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

near-term ⊙ cutting-edge ⊙ clean hydrothermal ⊙ innovative exploration ⊙ economically attractive ⊙ cascading systems ⊙ coproduced low-temperature ⊙ synergies ⊙ strategic minerals initiative ⊙ play fairway analysis ⊙ increase value stream ⊙ reservoir maintenance 30 GWe potential ⊙ advanced tools

⊙ solving non-technical barriers ⊙ regulatory streamlining ⊙ analysis national geothermal data system ⊙ reducing upfront risk

⊙ transformative science ⊙ enhanced geothermal systems demonstration ⊙ deployment ⊙ technical solutions ⊙ tracers 3D imaging ⊙ reduce cost and risk ⊙ cross-cutting collaborations ⊙ directional drilling ⊙ FORGE subsurface laboratory ⊙ next generation ⊙ 100+ GW potential

2013 Annual Report

Geothermal Technologies Office

February 2014

Director's Message

Year in Review

For the Geothermal Technologies Office (GTO), 2013 was a year of major achievements and repositioning to introduce major initiatives. The office saw its first commercial, grid-connected EGS demonstration project, which opens the door to increased industry-wide adoption at in-field and near-field EGS settings. Fundamentally, this means that abandoned or unproductive wells can be stimulated and turned to commercial production with highly attractive rates of return. Analysis from the National Renewable Energy Laboratory (NREL) suggests that there may up to 9.5 gigawatts electric (GWe) of additional potential in the U.S. from near-term EGS technologies alone. This and other successes in the EGS portfolio have paved the way for an EGS field site project, named FORGE—the Frontier Observatory for Research in Geothermal Energy—after an intense intra-office competition.

The Office also had gains in refining new tools, sensors, and technologies for harsh downhole environments to increase efficiencies. We continue to be excited about opportunities from coproduction and low-temperature resources, new exploration approaches upcoming play fairway analysis, and creating value by extracting valuable strategic materials from geothermal fluids. All of these themes saw material progress in 2013.

At the same time, the GTO portfolio is more than just technology research and development (R&D). This past year, we had significant advances in addressing non-technical barriers that face geothermal development. The Geothermal Regulatory Roadmap (GRR), a centralized, comprehensive resource that outlines all geothermal permiting requirements in the U.S., was completed for ten geothermal-rich states, with more on the way. As a successful, collaborative model, the GRR is already being adopted as a best practice by other program offices in EERE. A second non-technical challenge to industry adoption—open access to reliable geothermal-relevant technical data—has resulted in a National Geothermal Data System (NGDS), now in the final stages of testing and development. NGDS is a best-in-class example of how to maximize R&D through a deliberate data collection and management approach.

The Look Ahead

As we kick off 2014, GTO will once again be issuing funding opportunities in intriguing new technology categories. We expect to issue four major solicitations.Further, we will be working closely with other program offices at DOE to advance complementary, cross-cutting subsurface R&D, allowing us to better leverage internal resources and expertise. The GTO team is excited about new directions these initiatives will create and the expected impact on industry growth.

Contact us with your questions, ideas, and recommendations. Together we can position geothermal energy as a core component in clean energy production.

Douglas Hollett, Director

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The Geothermal Technologies Office Annual Report spans calendar year 2013.

Special thanks to the Geothermal Resources Council (GRC) for permission to use their excellent photography. GRC photos were used throughout unless otherwise noted.

Cover art: (top, left) DOE innovative exploration project at Jemez, New Mexico, courtesy of Greg Kaufman; (center, left) DOE Raft River, Idaho EGS Demonstration site; (bottom left) DOE Industry partner Electratherm develops the "Green Machine," courtesy Electratherm; (right) Desert Peak, Nevada - DOE's first grid-connected EGS demonstration, courtesy of Ormat.

Hydrothermal

Minimizing the risks and costs of discovering and characterizing new geothermal energy sources is vital to realizing geothermal as a significant contributor to the nation's baseload energy supply. In 2008, the U.S. Geological Survey (USGS) estimated that 30 gigawatts electric (GWe) of undiscovered geothermal resource exists in the western United States—ten times the current installed capacity.

Foro Energy, Inc. partners with the United States Department of Energy (DOE) to commercialize high power lasers for the oil, natural gas, geothermal, and mining industries. Photo courtesy of Foro Energy

New High-Power Laser Technology

The Geothermal Technologies Office (GTO) strives to partner with cutting-edge technology developers to pioneer applications that accelerate the adoption of geothermal energy. In 2013, Foro Energy, Inc. (Foro) partnered with the GTO, through a 50/50 costshare, to design a high-power laser system and laser-based well completion tool that could enable unique geothermal downhole well applications with the potential for superior thermal contacting between the wellbore and the surrounding geological formation.

As a key driver to significantly increase geothermal resource availability and competitively contribute clean, baseload power to the U.S. energy supply, this engineering prototype represents a fundamentally new tool for geothermal reservoir engineers that will allow them to increase fluid circulation and extend the available heat extraction resource per well. In addition to the potential for better access to the geothermal reservoir for heat extraction, the project also matures the core technology platform originally developed with a DOE Advanced Research Projects Agency–Energy (ARPA–E) award that enables the potential to decrease hard-rock drilling costs. The 3-year Foro project will culminate in an onsite downhole field demonstration.

Visit the GTO website at **geothermal.energy.gov** for more information on hydrothermal development, or contact **geothermal@ee.doe.gov**.

Caldwell Ranch has achieved a first-ever replicable strategy to reopen an abandoned steam field at The Geysers in northern California, with implications for development in other regions of California as well. Below, GTO team member Brittany Segneri attended a workshop there in June.

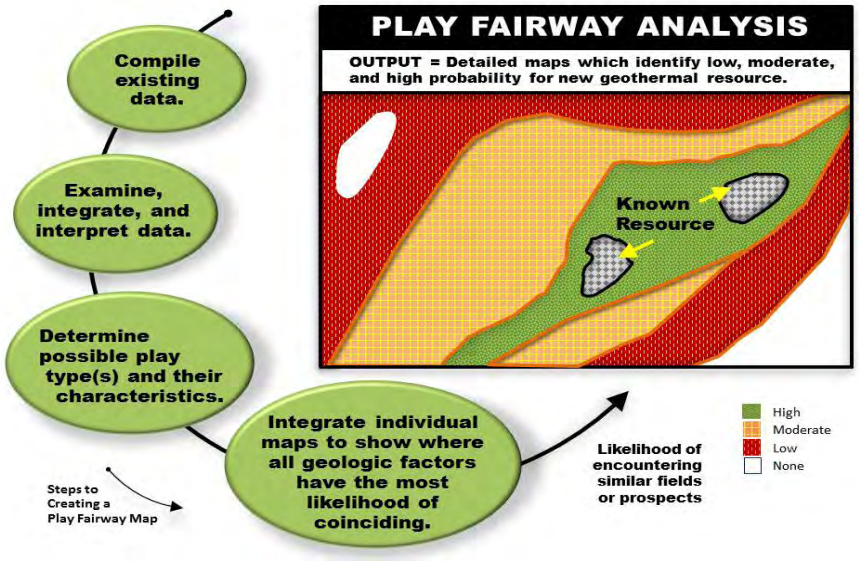
New Potential from Abandoned Wells

As part of a geothermal exploration effort to search for geothermal resources nationwide, a $5 million U.S. Department of Energy (DOE) investment to Calpine Corporation culminated in the confirmation of an initial 11.4 MW of equivalent steam this year—50% more than early estimates—from three previously abandoned wells at the Geysers geothermal field in northern California. Situated in the largest operating geothermal complex in the world, Calpine Corporation's Caldwell Ranch Exploration Project is a first-ever achievement to reopen an abandoned steam field, validating universally applicable technologies that bear immediate implications for other geothermal-rich regions of California–Coso, Salton Sea, and Medicine Lake–and nationwide. The project overcame barriers to bring commercial increases to unproductive geothermal wells and created 43 full-time temporary jobs and tax revenues to Sonoma County and the state of California.

Two technical achievements secured the success at Caldwell Ranch: Calpine's dramatic improvement of reservoir pressure—enhancing productivity of the wells—and the lowering of carbon dioxide concentrations and other deleterious gases in the steam by more than 65%. This project also took the innovative step of combining data sources, including temperature logs and isotopic measurements, to better define and model the 3-D volume of the geothermal reservoir. These innovative exploration steps could significantly lower the costs of geothermal development by avoiding risks associated with drilling and stranded assets. While modeling is not a new concept to geothermal development, pinpointing the reservoir and accurately measuring volume in this replicable model will better target drilling and prevent overestimating reservoir reserves. Calpine's reservoir model indicates that the Caldwell Ranch Project area and a portion of the EGS demonstration area are capable of producing between 40 and 45 MWe of new, sustainable electrical generation without any significant decline in the adjacent, existing steam fields. A proposed power plant has been permitted, and construction is dependent upon Calpine's ability to secure a long-term power purchase agreement.

The technology demonstrates that fields can rejuvenate in the proper settings. Letting a portion of a geothermal field lie idle for three or more years, allowing the reservoir to reheat, and then reopening or redrilling previously abandoned wells, provides a successful model at The Geysers, potentially expanding capacity there by 9 MW. In fact, this model can be replicated where conditions are similar—where there are decreases in reservoir pressure resulting from heat stored in the rock mass, like at The Geysers.

Hydrothermal



Play Fairway Analysis

We've all been there: searching for a lamp in a dark, unfamiliar room. How do you find it? Based on your experience, you may know where it is most likely to be, but you need to know where the furniture is, or you risk a severely damaged shin.

We use the same process when looking for energy resources buried so deep in the subsurface that there is no surface expression of their existence. Play Fairway Analysis is a practice first developed in the O&G industry that uses regional and detailed geologic and geophysical data to build a detailed picture of a buried basin to identify the most likely candidate locations for drilling. Based on this picture of the 'room,' explorers can more readily identify regions of the basin that are most likely to have one or more 'lamps' (or energy resource). While we cannot know for certain if a targeted site actually has the resource until we drill, the regions and their potential sites can be ranked on the probability of success so that we head for the most likely areas first. When used in O&G exploration, this process improves the likelihood of success of finding the desired energy resource —no more stumbling blindly in the dark—and reduces the costs associated with exploration and development.

GTO is adapting the Play Fairway Analysis methodology used by O&G and applying it to geothermal resource exploration. Combining this new approach with the geophysical and geochemical technologies and methodologies being developed by the Energy Department will reduce geothermal exploration risk, accelerate the development of additional geothermal resources, and increase the number of 'lamps' powered by the Earth's natural energy.

Facing Down Geothermal Costs

Widespread adoption of geothermal energy exploration in both hydrothermal and enhanced geothermal sectors is impaired by the high risk and cost of drilling deep wells in very hot formations, one of the costliest phases of geothermal development. To date there are no ultracapacitors commercially available that can operate at the extreme temperatures encountered in geothermal wells (> 200°C).

GTO investments have yielded a first-ever high-temperature geothermal ultra-capacitor to this barrier. Industry partner FastCAP Systems successfully demonstrated a product that is fully operational in 200°C conditions, cycling without failure and with little degradation and suitable for enabling pressure, temperature, and directional measurement and telemetry. The rechargeable energy storage unit for geothermal applications can handle extreme, high-temperature downhole environments. This is the world's first ultracapacitor for geothermal applications capable of safely achieving these temperatures.

Using vibration from the drill string to generate electricity, FastCAP developed the first ultracapacitor that can be used in a high-temperature geothermal setting. The project advances geothermal well drilling by extending the upper temperature limit of rechargeable energy storage capacity, adapting very high-temperature electronics and engineering vibrational energy generation to downhole geothermal applications, so there's no battery involved. The flexible system reduces associated costs and risks

with effective measurement tools for cutting-edge drilling technologies in harsh subsurface settings. As the project aims even higher to sustain equipment in a 250°C environment, FastCAP's tool will ultimately reduce the levelized cost of electricity (LCOE) for geothermal resource capture by up to a third. Data from the research will be made publicly available via the NGDS on an open-source platform.

Roadmap Plots Geothermal Milestones

Accurately characterizing the subsurface is a major hurdle in the identification and ultimate development of an estimated 30 GWe of undiscovered hydrothermal resources in the western United States. The GTO presented an Exploration Technologies Roadmap at the 2013 Stanford Geothermal Workshop, building on content from a series of community workshops and discussions originating in 2010. The Roadmap categorizes technology needs under technical pathways that target the key geothermal signatures of temperature, permeability, and fluid content. A time evolution of these pathways is proposed, tying in past and current GTO exploration R&D projects. Projecting out to 2030, the paper assesses technologies that could accelerate confirmation of the 30 GWe target. Ultimately, the Roadmap is a strategic development plan to help guide GTO R&D investments aimed at lowering the risk and cost of geothermal prospect identification. This is a living document that characterizes the current state and short- to long-term exploration goals of GTO. Revisiting these objectives regularly is important to gauge progress and realign approaches with the needs of the geothermal community and DOE renewable energy targets. GTO invites you to download the Roadmap from the Tools and Resources page of this report and provide feedback.

At left, a drill rig operated by RAM Power drills in the Imperial Valley of California. Photo courtesy of RAM Power. Right, PDC drill bits in action at a geothermal drilling site. (top) Dixie Valley power plant in Nevada.

Hydrothermal

With a potential resource capacity of 30 GWe nationwide, conventional hydrothermal resources rely on permeable rock and abundant fluid to access the earth's heat naturally. Low-temperature and coproduced resources make up a small but growing sector of hydrothermal development in geothermal resources below 150°C (300°F). Considered non-conventional resources, these technologies are bringing valuable returns on investment in the near-term, using unique power production methods. Low-temperature resources—once reserved for direct-use applications such as heating, greenhouses, fisheries, and mineral recovery—can now be used for power generation under the right conditions and have the potential to draw geothermal resources from across the nation, not just the western states.

Electratherm CEO John Fox (left) cut the ribbon on the company's "Green Machine" installation in April with Timothy Reinhardt, GTO physical scientist, and Joel Murphy, general manager of the Florida Canyon Mine for Jipangu International. Photo courtesy of Electratherm

Geothermal Brine Brings Low-Cost Power with Big Potential

A ribbon cutting in April at the Florida Canyon Mine in Nevada marked the beginning of another promising clean energy commercial enterprise. Thanks to a $1 million GTO investment, heat from geothermal fluids—a byproduct of gold mining—is generating electricity this year at 2¢ per kilowatt hour (kWh), with ElectraTherm's new plug-and-play technology. Building on this first-of-its-kind success, this geothermal electricity is the first in the nation to be generated from cost-free geothermal brine at a mine operation, without adding any additional emissions to the power system installation. The technology has the potential for extremely broad application in many parts of the country, including oil and gas (O&G) operations. Electratherm leveraged the initial DOE investment to commercialize this small-scale, mobile unit—called the Green Machine—with remote monitoring capabilities. In addition, resource potential is estimated at more than 3 GW of power from over 800,000 existing O&G wells nationwide. Product demand has tripled in five years, according to Electratherm, and annual increases are forecasted at 50% for the foreseeable future.

It is estimated that roughly 15–30 billion barrels of hot water are produced annually from these O&G wells. While coproduced hot water has historically been viewed as an inconvenience and a disposal issue for operators, today's low-temperature power conversion units can recycle the fluid to generate power. GTO is accelerating real-world deployment by validating the economic value to industry, improving efficiencies, and demonstrating the cost-competitiveness of these units. Ongoing R&D efforts will continue to drive efficiencies and add value, making energy from brine an economically attractive equation.

Batteries from Brine

Consumer uses of lithium batteries have soared over the last decade, powering everything from electric cars to tablets to cell phones. In fact, minerals like lithium, manganese, and zinc supply the raw materials for cathodes, glass, ceramics, lubricants, and many other products. Many minerals also have critical value for advanced manufacturing technologies. As demand grows in this burgeoning market, domestic supply is a growing concern. Global demand for lithium carbonate is expected to exceed 250,000 tons by 2017—a 60% increase over current usage, according to the thinkgeoenergy.com website.

Through Recovery Act funding, GTO partnered with California's Simbol Materials to develop technologies that extract these strategic materials from geothermal brines at a mining operation —a first-of-its-kind achievement. Simbol estimates that the mineral-rich Salton Sea region of southern California could supply enough lithium to produce up to half a million vehicle batteries per year. DOE support enabled the company to build the first demonstration facility there and mine lithium, manganese, and zinc from geothermal brines. As Simbol's Salton Sea plant creates an additional revenue stream from geothermal power production in the near-term, this model is ramping up for commercial-scale mineral recovery by spring 2014 and will be replicable for mineral extraction at other sites going forward.

A targeted GTO initiative focuses on strategic mineral extraction as a path to optimize the value stream of low-to-moderate-temperature resources, which reduces both costs and emissions.

New Working Fluids Cut a Wider Swath of Geothermal Reserves

Scientists at the Energy Department's Pacific Northwest National Laboratory (PNNL) have made a commercially viable discovery: how to capture substantially more heat from low-temperature resources. In a market where binary working fluids are costly and traditionally inefficient, this advance harnesses a much larger sector of near-term geothermal potential through inventive, low-cost solutions. Payback on this novel technology is now estimated in certain operational conditions at under 36 days, and DOE expects a commercialization plan by fourth quarter 2014.

PNNL developed the innovative liquid—called biphasic fluid—with the capability for rapid expansion and contraction and added tiny nanostructured metal-organic heat carriers (MOHCs) to boost power generation capacity near to that of a conventional steam cycle. The team found that the new working fluid has significantly exceeded performance requirements at lab-scale, with a 15% increase in power generation and capital cost reductions at existing plants. Put all these pieces together, and this innovation creates a new energy producing cycle that allows developers to exploit low-temperature geothermal sources for more economical power production.

To engineer this innovation, PNNL's expertise in nanotechnology and molecular engineering adapted advancements already underway at the lab. Nanofluids offer unique potential to improve efficiency of working fluids without major modifications to equipment or operating conditions; they increase thermal conductivity, improve heat transfer, and interact at the molecular level by increasing effective latent heat. Molecular stimulation of low-temperature resources from this project reduces capital costs, increases efficiency of the cycle, and expands the range of geothermal resources suitable for economic power production and waste heat recovery.

Hydrothermal

Geology on the Last Frontier

"Being a geologist in the Last Frontier requires flexibility, creativity, and a willingness to get your hands dirty," says Cathy Hanks, a visiting geoscientist to GTO on sabbatical from the University of Alaska Fairbanks (UAF). "And it helps if you aren't afraid of bears or helicopters!"

Cathy considers herself primarily a structural geologist, with an emphasis on O&G applications, but being in O&G requires knowing a bit about everything. So why did she choose to take a semester to visit GTO?

"Geothermal is just another way of getting energy from the earth," says Hanks. "The concepts and techniques of finding and extracting that energy are very similar to those used in oil and gas. I decided to visit GTO to get beyond the basics and find out what is happening at the cutting edge."

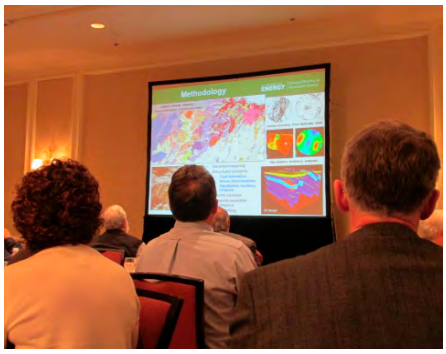
With degrees from Rice University and University of Washington, Cathy journeyed to Alaska to start work as an exploration geologist for ARCO Alaska in Anchorage. She was part of the team that evaluated the Bering Sea offshore basins for their petroleum potential, doing fieldwork in southwest Alaska and the Bering Sea islands from helicopters and boats and siting exploratory wells, drilled a hundred miles from land in 400 feet of water.

"I was the first woman to spend a night on one offshore rig, and I think the rig hands were totally terrified. But it was exciting to me. You never knew what was going to happen next," she says.

Cathy eventually left ARCO to get her PhD at UAF, where she studied the structural geology of the Arctic National Wildlife Refuge (ANWR) from helicopter spike camps (before the age of satellite or cell phones). The region was remote, she says, but the geology was great and the wildlife fantastic. "I've woken up to the Porcupine Caribou herd coming through my camp, to wolves howling… and once, to a mama grizzly with cubs." Fortunately she kept right on going. Her papers on the geology of the rangefront of ANWR remain some of the few detailed published studies of the area.

Following her PhD, Cathy stayed on at the university, where she became the go-to faculty for petroleum geology, with a specific task of teaching geology to the petroleum engineers. Cathy says she enjoys explaining geologic concepts to the engineers and watching the lights come on when they realize the importance of incorporating geologic uncertainty into their thinking. This interdisciplinary thinking has led her to a wide range of research efforts and collaborations. Most recently, Cathy served as lead principal investigator on a DOE-funded joint geology/petroleum engineering study aimed at extracting oil from a frozen reservoir on Alaska's North Slope. She is currently involved in a study examining shale oil potential on the North Slope, funded by the State of Alaska. Her visit to the GTO is sponsored by the Alaska Center for Energy and Power, which anticipates incorporating petroleum exploration concepts into their geothermal resource development efforts.

Cathy Hanks (above) has been a welcome addition to GTO's Hydrothermal team. Below Project Officer Mark Ziegenbein on tour at The Geysers and between meetings.



(top) Industry guests at the Peer Review opening reception; (center) geothermal stakeholders attentive during a luncheon presentation; (bottom) Edward Eugeni and GTO team member Sara Gonnion, coordinators of the 2013 Peer Review, at the closing session. (Below) NREL's Kate Young, who coordinated the Geothermal Regulatory Roadmap, takes a break between sessions with Brittany Segneri.

Dr. Kate Baker, Review Chair of the Annual Peer Review, stands at the podium with GTO Director Douglas Hollett and Dr. Bobi Garrett, Deputy Lab Director at NREL.

GTO 2013 Peer Review

In April, DOE-funded partners gathered in Denver, Colorado to share progress, successes and challenges at the Office's annual Peer Review. The peer review event offers a platform for annual evaluation of geothermal projects against the Office's stated objectives to recount new advances as well as barriers to progress. About 100 projects in GTO's portfolio were presented by their Principal Investigators, and evaluated and scored by independent, expert reviewers.

Each project is reviewed by a minimum of three experts who are asked to evaluate a 30-minute presentation by the funding partner. Presentations are scored by a panel of experts and followed with written comments that the Energy Department publishes. The event at the NGDS exhibit booth attended by over 200 participants—also provides researchers with an effective network for information sharing among geothermal stakeholders, which in turn enhances productivity of EERE investments. There were some notable changes made to this year's meeting based on attendee feedback from 2012. These included an expanded scoring scale, the addition of project objectives supplied in advance to reviewers in their project information packets, and a new geophysics/geochemistry technology area for review.

The Office funds over 150 research, development and demonstration projects, leveraging nearly $500 million in total combined investment. Each project represents a growing technology sector in conventional hydrothermal, low temperature and coproduced, or EGS technologies, along with technical and non-technical research and systems analysis. Each year, a portion of these funded projects are selected for review based on the scoring outcome and project status of the previous year's peer review. This year's Peer Review presentations were posted in May for public review on the GTO website, and reviewer comments were factored into the full report, which will be available in early 2014.

Enhanced Geothermal Systems (EGS)

Today DOE funds five active EGS demonstration projects and hundreds of lab-scale research efforts to develop technologies that address critical challenges to EGS commercialization. Two of these demonstrations have achieved milestones that accelerate the adoption of EGS in near-field environments. An MIT study estimates that more than 100 GW of geothermal energy can be accessed through EGS in the United States alone.

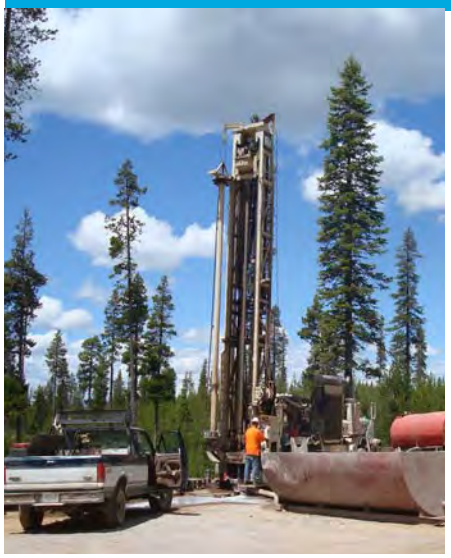
EGS encompasses a broad spectrum, starting with medium risk operations such as improving existing wells and hydrothermal reservoirs within operating fields. In these situations, EGS can be viewed as a reservoir management tool to insure against drilling unproductive or subcommercial wells. Green-field settings, on the other hand, represent a much higher technical and financial risk—one of the many reasons that GTO is developing the Frontier Observatory for Research in Geothermal Energy (FORGE) initiative.

GTO funding enabled the nation's first commercial-scale EGS to come online in April, connecting tomorrow's technology to the U.S. electrical grid today and setting the stage for future growth of geothermal power.

First-in-Nation Enhanced Geothermal System Project Powers the Grid

With support from EERE's Geothermal Technologies Office, Ormat Technologies' Desert Peak enhanced geothermal system (EGS) demonstration project, located in northern Nevada, has successfully used EGS technologies to increase the power output of a previously sub-commercial well, adding 1.7 megawatts of additional power to the operating field—a 38% increase. The result is the first EGS pilot project in America to generate commercial electricity. DOE provided $5.4 million in R&D investment, matched by $2.6 million in private sector funding.

Notable lessons learned from Desert Peak include the impacts and appropriate timing of various stimulation methodologies, including chemical and low-flow, shear stimulation. In addition, the importance of real-time borehole microseismic monitoring at sub-zero magnitudes has been validated for tracking the evolution of stimulations. This success confirms that EGS can be effectively used as a "reservoir enhancement tool" in or near the margins of existing hydrothermal fields, allowing operators to increase the productivity of previously drilled wells that have encountered sub-commercial permeability. This is a departure from the historical view of EGS as a high-risk, long term and expensive technology, usually referred to as "hot dry rock" projects. Key operators are rapidly learning that EGS could be applied to thousands of underproductive hydrothermal wells presently located within operational geothermal fields, with the capacity to increase productivity at each stimulated well pair by approximately 2-5 MW. That impact, according to the National Renewable Energy Laboratory (NREL), adds up to 6-10 GWe in new resource potential beyond the current U.S. installed capacity of 3.4 GWe. Importantly, new analyses at NREL and within GTO indicate that by leveraging existing wells, plants and infrastructure, new infield development can add power at 2-5/kWh as the technology quickly evolves from this initial, higher-cost R&D phase. The Office continues to see the overall U.S. potential for EGS to be over 100 GWe.



AltaRock drilling at the Newberry Volcano EGS Demonstration: a 50/50 costshare with the GTO.

Newberry Volcano

The AltaRock EGS demonstration project at Newberry Volcano near Bend, Oregon—a $21.4 million GTO Recovery Act investment—is currently the only project in our EGS demonstration portfolio located in a green-field setting.

In 2013, stimulation of well NWG 55-29, which began in October 2012, and subsequent data analysis, comprised the main thrusts of AltaRock's efforts. Over the ensuing two months, water was pumped at varying flow rates and pressures to shear open existing fractures and increase permeability in the subsurface. New diverter technologies were employed to target multiple zones of rock, increasing the stimulated volume more efficiently and with less water. Current analysis of the microseismicity and temperature profiles support the conclusion that stimulation of NWG 55-29 created multiple fracture zones originating from the wellbore.

After the stimulation was completed, AltaRock performed well logging and data analysis to provide additional insight into the results of the stimulation. This promising work at Newberry Volcano, slated to be complete by 2015, is critical for advancing the state of EGS green-field technologies and techniques, and the geothermal community eagerly awaits further progress in 2014.

Bradys Field

At the Bradys field site in Nevada, Ormat is working to improve the injectivity of well 15-12 to commercial levels, and to ensure a robust hydraulic connection with the rest of the producing field. A focused, downhole Environmental Assessment was completed by the Bureau of Land Management, with DOE as a cooperating agency, in January 2013, and a finding of no significant impact was made.

The first phase of the multi-phase stimulation was completed in April 2013, followed by the large-volume stimulation phase in September 2013. The project team is currently completing analysis and modeling to determine the optimum conditions for the next phase of well stimulation. Should the project prove successful, it will encourage future utilization of EGS well stimulations to improve the flow characteristics of non- or sub-commercial wells to the levels of commercial production and injection wells.

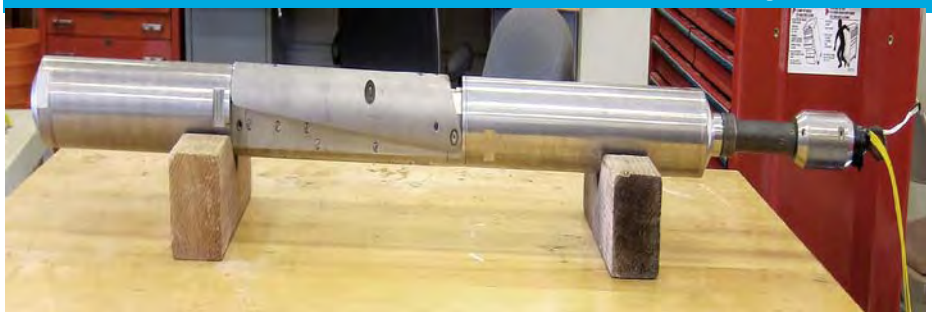
Raft River

At the Raft River geothermal field in Idaho, the University of Utah is developing and demonstrating thermal and hydraulic stimulation techniques required to create and sustain EGS reservoirs. After the project passed through a go/no go decision point in early 2013, thermal stimulation operations (with fluids that were cooler than those found in the reservoir) kicked off in May and continued until September. The ultimate goal is to improve the overall performance and output of the field.

During stimulation, a temperature profile of the entire vertical extent of the wellbore was monitored using a Distributed Temperature Sensor array designed by Lawrence Berkeley National Lab. This diagnostic tool enables valuable continuous monitoring of temperature evolution within the wellbore during fluid injection. Initial results are promising, and a large-volume stimulation is planned for spring 2014. Like the Bradys field demonstration, if successful, the Raft River project will encourage future utilization of EGS to improve the performance of unsuccessful or underperforming wells.

The Raft River EGS Demonstration Project in Idaho is testing techniques to sustain EGS reservoirs.

Enhanced Geothermal Systems



MagiQ and Sandia National Laboratory developed a high-temperature wellbore deployment system, which comprises a housing package equipped with a latching arm that mechanically clamps the tool system to the borehole wall. The middle section is the arm that swings out and clamps to the wellbore.

MagiQ Technologies Inc.

The ability to accurately locate and characterize the release of seismic energy, generated from micro earthquakes (MEQ) is of paramount importance to the development and monitoring of EGS. An innovative small business, MagiQ Technologies Inc. has developed a seismic sensor that does just that, all while operating at temperatures up to 300°C. In 2013, MagiQ successfully completed a Small Business Innovative Research Phase II award. This project culminated in the third-party testing and evaluation of their optical-based seismic sensor at Sandia National Laboratory's (SNL) Ground-Based Monitoring Research and Evaluation Center. MagiQ's sensor offers a number of important technical advantages: the sensor package does not contain electronic components that are failure-prone at high temperatures, it and can be scaled to hundreds of sensors deployed on a single optical fiber. Preliminary results show sub-Hz to multi-kilohertz (kHz) frequency response, with sensitivity less than 10 nano-gravity/Hertz $^{1/2}$ (up to 1 kHz), sampling rates up to 10 MHz, with a dynamic range of 80 decibels. The success of this technology development was made possible by a strong private-public partnership between MagiQ and SNL.

In a separate effort, SNL Geothermal Research Division developed a high-temperature wellbore deployment system, which comprises a housing package equipped with a latching arm that mechanically clamps the tool system to the borehole wall. MagiQ integrated their sensor package with SNL's deployment tool for a combined high-temperature seismic monitoring system. The full system was tested in a borehole at SNL's Ground-Based Monitoring Research and Evaluation Center. Based on the success of their Small Business Innovation Research project (Phase II), MagiQ is now commercializing their technology and expects a pilot deployment early in 2014. To date, the project has hired five new employees and expects to hire an additional five full-time equivalents next year.

** The Small Business Innovation Research (SBIR) program engages in highly competitive federal research and development that has commercial-scale potential. SBIR seeds capital in small businesses to stimulate technological innovation, and awards are based on feasibility of innovative concepts, strength of the scientific/technical approach, cost efficiency, and the potential impact for replicable commercialization.*

Downhole Sensor Holds Transformative Potential

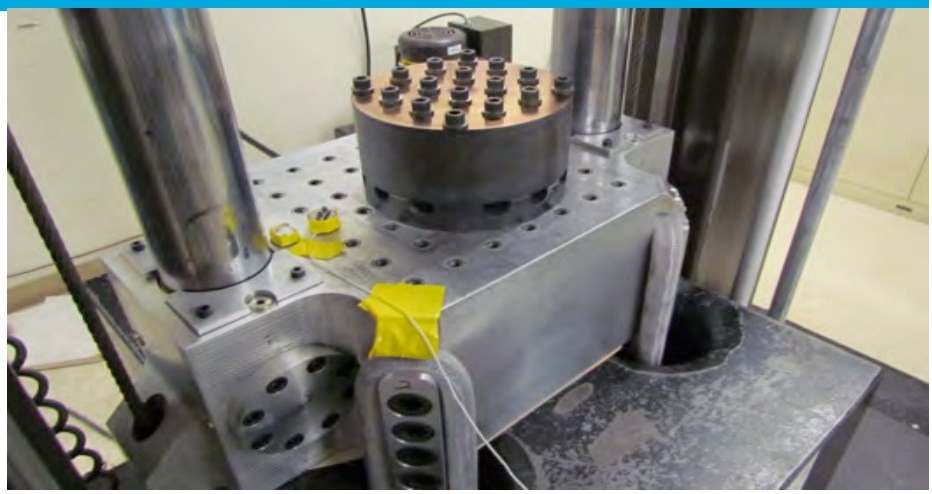
Long-term operation of electronics at high temperatures remains a challenge for the geothermal sector; many downhole sensors are prone to failure when deployed in high-temperature wells, which limits the availability and complexity of logging tools available for use in geothermal energy extraction.

Funded by a GTO Recovery Act award, GE Global Research has elevated Silicon Carbide (SiC)-based high temperature electronics to a new level of complexity and integration. SiC is a class of wide bandgap semiconducting material that holds transformative potential not only for high-temperature electronics but also for sectors ranging from industrial-scale variable speed drive motors to power electronics for a modern electric grid. Testing of the components developed by GE with the active electronic devices and packaging materials indicates operational lifetimes greater than 2000 hours at 300°C. This technology will help enable the use of more sophisticated electronics in drilling systems, sensor packages, and logging tools—all for deployment in geothermal environments.

Televiewer Maps Fractures

GTO partnered with Baker Hughes in 2008 to design, build, and test a downhole acoustic televiewer to map fractures in geothermal wellbores at temperatures up to 300°C. Following several years of component-level design and testing, Baker has integrated the components into two prototype tools. Successful testing was completed in large-scale, laboratory high-temperature/high-pressure test pits at temperatures up to 287°C in 2013, and the prototypes have also been field tested at Baker's BETA site in Oklahoma. Efforts are now underway to locate a suitable field testing site where the prototypes can be tested in actual geothermal wells under high temperature and pressure conditions. The EGS team is also working with Baker Hughes to conduct a side-by-side comparison of their newly developed, advanced televiewer with existing wellbore characterization tools. Following successful qualification and testing, development of this acoustic televiewer could create a new commercial service opportunity for Baker Hughes in the geothermal industry.

Turbine welding, courtesy of Ormat (lower left); miles of pipe at a geothermal power plant (below).



Through funding by the Energy Department, Sandia National Lab has refined a useful percussive hammer tool for harsh geothermal applications.

Percussive Hammer Enables Drilling

In 2013, Sandia National Laboratories (SNL) successfully completed the development of a high-temperature drilling technology able to withstand the harsh conditions present in geothermal reservoirs. SNL developed and tested a high-temperature downhole motor that includes an indexing tool for use with commercially available percussive hammers. Conventional pneumatic down-the-hole-hammer drilling systems—widely used in the mining and oil and gas sectors—perform well in hard rock environments and are capable of removing a volume of rock with low energy input. As a result, SNL identified the percussive hammer as a candidate technology for efficiently and effectively drilling geothermal wells. Hammer technology can lower the cost of drilling geothermal wells and improve well construction capabilities, including directional drilling.

Generating downhole rotation of the hammer, or downhole torque, has long been a challenge in high-temperature geothermal environments. Downhole rotation allows the face of the hammer to rotate and strike new rock instead of continuously striking the same, already rubbelized region. At high temperatures, elastomers—common components of oil and gas drilling systems and used to generate downhole torque—can fail to operate as designed within a short time. With this in mind, SNL designed components without any elastomeric materials, allowing efficient and continuous operation at 250°C.

The vein motor and indexing tool that can be easily integrated with existing pneumatic hammer bits. 2013 saw the successful characterization of the system's performance, which was comparable to positive displacement motors commonly used in oil and gas drilling. The project included a first stage analytical design followed by prototype development, further improved with a series of laboratory tests and material refinements. In 2013, SNL successfully characterized the tool's performance, generating greater than 2000 lb/ft of torque at 300 pounds per square inch of pressure. A provisional patent has been filed for the tool's design, and SNL has entered negotiations with a commercial partner to license this technology.

Enhanced Geothermal Systems

Reliable Drilling Equipment

GTO provided Recovery Act funding to Baker Hughes to develop a reliable drilling and steering system capable of performing in rock formations at temperatures up to 300°C. A system that is capable of directionally drilling wells at such high temperatures could have a large impact on the energy output of wells by increasing the accessibility of fractures in both hydrothermal and EGS settings. Baker is designing and integrating several components into this system including drill bits, motors, rotors, and stators. Laboratory and field testing is scheduled to be completed by the end of 2013.

As follow-on work to the Directional Drilling System project, Baker Hughes is also completing the proof of concept and engineering design on a high-temperature Measurement While Drilling (MWD) system. The final system would comprise a downhole navigation package capable of measuring well inclination and azimuth, a transmitter, a power system, and electronics capable of operation at temperatures up to 300°C. 2013 work has been focused on designing a cooling system that will be necessary to keep the electronics from overheating, as well as batteries for the power system and the navigational package. Should this project prove successful, it will enable informed drilling of directional wells by allowing geothermal drillers to continuously monitor and change the direction of the drill bit and string in real-time.

Accessing Seismic Data to Characterize the Reservoir

In 2013, A-Tech Corporation completed Phase I Proof of Concept activities related to the development of an innovative, rotation-enabled, seven-degree-of-freedom (7-DOF) seismic measurement tool for high-temperature geothermal applications. The tool will include an accelerometer, rotational sensor, and a pressure sensor. Utilization of this tool will allow for simultaneous measurements of p-wave and s-wave velocities, along with seismic wave directions. Measurement of these parameters with a single tool, rather than an array of sensors, will ultimately lower the cost and simplify the processing of seismic data for the purposes of characterizing a geothermal reservoir. This project was awarded in 2011.

Advances in High-Temperature Fiber Optics

With 2011 funding from GTO, Paulsson, Inc. is designing, building, and testing a fiber-optic, downhole seismic array that can outperform traditional geophones and withstand the high temperatures found in geothermal wells. The Paulsson team is working to develop a 15,000 foot, 200-level, 3-component prototype array for field deployment. A great deal of progress was made on this project in 2013; early in the fiscal year, Phase I Proof of Concept activities were completed as components of the array were built and tested in the laboratory and the field. Later in the fiscal year, the project successfully passed a required Stage Gate review, which allowed them to proceed with Phase II Prototyping activities. Using Phase I results, Paulsson, Inc. is now designing and building their prototype tool with further enhancements in bandwidth, sensitivity, and data processing time, surpassing the functionality of the components developed and tested in Phase I.

Adapting Oil and Gas Technologies

Hi-Q is adapting vertical seismic profiles (VSP), often used in oil and gas to identify fracture networks from the surface—a first-ever accomplishment in the geothermal sector. In 2008, GTO funded Hi-Q Geophysical to image fluid-filled fractures in EGS reservoirs using innovative VSP methods. Unique geologic conditions often encountered during

EGS Research & Development

EGS development—volcanic cover, highly altered rocks, and complex formations—often lack distinct velocity contrasts, making the data difficult to interpret and fractures virtually impossible to identify. In the early and mid-phases of the project, Hi-Q developed methods to identify appropriate seismic parameters to counteract the challenges associated with complex geology often coincident with areas of high geothermal potential. Hi-Q is now poised to enter the final phase of the project, field testing the first 4D seismic survey, including extensive VSP and surface multi-component reflection surveys, at the Bradys EGS demonstration project in Nevada. Analysis of the data will improve resolution of fluid-filled fractures within the geologic structures controlling reservoir properties at the site.

Flow test at the Faulkner plant in Nevada (top left); water vapor; field testing at Idaho National Laboratory; DOE EGS Demonstration site at Newberry Volcano, Oregon (courtesy AltaRock Energy).

Andy Sabin, director of the Navy Geothermal Program Office, points towards Sugarloaf during a field trip to the Coso geothermal field, as JASON study members take in the landscape. Sugarloaf, an 86,000-year-old rhyolite dome, is among a group of the youngest dated volcanoes in the field.

JASON EGS Report

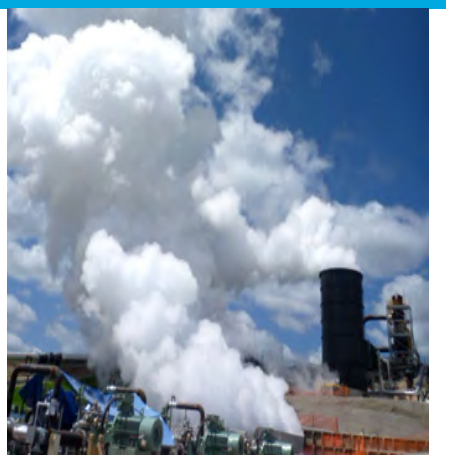
The development of novel technologies is needed to accelerate the commercialization of EGS. To gain an outside perspective on opportunities to leverage the best advancements from other subsurface disciplines to EGS, GTO contracted the JASON group in 2013 to undertake a study on the characterization and creation of EGS.

The JASON group is comprised of leading academic scientists who provide independent technical analysis to the U.S. government on topics ranging from national security, to the human genome, to energy systems. The group was created in the 1960s initially to help address key technical challenges for the intelligence and defense communities. Recently they have also contributed studies on energy systems, including support of the DOE Office of Science.

The JASON EGS study was the first to be commissioned by EERE. The report reviews geothermal resource estimates and constraints, highlights technologies and techniques that could be well suited for adoption in EGS characterization, presents extensive analyses and scaling arguments for heat transfer in engineered reservoirs, and addresses key environmental and lifecycle challenges and opportunities. Potential game-changing technologies are recommended that could promote scale-up of EGS. For example, the study proposes furthering advanced drilling and in particular microdrilling to enable more efficient and comprehensive reservoir characterization as well as monitoring small-scale field testing to constrain key physics and possibly future production schemes. Developing and validating new technologies at field scale is an undercurrent to the report's recommendations, with the freedom to conduct broad experimental campaigns in various geologic settings.

The JASON EGS Report was developed during a summer study period that began with a two-day briefing in La Jolla, California, where members of the geothermal community were invited to present state-of-the-art EGS technology developments alongside key challenges. After two days of talks and discussion, JASON study members visited the Coso geothermal field for a comprehensive tour of the site's geologic features, infrastructure, and the Navy geothermal plant. These interactions provided a background that the JASON group culminated into a final report to be released in January 2014.

Enhanced Geothermal Systems



Mapping the Future of EGS

While up to 90% of the geothermal power resource in the U.S. is thought to reside in EGS, hurdles to commercial development still remain. To that end, the GTO created an EGS Technical Roadmap that addresses the technology evolution required to facilitate large-scale EGS deployment. The Roadmap, published at the 2013 Stanford Geothermal Workshop in February, identifies the critical technology needs that will ultimately facilitate commercial success for EGS, and outlines opportunities for advancing these technologies on five- to 20-year timescales. Informed by community input, the Roadmap also traces technical research directions related to EGS as they have evolved through past and present practices. The roadmap is intended not only to guide priorities for GTO investment, but also to document and communicate the EGS Program R&D strategy to geothermal stakeholders, members of other subsurface science and energy sectors, and policymakers. GTO invites you to download the roadmap using the Tools & Resources page in this report and email your comments to our office.

(At top, left) Conventional geothermal power plant construction; (right) flow testing; (below) GTO Project Officer Greg Stillman makes the rounds at the poster session of the Geothermal Resources Council annual meeting; stakeholders at the annual industry gathering (bottom).

Visit the GTO website at **geothermal.energy.gov** for more information on EGS, or contact **geothermal@ee.doe.gov**.

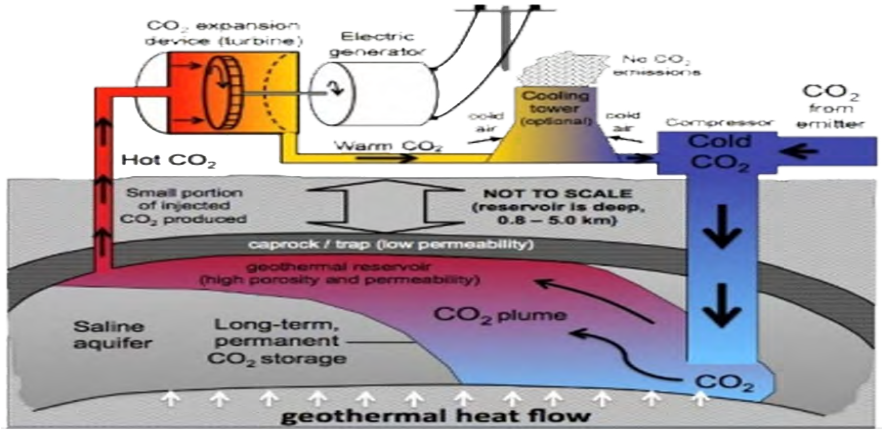
Geothermal Carbon Capture Goes Commercial

With early research funding from the Geothermal Technologies Office and the National Science Foundation, researchers are engineering a new kind of geothermal technology that will lock away unwanted carbon dioxide (CO_2) underground while safely using it to generate geothermal electricity—as much as double the output from conventional geothermal, according to some models.

Already at work in the oil & gas sector, CO_2 injection is being adapted for geothermal use through research led by Tom Buscheck, earth scientist at Lawrence Livermore National Laboratory (LLNL). If proven successful, this approach could move geothermal energy extraction far beyond the small handful of western states that take advantage of naturally occurring hydrothermal systems today. Heat Mining Company, LLC, a spinoff of the University of Minnesota research, expects to deploy an operational model by 2016.

The new power plant design replaces some of the geothermally heated water by injecting carbon dioxide and nitrogen into concentric, horizontal wells.

Co-principal investigator Jeffrey Bielicki, assistant professor of energy policy in the Department of Civil, Environmental, and Geodetic Engineering at Ohio State University, claims the technology can be twice as efficient as tapping geothermal reservoirs alone. Simulations also revealed that the new design could potentially sequester as much as 15 million tons of CO_2 per year, roughly equivalent to the emissions of three coal-fired power plants annually.



GTO investments at LLNL and LBNL and the University of Minnesota have yielded progress in harnessing CO_2 as a potential geothermal working fluid. Illustration courtesy of Dr. Martin Saar and Dr. Jimmy Randolph, University of Minnesota, 2013.

CO_2 as a Geofluid Shows Promise

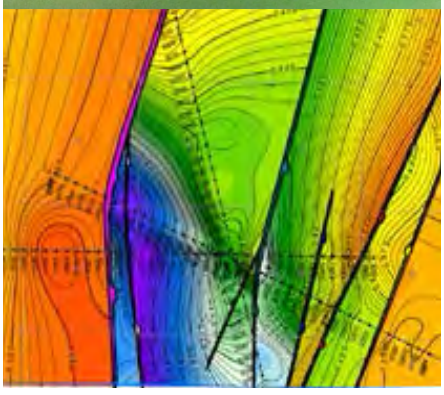
In 2013, GTO conducted a downselect review of projects funded under a 2011 funding opportunity announcement (FOA), focused on Innovation in Subsurface Heat Recovery Methods. The objectives of the FOA were to identify such innovations that could reduce financial risk and reduce potential environmental risks associated with EGS, such as water consumption induced seismicity, and subsidence.

An exciting outcome of the down-select review is the continuation of an innovative project underway at Lawrence Berkeley National Laboratory (LBNL), focused on supercritical CO_2 applications for geothermal energy. The LBNL team utilized a coupled wellbore and reservoir model to analyze the feasibility of super-critical CO_2 ($scCO_2$) geothermal and optimize designs of turbo expansion cycles using $scCO_2$ as a geofluid. The LBNL team identified environmental risks and potential induced seismicity hazards through an initial forecast of financial risk and techno-economic modeling—an additional requirement in Phase 1—and also provided an estimation of the potential resource for geothermal reservoirs conducive to CO_2 use in the U.S.

The subsequent phase, which will kick off in early 2014 constitutes a first-of-its-kind pilot scale CO_2 circulation testing—the parameters of testing were defined by modeling completed this year. Decades of research indicate that a thermosiphon will naturally develop when CO_2 is circulated between an injection and production well because of CO_2's compressibility and expansivity. This natural tendency to circulate has been theoretically shown to result in lower parasitic loads for heat mining than if water was used as the working fluid, but has never been demonstrated at field scale for geothermal energy applications. This natural thermosiphoning circulation test will take place at the Cranfield location in Mississippi and will ultimately validate the long-theorized benefits of the thermosiphon effect for geothermal energy. Furthermore, this pilot test will allow the analysis of critical thermophysical parameters that will aid in the design of the surface equipment required to optimize electricity generation.

Systems Analysis

Cross-cutting analysis is vital to deploying geothermal technologies. The Systems Analysis program focuses on reducing non-technical barriers to geothermal development in the United States by supporting analysis in environmental, policy, regulatory, economic, and data collection efforts. In fact, industry leaders agree that the single greatest need for locating the subsurface geothermal resource is comprehensive, accurate geothermal data. The National Geothermal Data System (NGDS) addresses this substantial challenge with an interoperable network of technical, geothermal-rich data using open-source software practices. The Geothermal Regulatory Roadmap addresses a second major barrier to geothermal development: permitting. This initiative helps developers streamline their regulatory timelines by coordinating a one-stop shop for all public permitting at the federal, state, and local levels.



NGDS Design & Testing Team members and DOE sponsor Arlene Anderson, second from right, illustrate the roller coaster effect—the ups and downs of data system design and testing—at the GEA Expo and GRC Annual Meeting in September. This gathering is the largest among geothermal stakeholders in the nation. From left: Jessica Alisdairi (AZGS), Christy Caudill (AZGS), Kim Patten (AZGS), Chris Kuhmuench (SCR), Steve Richard (AZGS), Anderson, and Sam Zheng (SCR).

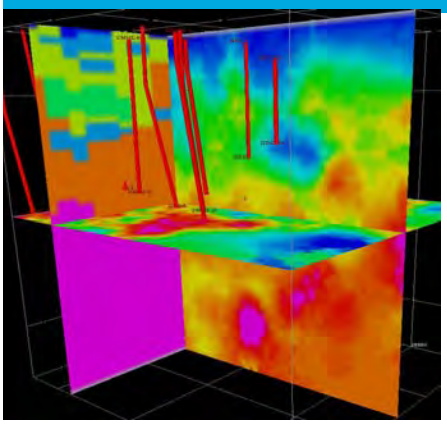
How the NGDS is Changing Geothermal Development

In conjunction with the state geological surveys, the National Geothermal Data System (NGDS) links thousands of databases, directories, and 85,000+ geologic maps that collectively constitute a national geoscience data "backbone" for research and practical applications. In addition, NGDS will supply data from the nation's leading academic geothermal centers, the geothermal industry, and a variety of federal agencies, including research from more than 200 projects funded by $300 million in Recovery Act funding.

NGDS potential to serve the geothermal industry—both in the U.S. and internationally—is growing, with 246 interoperable web services running, most gathering well data. Data cover geoscience features regarding geology, faults and seismicity, heat flow, geochemistry, temperature, and drilling. In fact, all industry partners leveraging DOE funds will feed survey data and geophysical, seismic, and fluid research into the open-source system. This is a "best-in-class" data collection and dissemination effort scheduled for deployment in spring 2014.

Since going live in March 2012, DOE's node on the data system, the Geothermal Data Repository (GDR), has received submissions from nearly 60 funds recipients. Project data providers are leading the way to meet an executive order from President Obama's Open Data Policy to make results of federally funded RDD&D public. DOE national laboratories and geothermal developers such as RAM Power and AltaRock Energy have made significant contributions already.

Exploratory drilling at DOE's Jemez, New Mexico site has completed a resource confirmation well at more than 5500 ft depth and is in the process of well testing and evaluation. Data from DOE-awarded projects like Jemez (left ***and***



Industry Weighs In

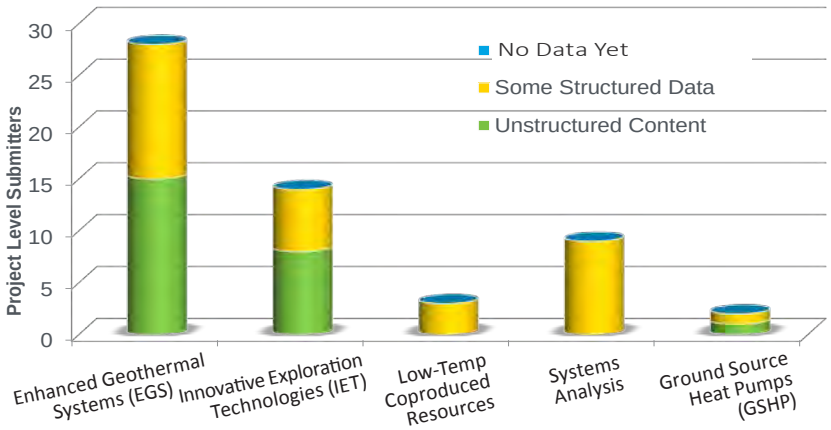
While final development of the NGDS is still underway, early-stage use of the system is already making an impact. For example, Dario Guerra of Big D Engineering, a small firm located near McAllen, Texas along the Mexico border, is evaluating the economic viability of utilizing the geopressured-geothermal (GP/GT) waters located under much of Hidalgo County, Texas. While fresh, potable water is a valuable commodity in the valley, for the population's drinking, irrigation, and ranching needs, non-potable brackish water is far more plentiful. In addition to the deep waters within the GP/GT zones, there is also quite a bit of shallow resource water in this same vicinity from oil and gas injection wells. Guerra is excited about the data being made available within the NGDS to further study this project. "We've shared some of the data being made available by Southern Methodist University and the Bureau of Economic Geology," he said. Additionally, he's been perusing what is online via the Arizona Geological Survey.

According to Guerra, "the NGDS website is the 21st century way to acquire multiple, up-to-date industry and academic sources to promote innovation and entrepreneurialism. The data is easily accessible and graphically presented so that the user becomes enthralled with it."

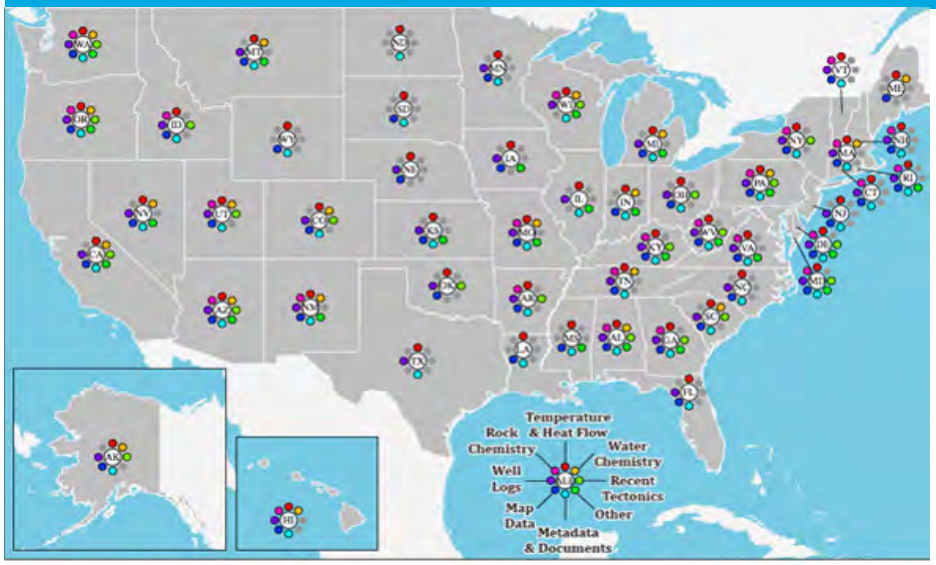
DOE's Node on the NGDS

NGDS operates as a system of distributed nodes, all in communication with one another. In line with DOE's strategic objectives, GTO will provide access to geothermal project information through the DOE-Geothermal Data Repository (GDR)—one of many nodes on the National Geothermal Data System currently under development. The Geothermal Data Repository node receives geothermal technical data from all DOE-funded geothermal projects. Each node will collect data and provide the other nodes access to the collected data. The DOE-GDR will be DOE's flagship node on the NGDS, and will be the submission point for all data generated by GTO's project awardees.

As part of GTO's stewardship of its public investment, all DOE project awardees are required to specify the types of data that will be generated as part of each task and project deliverable. Data will then be uploaded to the DOE-GDR. Submission of raw data and the provision of detailed and accurate metadata can fuel innovation in the geothermal sector. Furthermore, the linking of semantic concepts and the use of structured, standardized data can help insure the reusability of the data and advance understanding of geothermal sciences. All information will be disseminated across the distributed node network of the NGDS, which will supply easy access to a greater pool of geothermal-relevant information. Routine submission of publicly accessible data to the DOE-GDR can help to minimize the risk of future investment in geothermal technologies.



Systems Analysis



The State Geothermal Data website, funded by the Energy Department, offers an interactive data contribution map to compare contributions from all 50 states. The clickable map enables users to see datasets by state.

NGDS Thermal Conductivity Data is Saving Colorado Scientists Time and Money

Though he knew almost nothing about heat-pump technology before investigating items for NGDS data collection, Paul Morgan has since made a significant contribution to ground source heat pump design in his home state. Working with engineers in early-stage planning of geothermal ground source heat pumps for the Colorado State Capitol, Morgan noted that Denver was built over a basin that uses mostly surface water. So Morgan suggested the heat-pump system use water pumped from one of the aquifers for heat exchange—two boreholes, one producing well and one injection well, with a flow of 400 gpm. The original plan called for 300 drill-holes. As a consequence, the parking lot and park in front of the State Capitol were saved from several months of drilling.

"Compiling data for the NGDS project resulted in my recommendation to pump from the aquifer," says Morgan.

Thermal conductivity—one of the measurements in his data collection—was taken from drill-cutting samples for heat-pump drillholes, which ultimately led to Morgan's recommendation to the state.

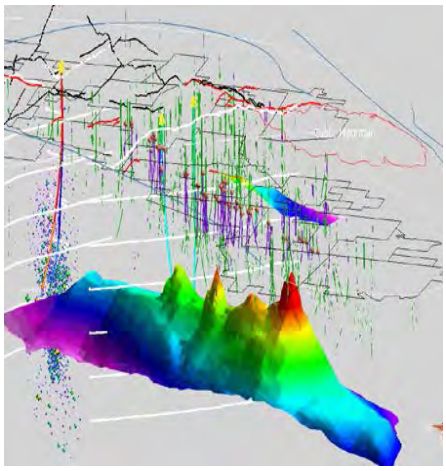
As a result of the NGDS project, Morgan has been able to make positive contributions to a number of heat pump projects.

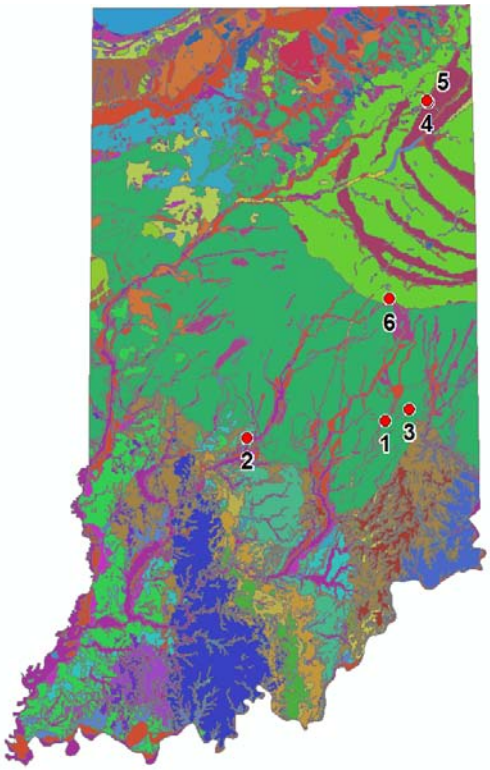
Illinois Geologists Curating Data

This year at the University of Illinois, state geologists and geosciences faculty are publishing year-3 data sets themselves—with support from the NGDS design team. Some of the data were validated ahead of schedule using a new validation tool developed by the Arizona Geological Survey (AZGS)—including active faults for all of Nevada. AZGS experts published detailed instructions for deploying and validating services submitted for the NGDS along with links on the United States Geoscience Information Network (USGIN) hub of the network. As more data nodes on the system independently curate the data, the system will gain long-term sustainability.

Oregon Data is On the Map

Oregon—the first state to use digitized data from the NGDS to map resources—now has a great tool for identifying the hot geothermal energy resource deep beneath the earth's surface. A state resource assessment map plots information on location, temperature, and other features statewide with this easy-to-use mapping tool. In addition to sharing existing data, Oregon is collecting new data through aerial infrared surveys to look for small variations in surface temperature that will identify potential geothermal resources. The state is also drilling three test wells—two in Lake County and one in Malheur County, to measure bottomhole temperatures and thermal conductivity: two indicators that validate whether geothermal heat flow is sufficient to drill for energy production. The interactive map is another example of the kinds of open-source data that can be accessed through the NGDS.





Map of Indiana showing the locations of Geothermal Monitoring Network sites and the diversity of surficial geologic deposits.

NGDS Aiding GSHP in Indiana

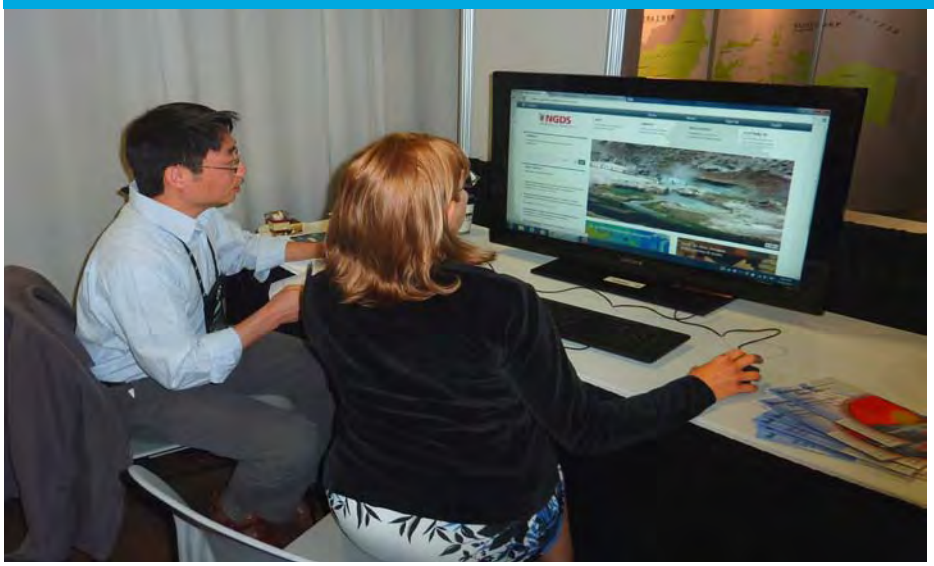
Leveraging GTO's investment in the GDR, the Energy Department's Buildings Technologies Office is using the NGDS to house heat pump data. The costs of exploiting shallow geothermal energy via ground source heat pumps (GSHP) can be minimized by allowing installers to design technologies that factor the appropriate thermal properties and predominant moisture regime of the geologic material being utilized. Researchers at the Center for Geospatial Data Analysis and the Indiana Geological Survey, for instance, developed a comprehensive monitoring network for in-situ measurements of shallow subsurface thermal conductivity, temperature gradients, and soil moisture. Continuous measurements of thermal gradients in the upper six feet of the ground are collected at six separate monitoring sites near Indianapolis and Fort Wayne, the two largest population centers in Indiana. Although software allows GSHP installers to optimize these configurations, input parameters must first be determined, including soil thermal properties and earth temperatures. Thermal data from the NGDS will support the design of more efficient systems by allowing GSHP installers to efficiently tailor their configurations to specific geological conditions and account for seasonal changes.

Through GTO state contributions to the NGDS, the Indiana Geological Survey established a shallow geothermal monitoring network on why geology is important to GSHP installers. The Indiana State Survey established thermal conductivity monitoring sites to determine variability in the glacial soils. Texture of sediment and soil wetness are vital measures of the ground's receptivity to ground source heat pumps, as the moisture is a driver for thermal conductivity in the near surface. Ultimately this data will help determine whether specific sites are conducive to GSHP.

GTO R&D focuses on geothermal energy production while geothermal heating and cooling for buildings is managed at the Energy Department by DOE's Buildings Technologies Office.

Lee Allison, State Geologist and Director of the Arizona Geological Survey, and Kim Patten, Associate Director for Planning and Development, network during GTO's annual Peer Review in April. Ram Power (right), is one of the recent submitters into the NGDS GDR (photo courtesy Ram Power).

Systems Analysis



User Testing at the Geothermal Energy Association's annual Expo provided valuable feedback to Dr. Sam Zheng, a senior research scientist with Siemen's Corporate Research, and GTO's Data Steward and Technology Manager Arlene Anderson. "We have started working on the low-hanging fruit fixes," said Zheng.

User Interface Testing at the Geothermal Energy Expo

At this year's annual meeting of the Geothermal Resources Council in early October, the GTO conducted user testing of the NGDS in preparation for its scheduled deployment in 2014. The Geothermal Energy Association's concurrent Expo was the perfect venue to gain feedback on the NGDS. At the NGDS exhibit booth, visitors from industry, research, and government tested both end-user and data-consumer viewpoints. Test scenarios covered map, library, and faceted searches, user ratings, resources, and tools. The NGDS design team received a solid day's worth of input to help improve the NGDS functionality.

Dr. Sam Zheng, a senior research scientist with Siemens Corporate Research of Princeton, New Jersey, also conducted similar user testing last year at the Stanford Reservoir Engineering Workshop and at GEA's Expo. This latest round of input is much improved.

The new data system received both positive feedback and practical suggestions for optimizing the network. Participants indicated the system was easy to use and that they would access the NGDS frequently once it is up and running. They found the search options easier than typical library searches and gave feedback in key areas: replacing the Data Watch section with more relevant data, linking the main image to Geothermal News, enhancing images, and changing Resources to a Tools tab—a dynamic page where users will be able to upload their own application for analyzing data. Overall, this third tier of user testing met with very positive feedback and applicable recommendations that will further streamline the NGDS user experience.

Geothermal Prospector

A team at the NREL has developed a Geothermal Prospector tool to provide data exploration and spatial analysis capabilities that support geothermal exploration. This application will be updated in 2014 to allow users to launch the Geothermal Prospector directly from NGDS datasets compliant with the Open Geospatial Consortium, a network of standard coding that enables interoperability among and between diverse geospatial data stores, providers, and applications. The Prospector will provide access to visualization and analysis capabilities for NGDS data. This new capability will also provide an opportunity to test and validate data listed in the NGDS.

This year, the GTO NGDS team—Arlene Anderson, **Dave Cuyler, and Jodi Deprizio—met with Dan Getman and his Data & Visualization staff to foster a partnership on GDR data curation efforts.**

NREL's Geothermal Prospector Team (above), led by Dan Getman, has released a helpful tool to navigate the NGDS. Left to right: Billy Roberts, Donna Heimiller, Ted Quinby, Mike Glason, Anthony Lopez, Dan Getman, Dylan Hettinger, Keith Searight, and Becca Stubbs. Photo courtesy of NREL.

For more information on Systems Analysis, visit the GTO website or contact **geothermal@ee.doe.gov**.

International Collaborations

Since the inception of geothermal energy development at DOE in the 1980s, the Geothermal Technologies Office has partnered with international organizations to improve science and engineering knowledge within the geothermal sector and promote education and information sharing worldwide. Asian and European organizations are active in EGS research and have funded long-term investigations with backing from the public and private sectors. In fact, government investment from the United Kingdom, Japan, and Germany helped to underwrite research that led to breakthroughs in EGS. This ongoing collaboration has yielded mutual benefits—under the framework of the International Energy Agency's Geothermal Implementing Agreement, signed in 1996—by facilitating technological advancements, avoiding duplication, and leveraging limited resources. Collaboration with international scientists involved in similar R&D continues to be a key component of the Energy Department's EGS R&D strategy. Recent cooperation between the United States and Japan led scientists at Kansas State University to collaborate with Japanese researchers to plan flow tests at the Hijiori, Japan research site. The results at Hijiori and at Fenton Hill, New Mexico strongly suggest that better imaging of fluid flow and temperature distribution in EGS reservoirs could dramatically improve injection and production well performance. The research in superresolution seismic imaging using time-lapse vertical seismic profiling and micro-earthquake data—undertaken at Los Alamos National Laboratory—has spurred field testing internationally. Jay Nathwani, GTO's chief engineer, facilitates international collaborations for the program.

The Raft River geothermal site, now commercially owned and operated, was formerly an Energy Department demonstration field site, where research investments yielded a deployable geothermal operation. Today, Energy Department EGS demonstrations are still tested adjacent to the operating hydrothermal field.

Regulatory Roadmap Spurs Geothermal Energy Development

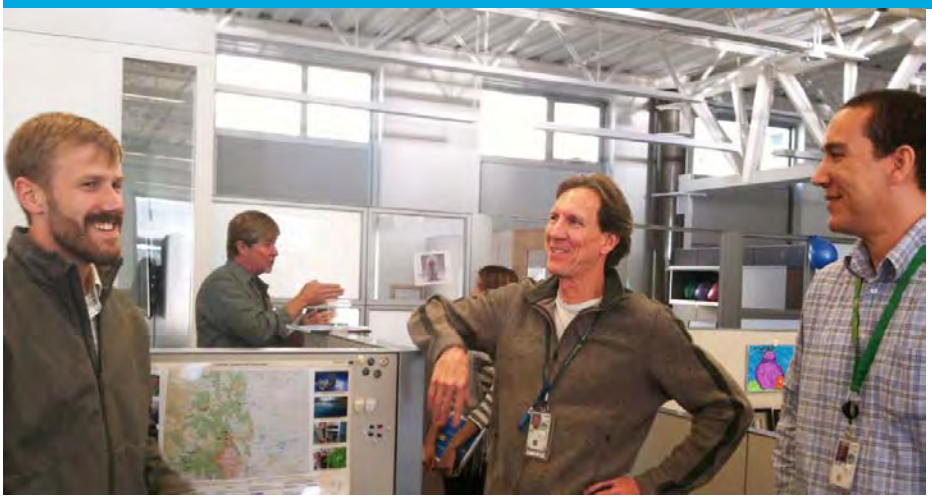
In an Energy Department report published in 2011, industry stakeholders identified the permitting timeline as a major barrier to increasing geothermal power plant development. To address this concern, the GTO collaborated with NREL to create a Geothermal Regulatory Roadmap that will help developers navigate regulatory requirements at every level of government to deploy geothermal energy projects. In partnership with the Bureau of Land Management, U.S. Fish and Wildlife Service, and U.S. Forest Service, NREL convened key federal, state, and local permitting officials, along with industry representatives, to identify potential opportunities for streamlining the efficient and responsible development of geothermal energy in the United States. The roadmap will help strengthen collaboration between federal and state agencies, speed the review of proposed projects, and implement steps that advance efficient and responsible evaluation. Streamlining the permitting process also helps lower development costs and reduces financial risk for utilities.

The roadmap includes distinct flowcharts that address all federal and state regulatory requirements for developing a geothermal resource—from land use and leasing plans, to drilling exploratory wells, to developing a geothermal power plant. These comprehensive flowcharts have now been completed for ten geothermal-rich states: Alaska, California, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Colorado, and Texas.

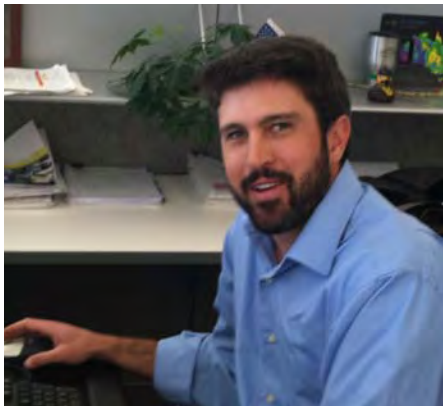
The roadmap is now available, and also includes links to permit application forms, policies, and supporting documents. Permitting resources for the first tranche of states are now complete and available and can be accessed on the Tools and Resources page of this report.

Jay Nathwani, GTO's chief engineer, (right) meets with international participants at the annual peer review.

People



The new 360,000 square-foot Research Support Facility (RSF) in Golden, Colorado is home to team members Erik Swanton, Mark Ziegenbein, Hydrothermal Program Manager Eric Hass, and Mike Weathers.



Dan King, AAAS Fellow, and Ben Phillips, GTO Science Advisor, at Forrestal headquarters; EGS Project Officer Bill Vandermeer at Golden ; the new RSF facility on NREL's campus.

Welcome Home – EERE Employees Move to the RSF Building in Golden

This fall, approximately 290 federal EERE employees in the Golden, Colorado office moved out of the Denver West Office Park and into the Research Support Facility (RSF) on the National Renewable Energy Laboratory (NREL) campus a mile away. The move supports DOE's commitment to decrease operating costs and energy use by residing in a state-of-the-art energy-efficient facility.

The RSF is the laboratory's newest sustainable green building. This 360,000 square-foot Leadership in Energy and Environmental Design (LEED) Platinum office building is a showcase for energy efficiency and renewable energy technologies. The RSF has won numerous awards for its innovative design, construction, and sustainable features.

"Working at the RSF is somewhat like being on a college campus," says Bill Vandermeer, on the EGS team. "The site is very conducive to travel by foot or on a bicycle, and is well integrated with the surrounding environment on the south face of Table Mountain. Interior spaces are modern and well-lit by daylight alone." Bill considers the innovative design a personal challenge to find new ways to be energy-efficient in his personal life as well.

The open working environment has increased the frequency and quality of interaction between EERE and NREL staff, fostered by informal meetings in hallways, meeting rooms, cafes, and gym.

Welcome, New Staff!

Christopher Richard brings a diverse background in business, economics, and policy to the team as a support contractor for GTO. He came aboard in November 2012 to provide support for GTO both in operations, as the office's budget execution analyst, and in Systems Analysis, fielding issues in economics, finance, and policy. In addition to his work at GTO, Chris is completing a PhD in Energy and Environmental Policy from the University of Delaware, where his doctoral research is aimed at modeling the effectiveness of policy incentives on the levelized cost of geothermal power. He also earned his MBA at the University of Delaware, specializing in economics.

Jodi Deprizio joined GTO as a support contractor in January 2013 for Geothermal Data Provision, assisting with the National Geothermal Data System project reviews and tracking data submissions from GTO funds recipients to support the DOE Geothermal Data Repository. Following a three-year internship with the U.S. Geological Survey (USGS). Jodi worked with the Global Fiducials Program to build a collaborative USGS archive of data imagery—once available only to the intelligence community—that now supports scientists and policy makers with global dynamic change. Her degree in environmental science and geology and ongoing graduate studies in geoinformatics and geospatial intelligence allow her to make contributions office-wide.

Mike Weathers is an engineer and project manager for the GTO. He joined DOE in 2009 and spent his last few years in the Weatherization Program, helping local governments manage Recovery Act energy efficiency projects. Before joining DOE, Mike worked in R&D for a large industrial equipment manufacturer, where he developed fluid controls technology for power plants and oil & gas facilities. Mike keeps busy managing about 2 dozen hydrothermal projects in GTO.

Erik Swanton holds a bachelors degree in Mechanical Engineering from Vanderbilt University and a Masters in Aerospace Engineering from University of Colorado. He has worked as a contractor to DOE for nearly three years and joined the Geothermal team a year ago with a general focus on hydrothermal projects.

The Valles Caldera in New Mexico, courtesy of NREL.

GTO Office Contacts

Douglas Hollett, Office Director

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Doug directs the Geothermal Technologies Office in the Office of Energy Efficiency and Renewable Energy (EERE) at DOE. He is responsible for both technical and project oversight and new technologies designed to advance geothermal's role in the U.S. energy portfolio. Doug brings 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 reservoirs using new geologic concepts, and through the use of new drilling and completion technologies.

Eric Hass, Hydrothermal Program Manager

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Eric supervises the hydrothermal portfolio for the Office, including innovative exploration technologies and low-temperature and coproduced resources. Prior to this, Eric managed the EGS program 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, EGS Program Manager

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

Jay Nathwani, Chief Engineer

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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 and Systems Analysis Supervisor

Margaret.Schaus@ee.doe.gov

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

Timothy Reinhardt, Low-Temperature & Coproduced Technology Manager

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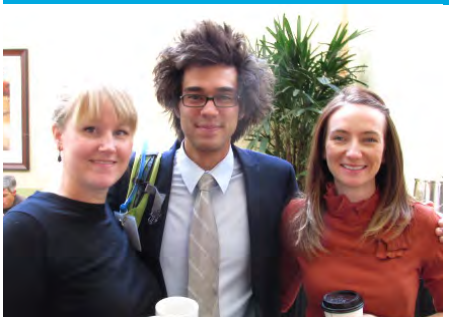
Tim is a physical scientist and the technology manager for low-temperature and coproduced resources, providing oversight and direction for technologies and projects in this sector. He received his bachelor's degree in Environmental Sciences from Northwestern University and and holds Master's degrees from the University of Oklahoma and the University of Texas /Austin.



GTO team members Elisabet Metcalfe, Greg Stillman, and Sara Gonnion (above); GTO Director Douglas Hollett presented a keynote during the opening panel at the Geothermal Resources Council Annual Meeting in September; GTO team member Alethia Marble at Forrestal headquarters.

Q&A with Margaret Schaus, Operations Supervisor

Q. So…what is an Operations Supervisor?

A. The Operations Supervisor role is a new one in EERE, and was created to help relieve the day-to-day operational demands placed on directors and staff in our technology offices. In short, my role is to manage the everyday activities that help our office run—things like budget, contracts management, legislative affairs, communications, staffing, and HR—so that Doug and the team can direct more of their time and attention to advancing our R&D mission. The other GTO hat I wear is as program manager for our Systems Analysis portfolio.

Q. *How do you like the role so far?*

A. It's never a dull moment, that's for sure! I do enjoy the challenge of trying to improve and streamline processes—probably because I was a performance auditor in my pre-DOE life. My role allows me to interact with folks in offices across EERE, and I really enjoy collaborating with others and figuring out how we can best work together. I also have a great group of colleagues in GTO, who are a terrific help in making my job easier.

Q. *What was your biggest highlight or challenge in 2013?*

A. This year, a number of EERE-wide business transformation initiatives were launched. Among other things, the end goal is to have more a consistent way of doing business across our offices, such as how we do lab AOPs and Funding Opportunity Announcements (FOAs). It took a lot of collective staff energy to help move all these changes forward, so there were some challenges there. But I'm hopeful this will be a highlight once it's all completed. Then there was the end of year lapse in appropriations (and I will leave it at that!)

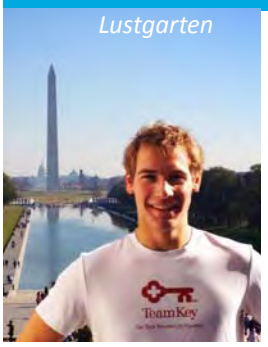
Q. *What are you looking forward to in 2014?*

A. Issuing some GTO FOAs! We will also be updating our Multi-Year Office Plan—essentially GTO's strategic plan—which will help to lay out our Office's goals and objectives for the next 5 years. I look forward to that being a great resource to share with our stakeholders.

Classroom Energy

Sixth graders at Old Mill Middle School in Millersville, Maryland had a Halloween visit from GTO staff Sharon Cosgrove and EERE's Einstein Fellow Josh Sneideman. The interactive day included makeshift laboratories like the one at right, where students compared emissions from a candle—invisible until they held a mirror close to the flame and watched carbon blacken its surface. The same mirror grew steamy but clear when held up to the water vapor piping out of a tea kettle. Young scientists talked over their energy options: burning hydrocarbons to generate steam or letting the Earth heat the water naturally with geothermal energy. One day one of these bright minds may bring the next breakthrough in clean energy. *Photo courtesy of Old Mill Middle School North.*

Education


Lustgarten

GTO Summer Interns

In June 2013, GTO welcomed two undergraduate interns to support the team over the summer: Eric Lustgarten, a rising senior at St. Lawrence University majoring in geology; and Darren Handoko, a rising sophomore at Stanford majoring in Chemical Engineering. "The coolest thing about the internship was our access to the full DC experience—from seminars to conferences and tours—all the interns were encouraged to observe and take part," Eric said.

As he completes his studies, Eric hopes to be a positive influence in the renewable energy sector. "My interests are in the promotion, research, and reality of renewable energy in our near future," he says.

"My summer at the Energy Department was an unforgettable, professional experience," says Darren Handoko. "I got to be at the intersection of some of the newest energy technology research, and I was able to contribute to DOE's communication and education strategy for the general public." Darren is actively engaged in the Internet and cleantech entrepreneurship scene in Silicon Valley and will be a research assistant at Stanford's Center for International Security and Cooperation studying the social and political implications of hydraulic fracturing.


Handoko

University of Rochester Wins Top Honors for Geothermal Innovation

Four finalist teams presented their findings at the National Geothermal Summit hosted by the Geothermal Energy Association in Reno, Nevada June 26-27, 2013. This year's first-place winner in the National Geothermal Student Competition (NGSC) is the University of Rochester, New York, comprised of Talor Walsh, Leah Sabbeth, and team leader David Brink-Roby. Kidus Alemayehu is not pictured. The Oregon Institute of Technology, University of South Dakota, and California Polytechnic University, Pomona also won the distinction of presenting innovative geothermal business plans to industry leaders at the event, where a team of judges ranked their proposals based on written and oral presentations.

NGSC is the Energy Department's annual intercollegiate contest that challenges undergraduate and graduate students to explore cutting-edge technologies, this year by crafting a business plan to develop a geothermal enterprise. While geothermal energy development predominantly occurs in the western United States, the student team from New York proposed an enterprise in a surprising location: the coal fields of Pennsylvania. Rochester's business plan leveraged clean, baseload geothermal energy to mitigate a superfund site there with novel technology.

Rochester's plan would tap heat generated by underground coal fires—naturally occurring smoldering deposits often found in coal mines. Of the 200 coal fires burning nationwide, the Rochester study targeted Pennsylvania, where 45 of these fires continue to burn in the subsurface, closer to the surface than in conventional geothermal drilling. Electricity is generated by using the heat to boil geothermal fluid into steam, resulting in low-cost, carbon-negative energy production from lost resources and long-term alternative energy credits to meet state renewable energy requirements.

Now in its third year, the hands-on competition emphasizes the Administration's pledge to accelerate science, technology, engineering, and math (STEM) education by exploring solutions and technologies that could lead to breakthroughs in geothermal energy development while reducing cost and risks.

Tools & Resources

In FY 2013, GTO supported the development of the following tools and resources, which are available for free and public use. Click on the links below, or use the url addresses to learn more about these resources.

2013 Reports

EGS Roadmap – a technology roadmap for strategic development of enhanced geothermal systems: http://www1.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)

Peer Review Presentations – Complete collection of technical presentations from GTO's 2013 Peer Review: http://www1.eere.energy.gov/geothermal/peerreview.html

Geothermal Technologies Market Trends Report – An updated snapshot of the geothermal market: http://www1.eere.energy.gov/geothermal/pdfs/market-report2013.pdf

GTO 2013 Peer Review Technical Report – Comprehensive final report summarizing GTO's 2013 Peer Review: http://www1.eere.energy.gov/geothermal/pdfs/2013-gto-peer-review-report-lowres.pdf

Latest GTO presentations – http://www1.eere.energy.gov/geothermal/presentations.html

JASON Study on EGS – A report conducted by the JASON group on EGS

Tools

Geothermal Prospector – (nrel.gov/gt_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.

Geothermal Regulatory Roadmap – (openei.org/wiki/GRR) a centralized information resource on the permitting processes for geothermal development in Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, and Texas.

GETEM Geothermal LCOE – (geothermal.energy.gov/geothermal_tools.html) the Geothermal Electricity Technology Evaluation Model (GETEM) is a detailed model of the estimated performance and costs of currently available U.S. geothermal power systems.

JEDI – (nrel.gov/analysis/jedi/about_jedi_geothermal.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.

National Geothermal Data System – (geothermaldata.org) slated for launch in 2014, the NGDS has already collected millions of datasets from state geological surveys, at stategeothermaldata.org and the Geothermal Data Repository, for DOE-funded projects.

Abbreviations

ARPA-E	Advanced Research Projects Agency - Energy
CO_2	Carbon dioxide
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EGS	Enhanced Geothermal Systems
FOA	Funding Opportunity Announcement
FY	Fiscal Year
GEA	Geothermal Energy Assoc
GDR	Geothermal Data Repository
GP/GT	Geopressured-geothermal
GRC	Geothermal Resources Council
GSHP	Ground source heat pump
GTO	Geothermal Technologies Office
GWe	Gigawatt (electric)
kHz	kilohertz
kWe	Kilowatt (electric)
kWh	Kilowatt-hour
LBNL	Lawrence Berkeley National Lab
LLNL	Lawrence Livermore National Lab
LCOE	Levelized cost of electricity
MEQ	Micro-earthquake
MIT	Massachusetts Institute of Technology
MOHC	Metal Organic Heat Carriers
MWD	Measurement while drilling
MWe	Megawatt (electric)
NGDS	National Geothermal Data System
NEPA	National Environmental Policy Act of 1969
NGDS	National Geothermal Data System
NGSC	National Geothermal Student Competition (annual)
NREL	National Renewable Energy Lab
O&G	Oil and gas industry
PNNL	Pacific Northwest National Lab
R&D	Research & Development
RD&D	Research, development, and demonstration
RSF	Research Support Facility (Colorado)
Recovery Act	American Recovery and Reinvestment Act of 2009
SBIR	Small Business Innovation Research program
$scCO_2$	Supercritical carbon dioxide
SiC	Standard industrial classification
SNL	Sandia National Laboratory
USGIN	Geosciences Information Network
USGS	U. S. Geological Survey
VSP	Vertical seismic profile