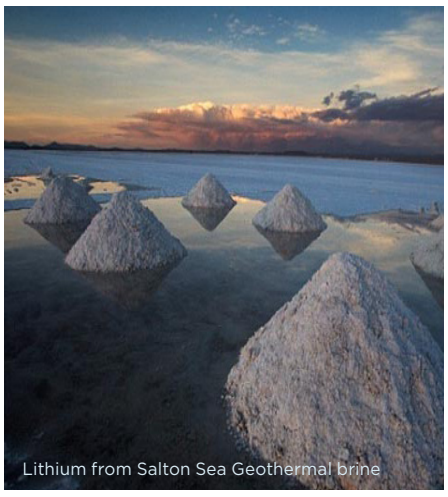
Drilling at the Geysers Field in Northern California, courtesy of Calpine Corporation

Game-Changing Discoveries for Working Fluids

Seven projects in the GTO portfolio currently focus on research and development of new and innovative geothermal working fluid technologies. The majority of these projects were funded by the American Recovery and Reinvestment Act beginning in 2009, so they are nearing the final, detailed analysis of their work. Among these, Pacific Northwest National Laboratory's (PNNL) research with Metal Organic Heat Carriers (MOHCs) deserves special mention. PNNL developed a new type of biphasic working fluid for subcritical geothermal systems. While microporous metal-organic solids are the primary heat carrier and heat transfer medium to support Organic Rankine Cycle (ORC) technology in all types of geothermal systems, this game-changer would substantially increase efficiency—up to 15% with a 40-day payback—at very low cost if it proves successful. Plant efficiencies would in turn increase geothermal power output.

Batteries from Geothermal Brine

Partnering with Simbol Materials, the GTO is pursuing development of mineral extraction technologies with the potential to power 300,000–600,000 electric vehicles per year from their plants. DOE support enabled the company to build the first demonstration facility and co-produce materials like lithium, manganese, and zinc from geothermal brines during the power production process. Simbol estimates that 50 MW in this mineral-rich region could also supply enough lithium to produce the vehicle batteries.



Lithium from Salton Sea Geothermal brine

Co-production Relocation Project—Strategic Initiative with Oil and Gas

In FY 2012, GTO launched a strategic initiative to further engage the oil and gas (O&G) sector in geothermal energy production. Co-production of geothermal fluids with O&G to generate electricity can have attractive economics under the right conditions: a levelized cost of electricity (LCOE) potential of $0.06/kWh and an incredibly large market, with a resource base estimated at 3,000 MW. In addition, co-produced geothermal resources deliver near-term energy savings, diminish greenhouse gas emissions, and extend the economic life of oil and gas fields by profitably utilizing O&G infrastructure.

However, this promising potential has not become fully commercial. The Rocky Mountain Oilfield Testing Center (RMOTC) in Wyoming was one of the first projects to validate the use of co-produced geothermal fluids from oil and gas wells, using binary ORC units. Based on that success, GTO is now exploring industry partnerships to deploy these binary units to new O&G fields. The objective of the RMOTC Relocation Project is to reduce the risk associated with co-production by collecting detailed data on operating geothermal systems installed in commercial oil and/or gas fields. Performance and site data such as flow rate, temperature, and even weather will be collected. The goal of data collection will be to significantly reduce cost and performance uncertainty, and in so doing, lower the barrier for market uptake. The current plan is to have the units shipped, installed, and commissioned at their new commercial sites by mid-year 2013.

The Green Machine, courtesy of Electratherm

Big Geothermal Potential in a Small Package

Heat from geothermal fluids at the Florida Canyon mine in Northern Nevada—once an unused byproduct of gold mining—will be generating up to 70 kW of electric power this year for $0.06–$0.08/kWh, thanks to an investment by DOE. DOE awarded ElectraTherm of Reno, Nevada, approximately $1 million to refine its patented technology for geothermal applications after ElectraTherm's "Green Machine"—a modular low-temperature heat-to-power generator—has proven itself at recovering heat from other sources: engine coolant, solar thermal, and biomass applications. Now, thanks to DOE support, the company is on schedule to complete this geothermal demonstration next year. The new prototype adds corrosion-resistant alloys and cleanable heat exchangers, specifically optimized for geothermal fluids; and a rugged, weather-proof shipping container-based enclosure, intended for plug-and-play deployment wherever low-temperature geothermal fluids are available.

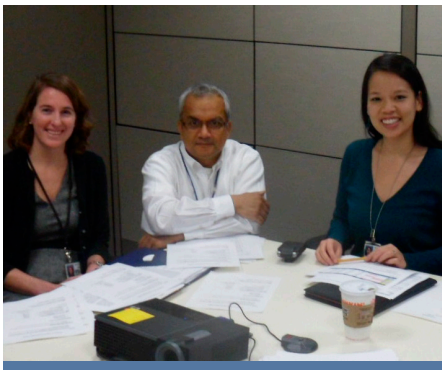
The Florida Canyon project is the first installation of ElectraTherm technology at a mining operation. Through funding from GTO, this small-scale heat-to-power technology has been adapted and refined for geothermal use and will provide a replicable model for future distributed geothermal generation applications domestically and abroad. President Obama visited ElectraTherm in 2011 to showcase green technologies and reinforce America's investment in research that can reduce our nation's dependence on fossil fuels.

The Green Machine's optimized control software enables unattended operation through remote control tuning, software downloading, startup, shutdown, and 24/7 data collection. Successful operation of such a small geothermal plant, on what was previously sub-commercial temperature and flow-rate resource, brings for the first time a distributed generation capability to geothermal power. While the individual output from the Green Machine is relatively small, the collective potential for a fleet of such machines, recovering waste heat at existing wells, is vast: according to the National Renewable Energy Laboratory, there are over 80,000 active wells producing between 176-257°F in the United States today.

ElectraTherm is a renewable energy company headquartered in Reno, Nevada. The company was founded in 2005 and utilizes a proven, patented Twin Screw Expander technology to make electricity out of low-temperature heat that would otherwise go to waste. The Green Machine's international fleet has surpassed 50,000 aggregate hours, as of December 2012.


GTO Team members Ben Phillips, LaShawn Foster, and Alethia Marble gather for a team meeting.

Brittany Segneri and Bill Vandermeer represent the GTO at a geothermal exhibit.


Caroline Mann, on detail with the GTO, meets with Jay Nathwani and Margaret Schaus.

PROGRAM HIGHLIGHTS

Enhanced Geothermal Systems Demonstrations

EGS 101

Enhanced Geothermal Systems (EGS) are man-made reservoirs, created where there is hot rock but insufficient or little natural permeability or fluid saturation. In an EGS project, fluid is injected into the subsurface under carefully controlled conditions, which cause pre-existing fractures to re-open. Increased permeability allows fluid to circulate throughout the now-fractured rock and to transport heat to the surface via a production well where electricity can be generated. While advanced EGS technologies are young and still under development, EGS has been successfully realized on a pilot scale in Europe and now at a new DOE-funded demonstration project at The Geysers.

AltaRock

The AltaRock EGS demonstration project, at Newberry Volcano near Bend, Oregon, represents a key step in geothermal energy development: demonstrating that an engineered geothermal reservoir can be developed at a greenfield site. The concept behind heat extraction from EGS is similar to that of a radiator: cold water is heated by circulating it through a very hot substrate—in this case, cracks in hot rocks more than 6,000 feet below the surface that are created or extended via fluid injection. The heated water is brought to the surface, converted to electricity, and then re-injected at depth. The AltaRock Project represents the largest cost share in the Geothermal Technologies Office, with a DOE commitment of $21.4 million towards the $44 million demonstration project total.

Drilling at Newberry

Newberry Volcano is now the site of an EGS Demonstration project. Stimulation is currently underway.

The project is currently testing various innovative technologies to create an EGS reservoir by injecting cold fluid into the subsurface at pressure. The project will utilize diverter technologies to temporarily plug zones of fluid loss so that new fractures can be reopened and extended, ultimately facilitating the availability of a larger rock volume for heat extraction from a single well. These unique diverters are comprised of non-toxic, biodegradable materials or naturally occurring minerals that temporarily seal fractures and eventually dissolve with time and heat.

2012 was an important year at Newberry. In late 2011 and early 2012, DOE engaged with the Forest Service and Bureau of Land Management (BLM) during the environmental review—or NEPA process—to identify potential environmental impacts and assist with technical evaluations of these impacts. Such early collaboration and technical assistance reduced the permitting time by avoiding surprises and ensuring that agencies had sufficient information to conduct a thorough review. After a rigorous assessment of the environmental impacts and active inter-agency coordination, BLM and DOE issued separate "Findings of No Significant Impact" on April 5, 2012. Further, early in 2012, AltaRock broke ground to install permanent seismic monitoring sensors that track the evolution of the reservoir and ensure pre-established safe limits on seismicity.

Following NEPA approval, AltaRock began to prepare the well pad for stimulation operations by deploying pumps, tanks and pipelines and finalizing operational plans. Stimulation is currently underway.

courtesy of the Geothermal Resources Council

The Geysers

Previously using cost share from the Geothermal Technologies Office, Calpine Corporation's EGS demonstration in Middletown, California completed a full year of stimulation in 2012, generating 5 MW equivalent steam from an abandoned well at the largest geothermal complex in the world. As one of six DOE-funded EGS demonstrations nationwide, Calpine is the first to complete a successful demonstration. A new power plant is in the works to accommodate new capacity from this and other wells in the northwest part of the field. The EGS demonstration at The Geysers took place in a distinct "high-temperature zone," defined by a high temperature steam reservoir and lower permeability at depth. In conjunction with the proximity to existing infrastructure, the project should result in a highly competitive levelized cost of electricity for geothermal energy. The implications of the success achieved to date at The Geysers are far reaching. Because of existing infrastructure and plant capacity, the ability to develop EGS reservoirs on the margins of existing hydrothermal fields adds to field productivity at a relatively low cost and in the short time frame.

Bradys

At the Bradys field EGS demonstration site in Nevada, Ormat is working to improve the injectivity of well 15-12 to commercial levels and to ensure a robust hydraulic connection between this well and the rest of the producing field. To this end, Ormat submitted a detailed plan for the planned stimulation phase of their project as part of their Phase II Stage Gate. The project was approved to move forward into Phase II after technical review by a panel of experts in 2012. Following approval of the stimulation plan, hydraulic stimulation of the target well using EGS technology will take place in 2013. Should the project prove successful, it would encourage future utilization of EGS well stimulations to improve the flow characteristics of non- or sub-commercial wells to the levels of commercial production or injection wells, providing domestic, renewable, baseload energy.

DOE and BLM have also collaborated on environmental permitting efforts. The Bradys Environmental Assessment completed its public comment period on the BLM website in December 2012.

Raft River

At the Raft River geothermal field in Idaho, the University of Utah is developing and demonstrating the techniques required to create and sustain EGS reservoirs, including thermal and hydraulic stimulation, with the ultimate goal of improving the overall performance and output of the field. The University of Utah successfully completed well rework operations at US Geothermal's Raft River field in March 2012. This sets the stage for the thermal and hydraulic stimulation of the target well and ultimately, demonstration of the technical viability of EGS technology at this site. Like the Bradys field demonstration, if proven to be successful, it would encourage future utilization of EGS well stimulations to improve the flow characteristics of non- or sub-commercial wells, to the levels of commercial production or injection wells. The Stage Gate Review was held on November 6, 2012. Pending clarification of certain technical details, a Go/No Go decision will be reached in January 2013, and Phase II activities would begin in February 2013.

Next Generation Technology Today

The resource capacity of EGS represents an incredible 100+ GW of potential energy in the US alone.

PROGRAM HIGHLIGHTS

Enhanced Geothermal Systems R&D

FY12 EGS R&D Success Stories

In FY12, several R&D successes were realized, both from historical (FY08) and newer (FY11) projects. An award that GTO made to Baker Hughes in FY08 to develop an acoustic televiewer to map fractures in well-bores has yielded a prototype televiewer after several years of component-level development. Baker Hughes is now ready to test the prototype at high temperatures and pressures, first in a laboratory setting, and then in an actual wellbore. Efforts are underway to conduct a side-by-side comparison of the newly developed, advanced Baker Hughes televiewer with existing wellbore characterization tools.

More recently, CleanTech Innovations, LLC completed Phase I proof-of-concept work on a Silica Polymer Initiator (SPI) gel formulated to withstand the high temperatures and pressures found within geothermal reservoirs. The gel would act as a chemical diverter capable of temporarily blocking off fractures within a wellbore to achieve the conditions necessary for multi-stage, zonally isolated stimulations. Multistage stimulations via zonal isolation represent a significant advance in EGS technology from the traditional single-zone hydraulic and/or chemical stimulation techniques. Following Phase I, CleanTech has identified a handful of gel formulations that withstand both the high-temperature and high-pressure conditions found within a geothermal reservoir.

Remodeled Geothermal Visitors Center Showcases Next Generation Technology

Calpine re-opened The Geysers Geothermal Visitor Center in Middletown, California, on August 30, 2012, featuring a remodeled building and new geothermal technologies exhibits for public education and outreach. The updated exhibit includes a history of The Geysers, geology and tectonics of geothermal systems, and technologies used in geothermal drilling and reservoir development. In addition, the exhibit highlights the role of reclaimed water in sustaining steam production. DOE and Calpine shared the cost of this renovation as part of the Northwest Geysers EGS Demonstration Project.

To address high temperature electronics needs, GE Global Research, GE Energy, and Auburn University are developing a novel platform of electronics technologies that can operate at 300°C. These technologies will enable down-hole measurement of temperature, flow, pressure, and other well properties. Three key technologies have been the focus of this study: silicon carbide (SiC)-based active components; high temperature packaging technology; and integrated temperature sensor and electronics, all of which can operate at 300°C.

Supported by GTO, the GE-led team recently developed a semiconductor fabrication process for SiC devices and integrated circuits (ICs) for high temperature telemetry applications. The research team also demonstrated a SiC frequency counter board with more than 500 hours of stable operation at 300°C. The circuit represents one of the most complex SiC ICs yet demonstrated, with promising stability.

The telemetry function, along with sensor-to-frequency conversion ICs, will lend itself to high-temperature tools used in harsh downhole drilling applications. The O&G community has also shown increased interest in ever higher-temperature capability, highlighting the potential synergies between the sectors.

Fracture Sustainability

Because greater reservoir volume and fracture surface area reduces thermal drawdown, the lifespan of an EGS reservoir is largely determined by how well permeability can be sustained. Through the life of a field, permeability can depend on how effectively irregularities in a fracture surface can keep the fracture propped open. To determine ideal site characteristics and the best techniques for EGS hydro-shearing, researchers at Lawrence Berkeley National Laboratory (LBNL) and Lawrence Livermore National Laboratory (LLNL) are engaging in an innovative collaboration to address issues of fracture sustainability.

The process measures the impact of asperity contact dissolution, mineral precipitation, and mineral dissolution on fracture aperture and flow path sustainability. Researchers at LBNL have designed a custom test chamber (Figure 1) to apply mechanical stress to a rock sample to open a fracture. Changes in fracture aperture are monitored by changes in the pressure needed to flow water through the cell. Some of the experiments are conducted on core samples from the GTO EGS demonstration projects (Figure 2). Data from these samples will inform ongoing operations at these sites. Separately, collaborators at LLNL are conducting mineral dissolution experiments so that reaction kinetics can be incorporated into the framework for understanding fracture sustainability.

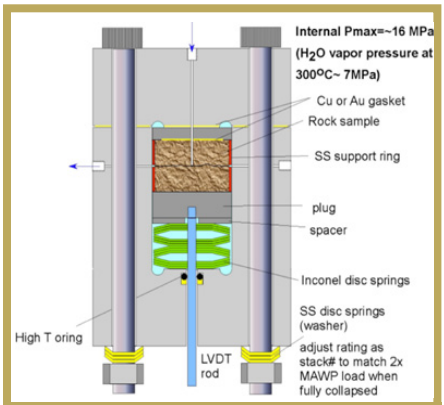


Figure 1
Test Chamber

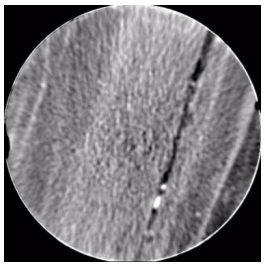
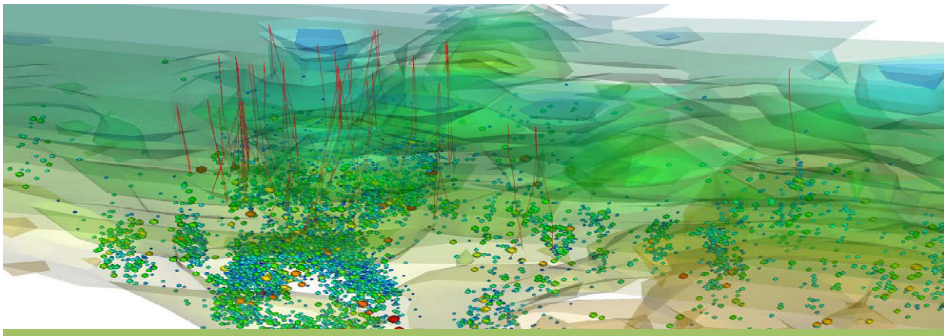


Figure 2
(above) CT Scan Showing Fracture at The Geysers (and below) Closed and Partially Open Fractures in The Geysers Prati5 Core



Induced Seismicity

Induced seismic events are generally small-magnitude earthquakes with low associated ground motion intensity that can be attributed to human activities. Induced events are thought to occur as a result of changes in pore fluid pressure or stress in the subsurface, and can occur by inducing slip on existing fractures in response to large volume fluid injection or extraction. Historically, public attention surrounding induced seismicity has been associated with various energy and industrial applications including mining, construction, waste-disposal, oil and gas production, carbon capture and storage, and geothermal development. The DOE, in collaboration with international partners and support from the geothermal community, has taken significant steps to ensure the potential hazard of induced seismicity associated with EGS is minimized, effectively managed, and communicated clearly and openly to stakeholders. Through the development of two protocols titled *Addressing Induced Seismicity* associated with EGS—the first issued by The International Energy Agency (IEA) in 2009, and the second published more recently in 2012 by DOE—the geothermal community has established an approach to address and estimate the risk associated with EGS-induced seismic events and a strategy for engaging public officials, industry, regulators, and the public to ensure safety and facilitate progress on well-designed projects. This protocol has been adopted by all DOE-funded EGS demonstration projects, five actively working in FY12.
In response to mounting public concern surrounding induced seismicity in 2010, Congress commissioned DOE to work with the National Research Council (NRC) to study the history and potential for induced seismicity from various energy technologies and identify any gaps that require further investigation. A committee was established to confer with various experts from academia, industry, and government, and engage stakeholders to understand their concerns. Findings from this report indicate that net fluid balance in the subsurface has an important effect on the amount and frequency of seismicity. In addition, geothermal systems suggested a lower risk for larger induced events, compared to other technology areas, because of reinjecting produced fluids into the reservoir. The committee recommended that critical hazard assessments be proactively performed on energy projects that involve injection or withdrawal of fluids from the subsurface. Furthermore, it was recommended that a "best practices" document be developed for each of the technologies and used by industry and government alike. The NRC cited the DOE-funded protocol as a guide for other communities to learn from and adapt—including the best practices, due out in 2013—that were developed by LBNL and collaborators.

Enhanced Geothermal Systems R&D

Code Comparison

Tim Scheibe at the Pacific Northwest National Laboratory (PNNL) is leading the GTO Code Comparison Study: a project effort for validation and improvement of numerical models capable of contributing to our understanding of the complex environments that characterize geothermal systems, where thermodynamics, hydrodynamics, rock mechanics, and chemistry all contribute vitally to system behavior across disparate length and time scales.

This year, PNNL helped lead a kick-off discussion of the effort with the Geothermal Reservoir Modeling Working Group at the GTO Peer Review Meeting. PNNL has developed a virtual collaborative platform, Velo, a wiki-based interface that serves as a framework for participant interaction and project execution (see Figure 3). This tool will facilitate discussion boards, host simulator details and problem descriptions, and ultimately serve as a repository for associated data, source codes, and other materials needed to maintain a productive geothermal modeling community.

In September, Tim joined International Partnership for Geothermal Technology (IPGT) modeling lead Rob Podgorney of Idaho National Laboratory for an IPGT Reservoir Modeling Benchmarking Workshop in Castasegna, Switzerland. There, an international group defined a set of increasingly complex benchmarks, test cases, and challenge problems that will form a starting point for a GTO Code Comparison problem set. The IPGT member countries also expressed great interest in participating in the GTO effort. By creating a community forum for model validation and improvement, forming a broad consortium of developers and their codes, and defining geothermal-specific test problems, PNNL and its partners will create a dynamic framework to support the current project objectives and ongoing needs in geothermal modeling. The effort will also ultimately help identify critical future development needs that will inform GTO investments in geothermal development.

Dan King and Elisabet Metcalfe confer with Tim Reinhardt at DOE headquarters.

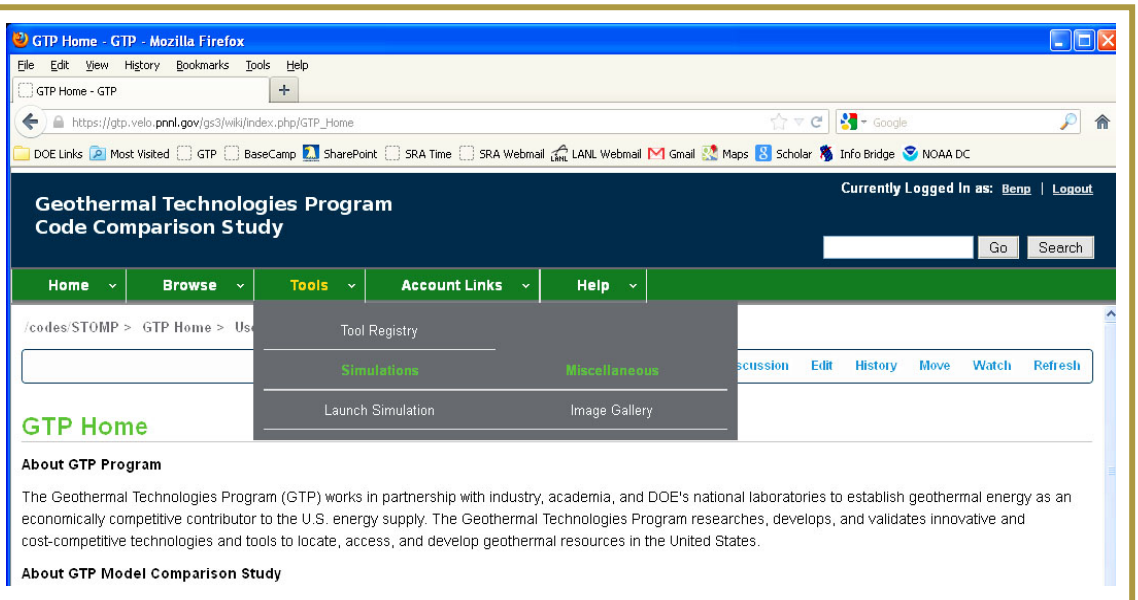


Figure 3
GTO Code Comparison Study

PROGRAM HIGHLIGHTS

Systems Analysis

Assessing Energy Production Potential

Funded by GTO through an Interagency Agreement with the US Geological Survey, the National Geothermal Resource Assessment and Classification Program assesses geothermal resource potential nationwide. Geothermal Field Studies continued, with data acquisition efforts ongoing at Warner Valley, Mono Basin, Pilgrim Springs, and northeastern Nevada. Interpretive work included definition of the areal extent of granitic plutons in the Great Basin. Hydrothermal System Life Cycle analysis included coupled heat, fluid, and chemical transport modeling, using a modified version of the numerical simulation model for chemically reactive non-isothermal flows of multiphase fluids in porous and fractured media, TOUGHREACT is used to replicate laboratory observations for permeability evolution and alteration mineralogy in fractured granite by incorporating the effects of alteration on reactive surface areas.

Jay Nathwani, Systems Analysis Supervisor, meets with Arlene Anderson, Physical Scientist, in the GTO offices.

The results have significant implications for the potential longevity of permeability in natural hydrothermal systems. Utilizing seismicity data from the Coso geothermal field, project personnel imaged subsurface geometries of active faults and developed mechanical models to predict permeability. The low-temperature assessment presented challenges because of the large number of systems being studied (>3000) and the difficulty with integrating disparate data sets. USGS continued comparing EGS experimental data to determine if engineered reservoirs can achieve permeability equivalent to that obtained in naturally occurring geothermal systems.

Modeling the Economic Benefits of Geothermal Development

For most people, the word "JEDI" conjures up images of distant galaxies and epic light-saber battles. At NREL, however, JEDI—the Jobs and Economic Development Impacts model—is a tool developed by the Lab that estimates the economic impacts of constructing and operating renewable energy or fossil fuel power plants. With GTO funding, NREL released a geothermal-specific version in September 2012: JEDI for geothermal development (JEDI Geothermal). JEDI Geothermal allows users to estimate project costs and direct economic impacts for both hydrothermal and EGS power generation projects. It follows similar models for solar, wind, biomass, marine, coal, and natural gas electricity generation. Each of the JEDI models contains common input requirements such as capacity factor, nameplate capacity, capital costs, and annual operations and maintenance costs.

JEDI Geothermal contains several unique attributes to account for the high upfront costs of drilling and exploration. Data fields represent big-ticket items like exploration, well and material costs, and reservoir stimulation for EGS. Depending on the expertise of the user, JEDI Geothermal can be configured with a sophisticated array of input parameters, and a toolbar of help commands to make the program easily accessible to the user.

Pioneering the Regulatory Roadmap Process

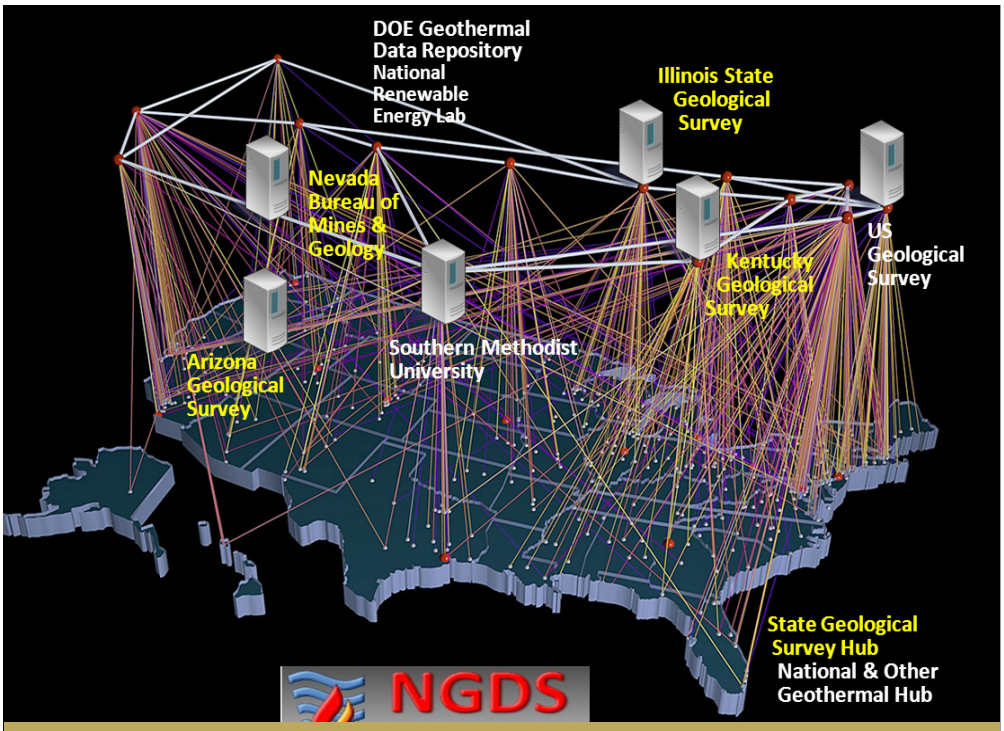
Working with the National Renewable Energy Laboratory (NREL), GTO initiated the development of a Regulatory Roadmap at the federal, state and local levels for geothermal power projects nationwide, to better understand what the current process looks like, to convene agency and industry stakeholders involved in permitting to validate the process, and to work with all stakeholders to streamline the regulatory process. Geothermal industry stakeholders have identified the permitting process and timelines as one of the most significant barriers to geothermal power project development. A GTO Blue Ribbon Panel Report also stated the need for a more streamlined geothermal permitting process. Reducing the permitting time, or reducing the number of required permits, can significantly lessen total project costs and investor risk, encouraging geothermal developments.

Beginning with geothermal-rich states—Alaska, California, Hawaii, Idaho, Montana, Nevada, Oregon, and Utah—NREL developed an excellent first draft of flowcharts and supporting written documents based on federal, state and local geothermal regulations. NREL also convened key permitting agency officials, industry personnel and stakeholders to review and comment on the draft flowcharts, ultimately preparing updated regulatory roadmap flowcharts, processes and other important documents. At the annual 2012 Geothermal Resources Council Meeting in Reno, Nevada, a workshop was assembled to present the findings and seek stakeholders' suggestions. Regulatory roadmap documents and flowcharts are available at http://en.openei.org/wiki/GRR.

PROGRAM HIGHLIGHTS

Systems Analysis

National Geothermal Data System (NGDS)



Distributed Access to Geothermal Data

The National Geothermal Data System (NGDS) is based on a DOE strategic planning directive to employ the most advanced informatics and ensure the geothermal community has broad access to scientific data. To achieve this goal, project data from all of GTO's awards are being uploaded into the DOE Geothermal Data Repository node on the NGDS. Through the use of an open data design platform, geothermal data sets can be linked with other high-quality, critical geothermal data and broadly disseminated through the NGDS. Communities of practice across the entire geothermal development domain are evolving vocabulary and data models for heat flow, geophysical exploration, drilling, and engineered reservoirs—information that will reduce risk and increase the likelihood of successful deployment by providing comprehensive data of known quality.

The NGDS reached a major milestone in November 2012, with the inclusion of data from more than one million wells. That number is expected to more than double within a year, drawing key scientific data from oil, gas, water, and geothermal wells. Spread broadly around the nation, these data nodes contribute a continuous stream of fresh data pertaining to geology, faults and seismicity, heat flow, geochemistry, temperature, and drilling. New geothermal data, in turn, will cut down on costly upfront costs and advance discovery and development of large-scale energy production. For that reason, industry frequently claims that accurate and available technical data constitutes the single greatest need in the geothermal industry.

An Energy Datapalooza

As part of Energy Data Initiative—a DOE-led effort in close partnership with the White House and other agencies—the Datapalooza 2012 event in October announced free access to over 900 datasets now available on Energy.Data.gov. In the last 6 months, the number of datasets has now doubled. The Energy Data Initiative seeks to work with data owners inside and outside of government to make energy-related data available, machine-readable, and accessible, while ensuring personal privacy is protected. Free data can enable the private sector to build products, services, and apps that advance a clean energy future. The Geothermal Data Provision Program partnered with Data.gov at the event to launch its Geothermal Prospector tool, which includes hundreds of state geological survey datasets and geothermal resource area descriptions. The adoption of a new Data.gov platform will enable easier sharing of program metadata.

Life Cycle Analysis

The Geothermal Life Cycle Analysis program supported the Office of the Undersecretary for Energy in developing a coordinated federal approach to better manage energy and water tradeoffs, also known as "the Energy-Water Nexus." GTO shared data related to geothermal power plant operations, water consumption, and non-cooling water use, including estimated reservoir water loss analysis and RD&D strategies with other department programs.

To learn more , visit: http://geothermaldata.org; http://stategeothermaldata.org; and https://gdr.openei.org/.

Select State NGDS Successes

NGDS Aids in Discovering Hawaii's Geothermal Resource

A project funded by GTO may help reduce Hawaii's dependence on foreign oil by exploring geothermal power as a clean, baseload alternative. Hawaii has the unfortunate distinction of having the highest electricity costs in the nation due to its dependence on oil for its electric supply. But the NGDS is forging a connection between state agencies to aid transition to a more sustainable energy supply—one that, in time, will prove less costly than oil. The new data makes a critical case for geothermal development—Hawaii's only economically viable source of baseload power. Researchers at the University of Hawaii (UH) are spearheading a collaboration with public and private stakeholders to catalog new information on geothermal resources in Hawaii. One of the most significant goals of the project is a new statewide assessment of geothermal resources. UH will conduct a broadly-based sequence of magnetotelluric surveys, characterizing geologic structures that are predicted to host geothermal resources and interpreting the information through geothermal data and site-specific hydrologic and geologic data. To date, the project has digitized roughly 1,000 geothermal reports for inclusion in the NGDS and digitized 3500 water wells in Hawaii to help with assessing Hawaii's geothermal resource potential.

Utah Offers Hope for More Potential Nationwide

The solution to America's energy needs might come from a new type of geothermal energy reservoir identified in sedimentary basins of Utah and Nevada. This summer, geoscientists from the Utah Geological Survey (UGS), in cooperation with the US Geological Survey (USGS), drilled seven geothermal gradient holes in Utah's Black Rock Desert basin to test a new concept of high-temperature geothermal resources in sedimentary basins. A drill hole near Pavant Butte in the north part of the basin yielded exceptionally high temperatures of 200°C at a depth of just 3 km. Based on drilling results, researchers conservatively estimate a basin-wide power density easily comparable to the energy output at The Geysers field in California, the US's most productive geothermal system. High temperatures encountered during oil exploration in the central Black Rock Desert basin motivated the UGS team to test whether deep sedimentary basins floored by older crystalline rock were capable of high heat flow. Drilling was funded by the Energy Department as part of the NGDS project, managed by the Arizona Geological Survey. Dr. Rick Allis, Director of the Utah Geological Survey and lead scientist on the sedimentary basin geothermal research, said that existing heat flow maps don't identify the geothermal energy potential in the area. There may be basins across the country that have similar unrecognized geothermal energy potential.

Geothermal Potential in Minnesota

In March, the Natural Resources Research Institute (NRRI) of the University of Minnesota, Duluth reported an important discovery: Minnesota's subsurface holds a promising source of easily attainable heat—much more than scientists previously thought, and much shallower. NRRI's research project, in conjunction with the American Association of State Geologists, was funded in part by GTO. The results derived from the new data show that Minnesota's heat and electric power potential is three times greater than previous analyses have shown, up to 18,409 MW from 6,161 MW calculated by the MIT-DOE report of 2006. This heat resource could power the entire state through a clean baseload geothermal energy source, according to NRRI researchers. Moreover, this significant heat source is also located, on average, seven kilometers shallower than previous reports have shown. And while some areas of Minnesota are hotter than others, certain counties have the heat potential for EGS technologies. Such locations in Minnesota can be found at just over seven kilometers depth, three kilometers shallower than previous measurements indicated—an exciting discovery that will dramatically reduce high upfront drilling costs. With three times more confirmed heat resources and a state mandate to switch 25 percent of its electricity generation to renewable fuels by 2025, Minnesota may find a larger role for geothermal energy in its future energy portfolio.

GTO Team
Office Contacts

Douglas Hollett, Office Director
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Doug is the Director of the Geothermal Technologies Office in the Office of Energy Efficiency and Renewable Energy (EERE) at the U.S. Department of Energy (DOE). In this role, he is responsible for both technical and project oversight and for new technologies designed to advance geothermal's role in the US energy portfolio. Doug has more than 29 years of experience in the oil and gas industry with Marathon Oil. While at Marathon, he most recently served as the Manager and Director for Unconventional New Ventures, where he was responsible for capturing and initiating new global opportunities in shale gas and tight oil reservoir using new geologic concepts, and through the use of new drilling and completion technologies.

Eric Hass, Hydrothermal Supervisor
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Eric Hass is supervisor of the Hydrothermal portfolio for the Geothermal Technologies Office, including innovative exploration technologies and low-temperature and co-produced resources. Prior to this, Eric was EGS supervisor for two years and has worked with DOE EERE since 1993 and GTO since 2004. Eric brings over 30 years of experience in oil and gas, mineral exploration, and renewable energy project/program management to the team.

Lauren Boyd, Acting EGS Supervisor
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Lauren is acting supervisor of the EGS portfolio for the Geothermal Technologies Office, including EGS R&D and demonstration projects. Lauren has an undergraduate degree in Geology from Vassar College and a Master's degree in Geology from University of North Carolina at Chapel Hill.

Jay Nathwani, Systems Analysis Supervisor
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Jay's diverse portfolio includes international issues, geothermal data systems, levelized cost of electricity analysis, and policy analysis. Jay has been with the DOE since 1991, starting at the Idaho Operations Office and moving to the Golden Field Office before coming to Headquarters in DC. Jay has a MS in Mechanical Engineering from California State University at Fullerton and a BS in Mechanical Engineering.

Margaret Schaus, Operations Supervisor
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New to the GTO team this year, Margaret joins the Office from the Business Operations side of EERE. Margaret oversees GTO's day-to-day business functions, including strategic planning, budget execution, contracts, communications, and staffing. Margaret has an undergraduate degree in Science, Technology and Society and a graduate degree in Management Science and Engineering, both from Stanford University.

A Fond Farewell

After almost four years at the Department of Energy, GTO bids a fond farewell to Hidda Thorsteinsson as she embarks on an adventure to geothermal-rich Iceland. Hidda will assume a new role there as Director of Research and Development for Orkuveita Reykjavikur, a public utility company providing electricity, geothermal water for heating, and cold water for Reykjavik and 19 other communities in Iceland, serving 67% of the Icelandic population.

Hidda came to the Department of Energy through EERE's Career Internship Program, following her graduate studies in geothermal engineering at MIT and a brief stint with a geothermal energy developer in Los Angeles. Hidda has been a key member and leader in the office, serving as the supervisor for the Hydrothermal team. She made manifold contributions to geothermal progress, identifying new hydrothermal energy potential nationwide and lowering exploration risk through research and development of innovative exploration techniques including remote sensing, advanced seismic, and joint inversion of geophysical methods.

Hidda will be greatly missed, but GTO is excited to see her continuing her knowledge and leadership in this field!

Iceland is unique in the world for its commitment to renewable energy. All of Iceland's electricity comes from renewable sources—73% hydropower and 27% geothermal—and 90% of its heat is geothermal. In 2008, the United States entered into an international agreement with Iceland and Australia to advance geothermal energy through knowledge transfer, collaboration, and RD&D.

Spotlight on Golden

At the base of the Rocky Mountains in sunny Colorado, the DOE Golden Field Office was commissioned in December 1992 to support the development and commercialization of renewable energy and energy-efficient technologies. As a satellite of DOE's Office of Energy Efficiency and Renewable Energy in Washington, DC, Golden's mission is to award grants and manage clean energy project contracts and to facilitate research and development partnerships. The Golden-based Geothermal Technologies Office (GTO) provides expertise in legal, environmental, procurement and financial assistance management as well as project management. Legal counsel provides support in business and environmental law to the office. The project management team manages the selection process, negotiates new awards, tracks project progress and continuation decisions, and works with procurement to manage modifications to existing awards. By providing oversight to financial assistance award recipients and applicants, the procurement team is tasked with ensuring compliance with federal and DOE procurement laws, regulations, and policies. The Office of the Environment manages all National Environmental Policy Act (NEPA) and environmental activities for the Office, preparing Environmental Assessments, Findings of No Significant Impacts, Categorical Exclusions, and Supplement Analyses for projects. Together, these teams, along with the headquarters office, work with award recipients to ensure active oversight of all GTO financial assistance and lab projects.

***Back**, from left: Casey Strickland, Environment/NEPA , Chris Dunne and Jeff Wild, Procurement. **Middle,** from Left: Melissa Jacobi, Genevieve Wozniak, and Kristen Cadigan, Procurement; Trish Cassen and Julie Anderson, Legal; Ava Coy and Sara Gonnion, Project Management. **Front** from Left: Bill Vandermeer, Project Management; Justin Lee, Procurement. **Not pictured:** Mark Ziegenbein, Project Management, and Eric Hass, Hydrothermal Supervisor*

Welcome Aboard!

In 2012, GTO welcomed Josh Mengers and Dan King to the team. Mengers joined GTO in August 2012 as a Presidential Management Fellow. His interest in renewable energy and background in mechanical engineering make him a natural fit for GTO and the EGS team. Mengers has a PhD in Mechanical Engineering from Notre Dame University.

Josh Mengers

King comes to the office from a research background in rock mechanics, performing high pressure and temperature laboratory experiments to learn about the mechanical properties of rocks. King's interest in the challenge of scaling up renewable energy production led him to pursue an AAAS Science and Technology Policy Fellowship, where he found the perfect match with GTO, joining the EGS team in September 2012. King has a PhD from the University of Minnesota.

Dan King

Meetings that Matter

Courtesy of the Geothermal Resources Council

Hollett Addresses Largest Gathering of Geothermal Stakeholders

US Department of Energy investments are tapping a vast resource of clean, baseload energy from the earth's heat, according to GTO Director Douglas Hollett in his Geothermal Resources Council (GRC) keynote address to over 1,000 in October 2012. The GRC annual meeting marks the industry's largest gathering of geothermal energy stakeholders in the nation. Hollett discussed public-private successes in identifying and validating geothermal resources in the western United States as well as the Department's work in research and development aimed at reducing deployment costs.

GTO Hydrothermal Presentations

Hydrothermal staff was busy this year, giving presentations and spreading the word on the sector's exciting new opportunities and challenges. Hidda Thorsteinsson and Tim Reinhardt gave program overview talks at the California Geothermal Energy Collaborative Forum in Davis, California, the Renewable Energy Conference in North Dakota, and the Icelandic Geothermal Cluster in Reykjavik, Iceland. Hidda also presented at the National Geothermal Summit in Sacramento, California, where she spoke on the challenges of finding new hydrothermal resources. Tim Reinhardt presented GTO low temperature and sedimentary progress at West Virginia's 1st Annual Geothermal Conference. In addition, team members attended the Stanford Geothermal Workshop, the American Association of Petroleum Geologists meeting, the Geothermal Resources Council Annual Meeting, the ARPA-E Innovation Summit in Washington, DC, and a meeting of the Colorado Geothermal Working Group.

Reducing the Risk of Geothermal Development through Data & Information

At a key presentation to the Geological Society of America in November 2012, Arlene Anderson discussed the evolving National Geothermal Data System and provided the status of various geothermal "nodes" on the network, including the office's DOE Geothermal Data Repository. She stressed the importance of geothermal data sharing in reducing the high upfront risk of geothermal development. The NGDS will provide online access to vital network of data providers and assist state and federal agencies in making land and resource management assessments. The NGDS will also foster the discovery of new geothermal resources by supporting ongoing and future geothermal-related research and increased public awareness of geothermal energy. GTO expects that the NGDS will be fully operational in FY14.

Peer Review

In May 2012, DOE-funded partners gathered in Westminster, Colorado to share successes and challenges at the office's annual Peer Review. The purpose of the review is to evaluate the projects against the program's stated objectives and recount new advances as well as barriers to progress. Attended by over 300 participants in FY12, the office's Peer Review provides a valuable network for information-sharing among geothermal stakeholders and evaluating the progress of DOE-funded projects. Each project is reviewed by a minimum of three experts who are asked to evaluate a 20- to 30- minute presentation provided by the principal investigator. Experts are then asked to score the presentation and supply written comments to the office. Project presentations are assessed according to relevance and impact of the research, technical approach, progress and inroads in new technology sectors, and project management.

Members of the GTO Team at the Geothermal Energy Association Expo

In October, GTO members convened in Reno to share progress. *From left*: Ava Coy, Hidda Thorsteinsson, Lauren Boyd, Arlene Anderson, Margaret Schaus, Elisabet Metcalf, Rachel Bilyk, and Alethia Marble.

Faulds Awarded GTO Peer Review Award for Research Excellence

Doug Hollett, Director of the Geothermal Technologies Office, presented the GTO's first-ever Peer Review Excellence Award to James Faulds of the University of Nevada, Reno, at the annual conference of the Geothermal Resources Council (GRC) in Reno, Nevada in early October. The event comprises the industry's largest annual gathering of geothermal energy stakeholders in the nation. Among the office's 154 research and development projects leveraging nearly $500 million in total combined investments, only one recipient earned top marks across the board in every evaluation category during the office's annual peer review. Hollett recognized Faulds for his landmark research characterizing structural controls of EGS and conventional geothermal reservoirs. The research will help to better target industry drilling investments. Faulds initiated a three-year research project under Recovery Act funding in early 2010 to address insufficient site selection data. His research team has developed comprehensive structural models that will lower geothermal development costs and facilitate exploration. A robust technical report of peer-reviewed projects will be available on the office website in early 2013.

Lauren Boyd Attends Re-Opening

GTO's EGS Supervisor Lauren Boyd spoke at the re-opening ceremony of The Geysers Geothermal Visitor Center in August 2012. She is pictured here with Patrick Dobson of LBNL, who played an integral role in helping Calpine update content for the center.

Acronym List

ARRA	American Recovery and Reinvestment Act of 2009
DoD	US Department of Defense
DOE	US Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EGS	Enhanced Geothermal Systems
FY	Fiscal Year
GTO	Geothermal Technologies Office (previously Program)
GW	Gigawatt
kWh	kilowatt hour
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
MW	Megawatt
NEPA	National Environmental Policy Act of 1969
NGDS	National Geothermal Data System
NREL	National Renewable Energy Laboratory
PNNL	Pacific Northwest National Laboratory
R&D	Research and development

Education & Outreach

Geothermal Academy

Through GTO funding, the National Geothermal Academy operates an 8-week intensive summer course, created to educate the next generation of geothermal scientists, engineers, plant operators, technicians, and policy makers in practical, detailed geothermal science and technology. Now in its second year, the course has successfully graduated over 98 students. This advanced, technical program is offered at the undergraduate or graduate level, with individual weeks available for professional development. Geothermal experts from across the nation and the world serve as instructors, each responsible for developing curricula. Fourteen instructors from various universities and the private sector collaborate to craft a challenging, up-to-the-minute course about all things geothermal. The Academy is currently planning for an even better summer 2013 program.

GTO in the Schools

Fourth-graders at Hyde Addison Elementary School were surprised by a visit from the Geothermal Technologies Office during their science lab in November 2011. Greg Stillman, a physical scientist within GTO, focused his talk around the basics of subsurface science and geothermal energy. Students learned about the heat of the earth's crust and how it can be harnessed to meet our energy needs. The lesson finished with a hands-on rock characterization activity where students formed small groups and 'characterized' rock samples based on their observations.

In March 2012, Stillman addressed a group of high school students visiting DOE headquarters as part of a Washington DC seminar to gain firsthand knowledge about the US Government and its processes. This specific group was interested in geothermal energy and how this renewable source can be used to meet our country's energy needs. During the 90-minute presentation, Stillman discussed the basics of geothermal energy use, opportunities and challenges faced by this sector, and how geothermal energy fits into the bigger integrated picture of energy supply and demand in the US.

Idaho State Wins National Student Competition

Students at Idaho State University display their poster at the annual meeting of the Geothermal Resources Council in Reno, Nevada this year, as one of 3 top finalists in the National Geothermal Student Competition hosted by the Energy Department's Geothermal Technologies Office. The group won the competition with their study on *Development of an Integrated, Testable Conceptual Model of Blind Geothermal Resources in the Eastern Snake River Plain: Application to the Newdale Geothermal Prospect*.

Student teams from Boise State University and Southern Methodist University Geothermal Laboratory were also featured at the conference and finished second and third in the competition. The NGSC challenges students nationwide to conduct cutting-edge research in geology, geoscience, chemical and bio-molecular energy and engineering that could lead to breakthroughs in geothermal energy development.

Pictured *from left* are Adam Koster, Holly Young, Michael Ginsbach, and Rebecca Ohly. Dr. Desmond Stubbs, from the Oak Ridge Institute for Science and Education, who coordinated the competition for DOE, stands to the left of Dr. Michael McCurry, the team's mentor at Idaho State, *far right*.

Annual Report 2012

GEOTHERMAL TECHNOLOGIES OFFICE

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

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