U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Technologies and Innovations Enabled by the U.S. Department of Energy Geothermal Technologies Office

September 2017

Prepared by Pacific Northwest National Laboratory
for the U.S. Department of Energy Geothermal Technologies Office

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Emerging Technology Innovation Descriptions

- Enhanced Geothermal Systems
- Hydrothermal Resources
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Background

The investigation described in this report identified and documented the research and development (R&D) innovations and technologies that resulted from U.S. Department of Energy (DOE) support through the Geothermal Technologies Office (GTO) in the Office of Energy Efficiency and Renewable Energy (EERE).

This report tracks technologies that were subsequently commercialized by industry and those that are projected to be commercialized in the next 3 to 5 years. These results document the impact of GTO's applied R&D funding from fiscal year (FY) 2009 through FY 2017.

In FY 2014, GTO directed Pacific Northwest National Laboratory (PNNL) to undertake the analysis based on the laboratory's previous expertise, existing databases, and familiarity with EERE Office programs through years of similar analysis. PNNL conducted an investigation to identify GTO-funded innovations by examining GTO's funded research portfolio, including, American Recovery and Reinvestment Act (ARRA), Small Business Innovation Research (SBIR), and Small Business Technology Transfer (STTR) program awards. PNNL reviewed project listings provided by GTO office staff, published annual peer review reports, and project listings on GTO's EERE website. This resulted in 385 identified project items, which, with assistance from GTO staff, was further reviewed and reduced to 214 potential projects that could result in commercial technologies. PNNL, with assistance from GTO staff, established contact information from those 214 project's principle investigator or point of contact. PNNL then contacted each project contact and inquired as to each project's technology status to determine which projects have any technology that was either commercialized, emerging (commercial within 3-5 years), or potential (> 5 years from commercialization).

As of the end of FY 2017, PNNL has identified 69 active projects with technologies from the 214 projects investigated. These 69 active projects produced 16 commercial, 22 emerging, and 31 potential technologies, the remaining 145 projects investigated were either inactive or would not produce any technology for commercialization. Of the majority of the commercial technologies, nine are from the enhanced geothermal system subprograms; four are from the low temperature and coproduced subprogram, two from the hydrothermal resources subprogram, and one crosscutting. The emerging technologies are approximately evenly distributed across the enhanced geothermal systems, hydrothermal resources, and low temperature and coproduced subprograms. The majority of the potential technologies (24) are from the enhanced geothermal systems subprogram with the remaining seven technologies crosscutting.

Half of the commercial technologies were initially funded in 2009 with five technologies achieving commercial status in 2013. Since 2011, approximately two technologies per year have been commercialized or in-use. On average, it takes approximately six years from the initial funding year for a technology to become commercialized. Nine of the emerging technologies were funded in 2009, four technologies prior to 2009, and the remaining nine technologies were funded post 2009. Most of the potential technologies were funded before 2012 (25) with the remaining six technologies funded from 2012 onwards.

This report documents the specific technology innovations, both commercial and emerging, developed by industry and supporting partners that can be attributed to early GTO R&D funding.

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Technology Innovations Tracking List

Enhanced Geothermal Systems

Hydrothermal Resources

Low Temperature & Coproduced Resources

Crosscutting Technology Innovations

Enhanced Geothermal Systems Technology Innovations

Technology Title	Company	Innovation Status
300°C Capable Electronics Platform and Temperature Sensor System for Enhanced Geothermal Systems	GE Global Research	Emerging
3D Data Analysis of Seismic Data in Geothermal Reservoirs Using Noise and Coda Wave Correlation	Fugro William Lettis and Associates	Commercial
Abrasive Slurry Jet Drilling of Microhole Arrays in Enhanced Geothermal Systems	Impact Technologies LLC	Emerging
Advanced Stimulation Prediction Model for Enhanced Geothermal Systems	Colorado School of Mines	Emerging
Controlled Pressurization for EGS Well Stimulation	Sandia National Laboratories	Emerging
Desert Peak Enhanced Geothermal System: Improving Electric Power Generation	Geothermex & Ormat Nevada, Inc.	Commercial
Enhanced Geothermal System for Increasing Electricity Generation at Brady's Hot Springs, Nevada	Ormat Technologies, Inc.	Commercial
Fiber/Copper Cable Solution for Long Term Temperature and Pressure Measurement in Supercritical Reservoirs and EGS Wells	Draka Cableteq USA, Inc.	Commercial
High Performance Fluoroelastomer Nanocomposite Seals for Geothermal Submersible Pumps	NEI Corporation	Emerging
High Temperature Directional Drilling System	Baker Hughes Oilfield Operations	Emerging
High-Temperature Circuit Boards for Use in Geothermal Well Monitoring Applications	Composite Technology Development, Inc.	Commercial
Imaging Fluid Flow in Geothermal Wells Using Distributed Thermal Perturbation Sensing	Lawrence Berkeley National Laboratory	Emerging

Enhanced Geothermal Systems Technology Innovations

Technology Title	Company	Innovation Status
Multichip Module (MCM) to Enhance High Temperature Accelerometer Measurements	Sandia National Laboratories	Emerging
NANUQ® CTD-1210R: High Temperature Electrical Insulation	Composite Technology Development, Inc.	Commercial
OM300: GeoThermal MWD Navigation Instrument (A High Temperature 300°C Directional Drilling Tool)	Honeywell Aerospace & Applied Physics Systems	Emerging
SPI Silicate Conformance Gels for Improved Process Efficiency in Geothermal Zonal Applications	Clean Tech Innovations	Commercial
Stinger Enhanced Drill Bits for EGS	Novatek, Inc.	Commercial
Well Monitoring Systems for EGS	Perma Works LLC	Commercial

Hydrothermal Resources Technology Innovations

Technology Title	Company	Innovation Status
Advanced Heat/Mass Exchanger Technology for Geothermal and Solar Renewable Energy Systems	University of Nevada, Reno	Emerging
Auto Indexer for Percussive Hammers in Hard Rock Formations	Sandia National Laboratories	Emerging
Deep Geothermal Drilling Using Millimeter Wave Technology	Impact Technologies LLC	Emerging
El Paso County Geothermal Project at Fort Bliss	El Paso County, Ruby Mountain Inc. & Energy and Geoscience Institute at the University of Utah	Emerging
Fiber Optic Downhole Seismic Receiver Array for Surveying and Monitoring of Geothermal Reservoirs	Paulsson, Inc.	Commercial
GeoOptics: High-Temperature Optical Seismic Sensor	MagiQ Technologies, Inc.	Commercial
Harsh Environment Silicon Carbide Sensor Technology for Geothermal Instrumentation	UC San Diego	Emerging
Improved Cement for Geothermal Wells	Trabits Group LLC	Emerging

Low Temperature & Coproduced Technology Innovations

Technology Title	Company	Innovation Status
Beowawe Binary Bottoming Cycle[1]	Beowawe Power LLC	Commercial
Bottoming Binary-Cycle Power Plant Using Low-Temperature Geothermal Fluids	Terra-Gen LLC	Commercial
High-Temperature Ultracapacitors for Geothermal Exploration	FastCAP Systems, Inc.	Emerging
Low-Temperature Stirling Engine for Geothermal Electricity Generation	Cool Energy, Inc.	Emerging
Metal Extraction Geothermal Fluids	Simbol Mining Corp.	Emerging
Metal Organic Heat Carrier Nanofluids for Low-Temperature Geothermal Systems	Pacific Northwest National Laboratory	Emerging
Mineral Extraction from Geothermal Fluids	Lawrence Livermore National Laboratory	Emerging
Novel Energy Conversion Equipment for Low Temperature Geothermal Resources	Johnson Controls, Inc.	Emerging
Power Generation from Low to Intermediate Temperature Resources	University of North Dakota	Commercial
Power+ Generator™: Electrical Power Generation from Heat Co-Produced in Geothermal Fluids	ElectraTherm, Inc.	Commercial
Variable Phase Turbine Power System for Low Temperature Geothermal Resources	Energent Corporation	Emerging

[1] For more information refer to “Bottoming Binary-Cycle Power Plant Using Low-Temperature Geothermal Fluids”

Crosscutting Technology Innovations

Technology Title	Company	Innovation Status
Vortex Enhanced Direct Contact Heat Exchanger for Geothermal Cooling	Advanced Cooling Technologies, Inc.	Commercial

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Technology Innovation Descriptions

Enhanced Geothermal Systems

- 3D Data Analysis of Seismic Data in Geothermal Reservoirs Using Noise and Coda Wave Correlation
- Desert Peak Enhanced Geothermal System: Improving Electric Power Generation
- Enhanced Geothermal System for Increasing Electricity Generation at Brady's Hot Springs, Nevada
- Fiber/Copper Cable for Long Term Temperature and Pressure Measurement in Supercritical Reservoirs and EGS Wells
- High-Temperature Circuit Boards for Use in Geothermal Well Monitoring Applications
- NANUQ® CTD-1210R: High Temperature Electrical Insulation
- SPI Silicate Conformance Gels for Improved Process Efficiency in Geothermal Zonal Applications
- Stinger Enhanced Drill Bits for EGS
- Well Monitoring Systems for EGS

Hydrothermal Resources

- Fiber Optic Downhole Seismic Receiver Array for Surveying and Monitoring of Geothermal Reservoirs
- GeoOptics: High-Temperature Optical Seismic Sensor

Low Temperature & Coproduced Resources

- Bottoming Binary-Cycle Power Plant Using Low-Temperature Geothermal Fluids
- Power Generation from Low to Intermediate Temperature Resources
- Power+ Generator™: Electrical Power Generation from Heat Co-Produced in Geothermal Fluids

Crosscutting

- Vortex Enhanced Direct Contact Heat Exchanger for Geothermal Cooling

Enhanced Geothermal Systems

- 3D Data Analysis of Seismic Data in Geothermal Reservoirs Using Noise and Coda Wave Correlation
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- Well Monitoring Systems for EGS

3D Data Analysis of Seismic Data in Geothermal Reservoirs Using Noise and Coda Wave Correlation

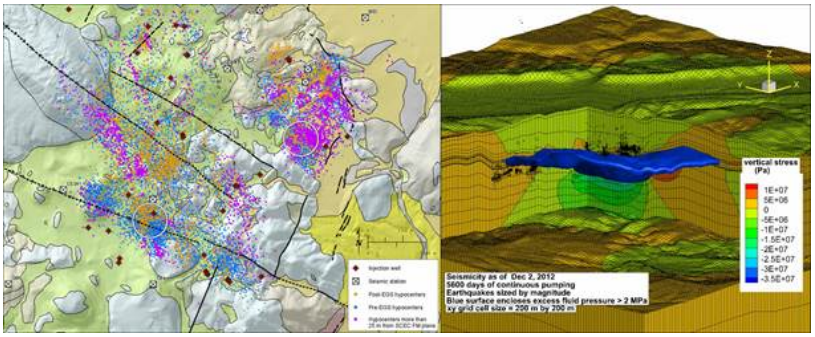
Enhanced Geothermal Systems | Commercial Technology

Seismic Data Analysis Accurately Determines of Sub-Surface Activity in Geothermal Reservoirs

Exploration, evaluation, and development of geothermal resources typically has relied on analysis of active seismic sources, including surface and/or vertical seismic profiling to accurately locate induced micro-earthquakes (MEQs). The location accuracy of these techniques are sensitive to three-dimensional (3D) compression and shear-wave (P- and S-wave) velocity structure. Seismic waveform analysis typically requires large-scale supercomputing facilities and small changes in the analysis scope, e.g. maximum frequency range, can increase computation time by orders of magnitude. Advances in graphic processing units (GPUs) allow teraflop computational capabilities in a single inexpensive graphics card. These advances combined with parallel programming and other computing techniques, e.g., message-passing libraries (MPIs), could enable PC-based analysis of 3D seismic waveform data.[1]

With assistance from GTO (as part of the American Recovery and Reinvestment Act), Fugro Consultants, Inc. developed a method for accurately locating MEQ locations with better resolution of the 3D velocity structure. The technique uses correlation Green's function (CGF) methods to analyze ambient noise and MEQ coda data from combinations of seismographic monitoring stations in the region of interest and has been integrated into their current surveying practices. The body- and surface-wave travel-time and waveform analysis analyses provide a 3D P- and S-wave velocity structure in the top several kilometers of the earth's crust. The information and software tools developed by Fugro provide a quantitative basis for improved seismographic equipment deployment in the field for optimized ambient noise and MEQ data analyses in support of EGS development.[2]

Current code development and optimization has led to further applications in academic geothermal and geological research. Analysis of U.S. Geological Survey (USGS) data has also been expanded to assist in early detection of national earthquake hazards.



Seismic Analysis Output for Coso (LHS) and Paradox Valley (RHS)

Overview

- Developed by Fugro Consultants, Inc. in collaboration with U.S. Department of the Interior, Bureau of Reclamation, U.S. Geological Survey, University of Wyoming, and Virginia Tech.
- Commercialized in 2015.

Applications

Can be used for field analysis of seismic data in support mining, oil, gas, and geothermal exploration and production.

Capabilities

- Allows high-accuracy (<10 m) determination of MEQs, fault/shear planes, and fractures.
- Provides in-situ computationally intensive seismic analysis.
- Provides inexpensive seismic monitoring with increased resolution.
- Achieves 30x speed improvement compared to 10x using commercially available code.
- Achieves additional computational modeling performance gains by using additional or multiple GPUs.

Benefits

Cost Savings

Reduces seismic risks by providing near-real-time analysis results during EGS stimulations.

Public Safety

Optimized data algorithms improve USGS data analysis for early detection of potential national earthquake hazards.

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[1] GTO ARRA Project 2010
[2] GTO 2013 Peer Review Presentation

Desert Peak Enhanced Geothermal System: Improving Electric Power Generation

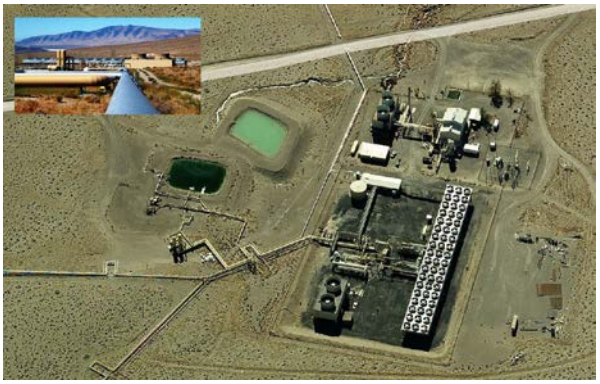
Enhanced Geothermal Systems | Commercial Technology

Stimulation Process Increases Productivity and Extends Usable Life of Geothermal Reservoirs

GTO's initiatives to develop and deploy technologies for clean domestic power generation include promoting commercial pathways to enhanced geothermal systems (EGSs).[1,2] In nature, geothermal systems occur as hydrothermal systems (e.g., hot springs or geysers). Typically, geothermal energy is harnessed for generating electricity (e.g., binary power plants). In contrast, an EGS is a fabricated geothermal reservoir created by injecting fluid at low-pressure into the subsurface to open or re-open pre-existing fractures. This allows the fluid to circulate throughout the hot rock, creating a geothermal reservoir. Technologies for EGS include directional drilling and pressurized water to enhance flow paths in the subsurface rock and create new reservoirs, capturing energy from resources that were considered uneconomical or unrecoverable.

With funding from GTO, Ormat Nevada, Inc. (Ormat) has used numerous EGS technologies to extend the life of a poor performing well, #27-15, in the Desert Peak geothermal field in Nevada. Ormat conducted a comprehensive geophysical data analysis that included several surveying techniques (e.g., seismic refraction and reflection, magnetotelluric, and sonic log data). This analysis was used to determine a stimulation plan to propagate pre-existing soft rock fractures. Ormat then used shear, chemical (chelating and acid agents), and hydro-frac stimulation techniques to open up permanent fractures and enhance hydraulic connection (flow) with the heat-producing reservoir. Seismicity was continuously monitored and analyzed during the stimulation process. The productivity of the marginal well was improved after well maintenance and a second pulse stimulation was performed, enabling a higher fluid injection rate than initially observed (> 2 gpm/psi).

This improved hydraulic connection to more productive areas of the geothermal field has increased power generation output by 38% (1.7 MW) at Ormat's Desert Peak #2 binary power generation facility. This facility consists of two binary power plants with a combined electric power output of approximately 25 MWe. The Desert Peak facility was recognized in April 2013 as the nation's first commercial EGS project to supply electricity to the grid; the power was sold to NV Energy as part of their geothermal energy portfolio.[3]



Ormat's Geothermal Power Plant at Desert Peak in Nevada

Overview

- Developed and deployed by Ormat Nevada, Inc. in collaboration with industry partners.
- Electricity generated was first supplied to the power grid in 2013, supplying power to Los Angeles as of 2015.

Applications

Can be used to stimulate marginal geothermal fields for power generation.

Capabilities

- Provides a systematic multi-disciplined, multi-phased planning and implementation process for EGS stimulation of marginal/non-productive wells.
- Achieves geothermal well stimulation using viable and current technologies.
- Achieves increased well productivity (e.g., 38% power generation increase) at Desert Peak well #27-15.

Benefits

Cost Savings

Provides thorough analysis, optimization, and cost estimate associated with EGS reservoir development, minimizing risk, and cost.

Environment

Provides power generation using naturally occurring geothermal resources and reduces the need to construct new wells.

Viability

Uses commercially viable, repeatable, transferable, and cost-effective technologies.

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[1] For more information: EERE GTO Website - Enhanced Geothermal Systems
[2] For more information: EERE GTO EGS Factsheet - DOE/EE-0785, September 2012
[3] For more information: EERE GTO Article - "First Commercial Success for EGS", April 2013

Enhanced Geothermal System for Increasing Electricity Generation at Brady's Hot Springs, Nevada

Enhanced Geothermal Systems | Commercial Technology

Stimulation Process Increases Productivity and Extends Usable Life of Geothermal Reservoirs

Nevada has over 300 hot springs, the most of any state, and Brady's Hot Springs is one of the hottest, with fluid temperatures around 210°F at the surface.[1] The geothermal resource at Brady's Hot Springs is a series of active vents and fumaroles that can be readily seen at the surface. The geothermal reservoir at Brady's Hot Springs was identified as a good candidate for GTO's initiative to improve and increase geothermal power generation using enhanced geothermal systems (EGSs).

With funding from GTO, Ormat Nevada, Inc. (Ormat), has used numerous EGS technologies to increase well stimulation in the southwestern part of the geothermal field near the Brady's fault production area. Ormat has used their "EGS Toolbox", an approach and strategy developed from experience on previous EGS projects. They conducted a comprehensive analysis and modeling of core samples, lithologic, temperature, InSAR, and Schlumberger FMI wellbore imaging data from the area around a marginal well (#15-12 ST1). The combination of tectonics, geology, petrology, rock mechanics, and stress analysis indicated that the well intersected rock formations suitable for EGS stimulation (i.e., a formation favorable for development of hydrothermal circulation).[2]

The stimulation plan leveraged the experience from previous work at Desert Peak. At Brady's Hot Springs, low-pressure shear, mixed-mode hydro-shear stimulation (injection at increasing rates and pressures), and high-rate pulse stimulation were used. Real-time seismic monitoring was used to observe micro-earthquake (MEQ) events to track progress and stimulation effectiveness. The enhanced permeability in well #15-12 ST1 has improved hydraulic connection and is currently being evaluated to increase power generation. Geothermal power generation at Brady's Hot Springs started in 1992 and currently consists of three double flash units with a total capacity of 24 MW_e.[3]



An Ormat Geothermal Power Plant at Brady's Hot Springs in Nevada

Overview

- Developed and deployed by Ormat Nevada, Inc. in collaboration with industry partners.
- Geothermal power generation at Brady's Hot Springs began in 1992.

Applications

Can be used to stimulate marginal geothermal fields for power generation.

Capabilities

- Provides a systematic multi-disciplined, multi-phased planning and implementation process – "EGS Toolbox" – for EGS stimulation of marginal/non-productive wells.
- Provides real-time seismic monitoring of MEQ events to gauge stimulation progress.
- Achieves geothermal well stimulation using viable and current technologies, including low-pressure hydraulic techniques.
- Achieves increased well productivity (e.g., 10% power generation increase) at Brady's Hot Springs well #15-12 ST1.

Benefits

Cost Savings

Provides thorough analysis, optimization, and cost estimate associated with EGS reservoir development, minimizing risk, and cost.

Environment

Provides power generation using naturally occurring geothermal resources and reduces the need to construct new wells.

Viability

Uses commercially viable, repeatable, transferable, and cost-effective technologies.

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[1] For more information: http://www.hotspringsenthusiast.com/Nevada.asp
[2] For more information: Ormat Brady EGS GTO 2013 Peer Review
[3] Visit: http://www.nvenergy.com/renewablesenvironment/renewables/geothermal.cfm

Fiber/Copper Cable for Long Term Temperature and Pressure Measurement in Supercritical Reservoirs and EGS Wells

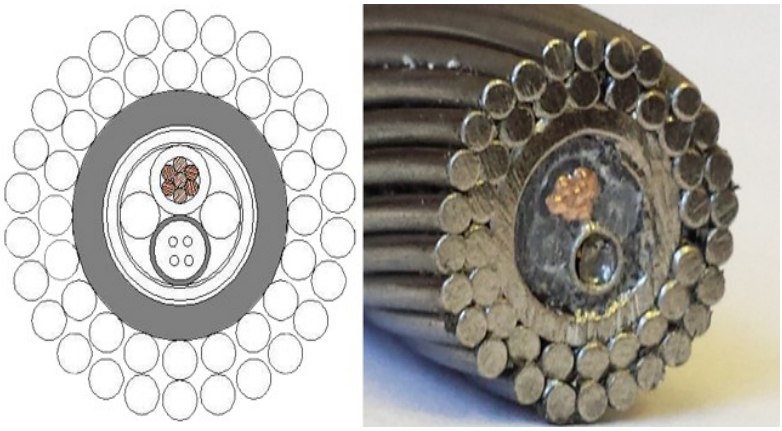
Enhanced Geothermal Systems | Commercial Technology

Durable Fiber Optic Cable and Cable Carrier Provides Data and Power Connection in Downhole

The search for new energy resources, particularly in sub-surface operations found in oil, gas, and geothermal energy exploration, can be aided by technologies and tools that provide data about the conditions encountered (e.g., temperature and pressure).[1] Temperature measurements are used in downhole processes to monitor the status or production performance. Downhole sensors typically use fiber optics to obtain thermal profiles along the entire length of the well and transmit data to the surface. These cables incorporate electrical conductor carriers that provide power and communications with other sensors. The cables and sensors must withstand the harsh environments found in geothermal and other similar sub-surface applications (e.g., high temperature, pressure, and highly corrosive applications).

Draka Cableteq USA, Inc., with assistance from GTO (as part of the American Recovery and Reinvestment Act), has developed a self-supporting fiber optical cable (no additional support or protective covering is required) using hydrogen tolerant optical fiber and a polyimide coating; both are rated for use at depths down to 10,000 m and temperatures up to 300°C.[2] Draka developed a unique glass chemistry process with fluorine doping, which improved the fiber's resistance to hydrogen darkening. Hydrogen darkening, which is negligible below 85°C, is a concern (light transmission) at the higher pressures and temperatures observed in downhole applications. The self-supporting and high operating temperatures required a new dry buffer-tube cable design, with non-gel filler, using optical fiber(s) housed within a metal tube. Draka has since been awarded a U.S. patent (USPTO 8,9292,701) for their dry buffer-tube design. The optical fiber went through a series of tests at Sandia National Laboratory, during which resistance to hydrogen was measured and the cable was evaluated at an Altarock Energy test site where Raman and Brillouin temperature measurements were used to validate the cable design.

Draka Cableteq commercially released the cable in late 2013; incorporating HP & HT polyimide coated optical fibers for harsh environment applications. The cables included electrical conductors insulated with DuPont Ecctreme™ ECA 3000 high temperature perfluoroplastic.



Draka Cableteq's Downhole Cable

Overview

- Developed by Draka Cableteq USA, Inc. in collaboration with industry partners.
- Commercialized in 2013 and available from Prysmian Group.

Applications

Can be used in downhole applications in oil, gas, and geothermal applications.

Capabilities

- Provides self-supporting fiber optic cable for temperature and pressure measurements at depths up to 10,000 m.
- Achieves operation in harsh environments at temperatures up to 300°C and high pressure (up to 2000 bar).
- Provides resistance to hydrogen darkening at high temperatures (up to 300°C).
- Provides single (SMF) and multi-mode (MMF) optical fiber options.

Benefits

Cost Savings

Allows downhole measurement data collection, which is needed to assess exploratory actions and downhole production potential or performance in oil, gas, and geothermal sectors.

Usability

Provides a multi-purpose, long-term deployment fiber optic distributed temperature sensor as well as a power/communication link for downhole measurement sensors.

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[1] For more information: 2011 GTO Peer Review Summary Report
[2] For more information: 2013 GTO Peer Review Presentation

High-Temperature Circuit Boards for Use in Geothermal Well Monitoring Applications

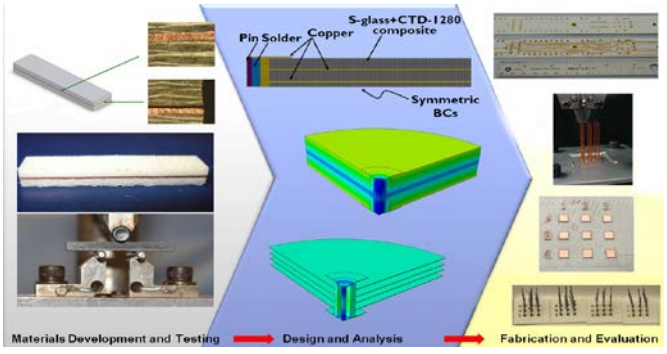
Enhanced Geothermal Systems | Commercial Technology

Circuit Board Material Improves Reliability when Operating in Harsh Environmental Conditions

Geothermal energy offers an abundant, renewable source of power, which in the United States is produced from relatively shallow wells that contain naturally occurring water sources. Expanding the use of geothermal energy will require technologies that can extract thermal energy from hot, dry rock deep below the surface, up to 10 km depths. Enhanced geothermal systems (EGSs) are created by pumping water into these deep wells to create geothermal reservoirs.[1] Technologies used to create EGSs must withstand high pressures and temperatures near 350°C. Ruggedized data-logging and any other electronic devices used to explore, map, and monitor underground activities in EGS processes are needed. The sub-surface conditions at these depths presents an operational reliability challenge for multilayer printed circuit boards (mPCBs) that become unstable. The highest temperature rated circuit boards currently available have a maximum rating in the 200 – 250°C range (military specification per MIL-STD-810G is 50°C max).

Composite Technology Development, Inc. (CTD), with assistance from GTO (as part of the American Recovery and Reinvestment Act) and collaborators, has developed a new class of high-temperature resin that can operate reliably in EGS environments and can be used for mPCBs. CTD evaluated numerous glass reinforced organic and inorganic polymers using test methods to model electromechanical durability and reliability (e.g., conductor adhesion, shear strength, elevated temperature, and thermal shock testing). Conductor adhesion is crucial to preventing delaminating and electromechanical failure. CTD has fabricated and tested prototype functional electronic packages under simulated EGS well conditions (T ~300°C) and observed reliable thermal stability and electrical insulation. CTD also found that the high-aspect-ratio packages needed for downhole equipment required a glass fiber reinforced polymer versus a ceramic based multilayered circuit module (MCM) to prevent damage from mechanical and vibrational loads.[2]

The material developed is now a part of CTD's 1800 class of silica/silicone based resins and insulation systems. These materials have high temperature capabilities, can be processed using several standard processes, and are used as electrical insulation and/or in a structural capacity. End users have shown interest in these materials for motor, generator, magnet, and circuit insulations, with applications in the geothermal, oil, and gas industries.



CTD-1280 Development Cycle

Overview

- Developed by Composite Technology Development, Inc. in collaboration with Calumet Electronics Corporation and Sandia National Laboratories.

Applications

Can be used for fabricating electronics (mPCBs and modules) or insulating systems where reliable operation in harsh conditions (elevated temperature and pressure) is required (e.g., geothermal, oil and gas, and fusion reactor applications).

Capabilities

- Provides reliable mechanical, thermal, and electrical properties at elevated temperatures and pressures.
- Provides strong adhesion to copper and resists delamination in single and multilayer circuit boards.
- Provides compatibility with existing state-of-the-art circuit board fabrication manufacturing processes and practices.

Benefits

Cost Savings

Reduces costs associated with lost production and equipment replacement or downtime caused by environmentally induced stress failures.

Reliability

Improves circuit board operational reliability and robustness in harsh environments by using a glass fiber reinforced polymer versus ceramic-based circuit board materials.

Safety

Ruggedized electronic equipment operating in harsh environments could prevent facility damage and/or personnel injury caused by equipment failures.

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[1] GTO 2012 EGS Factsheet
[2] GTO 2012 Peer Review Presentation

NANUQ® CTD-1210R: High Temperature Electrical Insulation

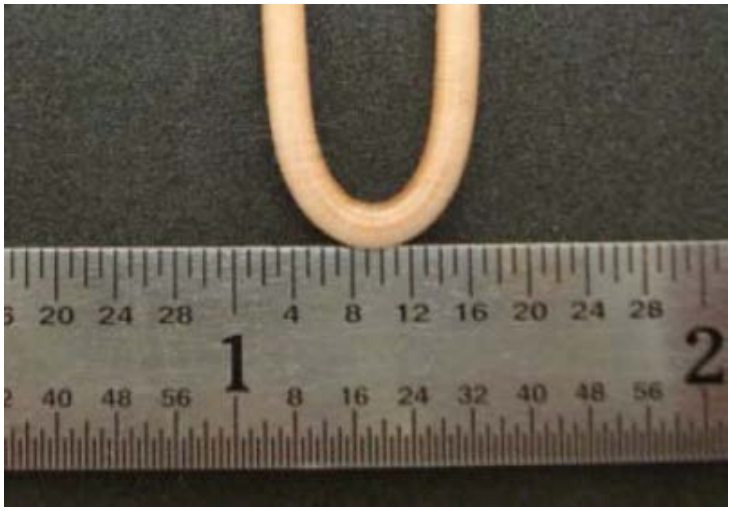
Enhanced Geothermal Systems | Commercial Technology

Insulation Improves High Temperature Performance

Geothermal technologies represent an attractive source of renewable energy that could provide the U.S. with sustainable power from many domestic locations. However, these sources often require substantial downhole depths prior to becoming viable geothermal sites. Large hole depths lead to increased operating temperatures that prohibit the long term use of conventional polymer wire insulations. Insulation failure can lead to electric current leaks and eventual failure of the electronic submersible pumps (ESPs) and motor lead extensions that are connected to the failing wire. New high-temperature capable solutions are needed to improve wire reliability in deep downhole.

Composite Technology Development, Inc. (CTD), and industry partners Von Roll USA and Wood Group ESP; with assistance from GTO, in the form of SBIR grants including a 2013 Xlerator grant; has developed a new, highly flexible composite material, CTD-1210R, for electrical insulation at high temperatures. The insulation improves high temperature durability without sacrificing the mechanical properties needed for proper spooling and downhole deployment activities. At temperatures over 250°C the wire has up to eight times higher electrical resistivity compared to common polymer insulations. The insulation properties allow it to be applied in fields that have extreme conditions. These include applications in motor windings, downhole heaters, and micro-hole drilling operations.

CTD-1210R is a commercial material and is fabricated through a continuous in-line process. It is supplied as insulated wire and currently available on 12 AWG copper wire. The intended application is for use in ESP motors, but the material and process are applicable to other wire sizes and cables. CTD is investigating further applications in the oil and gas industries as well as possible applications in high temperature motors, engines, and generators.



CTD-1210R Insulated Wire bent to high strain

Overview

- Developed by Composite Technology Development, Inc. in partnership with Von Roll USA and Wood Group ESP.
- Commercialized in 2016.

Applications

Can be used in power supply applications that are exposed to high temperature conditions.

Capabilities

- Provides high temperature insulation with low electric current leakage.
- Provides improved performance at 300°C in oil and up to 450°C in air.
- Offers excellent copper wire adhesion.
- Long-term thermal stability at 300°C.
- High strain capability for motor winding.
- High abrasion resistance for demanding motor winding activities.

Benefits

Cost Savings

Reduces replacement costs by offering improved long-term thermal stability.

Durability

Offers high strain capability and abrasion resistance.

Environment

Allows electronic submersible pumps to be implemented at greater depths.

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SPI Silicate Conformance Gels for Improved Process Efficiency in Geothermal Zonal Applications

Enhanced Geothermal Systems | Commercial Technology

Injectable SPI Gel Solution Improves Reservoir Process Efficiencies and Reduces Costs

CO_2 flooding is used by the oil industry to recover oil from reservoirs that have been depressurized through primary production techniques. The process uses injected CO_2 to force oil toward a production well.[1] While this method is often used to extend the life of existing wells, it can be hampered by the tendency for injected CO_2 to follow paths of least resistance. Flow convergence forces operators to inject more CO_2 than is ideal and often requires injected CO_2 to be heavily recycled, reclaimed, cleaned, and reinjected. This leads to low process efficiency or increased operating costs because wells stop producing and a new viable location has to be found. This same process inefficiency occurs in oil resevoir waterflooding and enhanced geothermal systems operations.

To address these issues Clean Tech Innovations, with assistance from GTO, has developed a new Silicate-Polymer-Initiator (SPI) gel for high temperature geothermal applications. The SPI gel can be injected as a water-like solution into existing wells to set up and block areas of high flow. This forces injectable fluids (CO_2, water) to contact different areas of the reservoir. Multiple injections of SPI gel can incrementally close high flow areas to drastically improve overall yield from existing wells. SPI gels offer durability benefits over common cross-linked polyacrylamide gels that allow them to seal even in difficult situations while retaining the capability to be removed without drilling.

SPI Technologies offers customized gel treatment options to further increase SPI gel performance. Treatment options are available for both injection and production wells in CO_2, waterflood and geothermal applications.



SPI Technologies' SPI Silicate Gel

Overview

- Developed by Clean Tech Innovations LLC for oilfield waterfloods and CO_2 floods. Now extended to high temperature geothermal applications.
- Commercialized in 2016 by SPI Technologies LLC.

Applications

Can be applied in oilfield waterflood and CO_2 flood wells to improve process efficiency, yields and reduce costs.

Capabilities

- Reduces CO_2 cycling into injection wells by up to 70%.
- Reduces CO_2 gas to oil ratios by up to 81%.
- Offers up to 10 times greater gel strength compared to high molecular weight polyacrylamide gels.

Benefits

Cost Savings

Reduces the amount of CO_2 needed during the CO_2 flooding process by blocking low yield flow paths and minimizes the need for CO_2 re-injection activities in both oil and geothermal applications.

Efficiency

Improves process efficiency, reducing cycling of injectants (CO_2, water) that allows more oil to be produced from existing CO_2 flood wells or higher temperature produced water from geothermal wells.

Flexibility

SPI silicate gel formulations can be tailored to individual applications to improve yields, including high temperature applications.

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[1] For More Information: Carbon Dioxide Enhanced Oil Recovery.

Stinger Enhanced Drill Bits for EGS

Conical-Shaped Diamond Cutting Elements Improve Drill Bit Performance and Durability

The widespread development of enhanced geothermal systems will require drilling through a variety of hard rock formations to gain access to the subsurface geothermal (hot rock) resource. Fixed-blade drill bits using disk-shaped polycrystalline diamond compact (PDC) cutters experience a decline in rate of penetration (ROP) during bit runs in hard rock formations. To counteract the drop in ROP, drill operators often increase the weight on bit, which wears out PDC cutter edges and eventually results in the bit being pulled.

With assistance from the U.S. Department of Energy's Geothermal Technologies Office, Novatek, Inc., developed conical-shaped PDC cutters that improve the performance of fixed-blade shearing bits in hard rock formations. Novatek's Stinger cutters have a thicker polycrystalline diamond "table" (the part of the cutter that comes in contact with the rock) than disk-shaped cutters, which improves impact strength and wear resistance. The conical shape of the Stinger cutters applies a more concentrated point load on the rock than a conventional PDC cutter, which breaks hard rock formations more efficiently. The combination of concentrated cutting force and improved durability enables greater ROP. As a result, drilling objectives can be achieved in fewer drilling days. The Stinger cutters are currently being used in oil and gas drilling applications in the North Sea and North Dakota.

The conical diamond cutters are also being used in asphalt milling equipment as a longer-lasting substitute for the conventional tungsten-carbide "teeth" in milling drums. The polycrystalline diamond milling teeth last 40 times longer than tungsten-carbide milling teeth.[1] This improved durability reduces equipment downtime for teeth replacements and reduces teeth replacement costs. Over 200 asphalt milling drums with Novatek's polycrystalline diamond milling teeth are operating worldwide.



Drill Bit with Novatek's Stinger Conical PDC Cutters

Overview

- Developed by Novatek, Inc.
- Commercialized in 2013.
- Used by Smith Bits/Schlumberger (http://www.slb.com) for oil/gas drilling and by Caterpillar, Inc. (http://www.cat.com/) for asphalt milling.

Applications

Can be used to drill wells for enhanced geothermal systems and oil/gas production. Can also be used in crushing/grinding applications, such as asphalt milling and mining.

Capabilities

- Increases drilling ROP in hard rock formations relative to bits using conventional PDC cutters.
- Applies a concentrated point load to crush the rock, resulting in larger cuttings that improve lithology analysis.
- Drills with less torque than bits with conventional PDC cutters, enabling improved directional drilling with higher build rates.

Benefits

Cost Savings

Reduces well-drilling costs by reducing the number of drilling days required to achieve an objective. Reduces asphalt milling costs by reducing the number of teeth replacements.

Durability

Lasts 40 times longer than conventional tungsten carbide teeth used in asphalt milling drums.

Energy Savings

Reduces milling machine fuel consumption through improved asphalt milling performance.

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[1] *Performance Comparison of Diamond-Enhanced and Tungsten Carbide Teeth for Road Milling*. Transportation Research Record: Journal of the Transportation Research Board. Issue Number 2282, pp 45-48. 2012.

Well Monitoring Systems for EGS

Electronic Equipment Operates at High Temperature and Pressure Found in Geothermal Wells

The discovery and development of geothermal resources requires sub-surface imaging and characterization to validate and determine cost-effective, optimized approaches for development into an extended geothermal system (EGS). Geothermal wells are hot—too hot for conventional electronic equipment used in oil and gas exploration. It has been common practice to use oil and gas well logging equipment tools placed inside a thermally insulated container for protection. The equipment must be retrieved after 8 to 10 hours to prevent damage, which is rather inconvenient as EGS operations (testing and stimulation) can run for months at a time.[1]

Perma Works LLC (PW), with assistance from GTO, has developed downhole monitoring tools that can withstand the extreme downhole environments without any time restrictions.[2] PW licensed High-Temperature Silicon-On-Insulator (HT SOI) electronics technology from Sandia National Laboratories; this technology was originally developed for aircraft engine controls. PW needed the HT SOI high-temperature rating to design and develop their tools for monitoring geothermal wells. HT tools for measuring pressure, temperature, and fluid flow were developed; analog electronics rated for 300°C for pressure and temperature measurement (PW-PT550AT), digital electronics rated for 250°C for temperature, pressure, and fluid flow measurement (PW-PT480D), and digital electronics rated for 300°C (PW-PT575). A fiber optic interface option and a rechargeable battery (Electrochemical Systems, Inc.) are still under development. All sub-components were specifically developed for extreme conditions; the EEPROM chips (Honeywell[3]) and digital oscillators (Frequency Management[4]) have been commercialized by their respective developers for other applications.
Since 2012, Perma Works has offered their EGS well monitoring system as a complete system and provided electronics for data logging and EGS monitoring services. Systems have been deployed worldwide, including Australia, New Zealand, and the U.S.



Perma Works' Downhole Monitoring Tool and Sub-Components

Overview

- Developed by Perma Works LLC, in collaboration with Honeywell, Inc. and Frequency Management Systems.
- Commercialized in 2012, electronics, systems and services available from Perma Works LLC.

Applications

Can be used for monitoring downhole operations and production in mining and geothermal applications.

Capabilities

- Provides unmanned, extended operation at high temperatures and pressures (300°C and 25,000 psi) down to 10,000m depths.
- Provides system (tool-cable-surface recorder) for real-time monitoring of temperature, pressure, and fluid flow and interfaces with standard industry data logging platforms.
- Provides fluid flow measurement (50 readings per second) using magnetic sensor eliminating failure prone mechanical spinners.

Benefits

Cost Savings

The tool can remain in the well during all phases of well stimulation and production testing, and does not require an onsite logging truck and crew.

Productivity/Maintenance

Geothermal power plants can use the system during normal plant maintenance cycles to monitor reservoir recovery and pull down, track reservoir response, and optimize plant power output.

Usability

The instrumentation can also monitor surface wellhead pressure and temperature to aid modeling the reservoir response.

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[1] For more information: GTO Program 2011 Peer Review
[2] For more information: GTO Program 2013 Peer Review
[3] For more information: Honeywell HT EEPROM Datasheet
[4] For more information: Frequency Management HT Crystal Oscillator Datasheet

Hydrothermal Resources

Fiber Optic Downhole Seismic Receiver Array for Surveying and Monitoring of Geothermal Reservoirs

GeoOptics: High-Temperature Optical Seismic Sensor

Fiber Optic Downhole Seismic Receiver Array for Surveying and Monitoring of Geothermal Reservoirs

Hydrothermal Resources | Commercial Technology

In-Situ, Robust, Seismic Detector for Borehole Operations

Enhanced geothermal system (EGS) resources can occur within a wide variety of geographic and geologic settings, and in some cases, with no visible surface manifestation. If EGS resources are to be used for the nation's energy supply, the cost and risk associated with exploration, characterization and development must be minimized. In order to develop an EGS for power generation, accurate reliable subsurface characterization and monitoring are needed. Borehole seismology can be used for these applications because it provides high-resolution characterization with good signal to noise ratio and precise monitoring and mapping of reservoir injection processes. Unfortunately, borehole environments are very demanding and the current state-of-the-art borehole seismic instruments are not robust enough for long term monitoring, nor do they have sufficient capability to record large bandwidth data and the sensitivity to detect small micro-seismic events.[1]

Paulsson, Inc. (PI), with assistance from GTO, has developed a fiber optic, downhole seismic array that can outperform traditional borehole seismic detectors or geophones used in geothermal wells. The new array technology is capable of operating at depths down to 15,000 ft., and at high temperatures and pressures (T ≥ 300°C and P > 30,000 psi) in vertical and highly deviated boreholes. The fiber-optic system offers enhancements in bandwidth, sensitivity, and data processing time compared to other options. The array can create more accurate, detailed seismic images than current technologies and is small enough to be mounted on the outside of casings without the need for drilling large holes. The sensor also provides the ability to operate large horizontal arrays that can provide volumetric rock-mass stress distributions.

Paulsson, Inc. currently offers its surveying service as a part of a consultation package that also includes project review, analysis, and processing of recorded data.



PI's Fiber Optic Seismic Sensor (FOSS)™ Array

Overview

- Developed by Paulsson, Inc.
- Commercialized in 2016 at multiple domestic customer sites.

Applications

Can be used to characterize EGS and hydrothermal resources, such as subsurface structure and stratigraphy, as well as monitoring injection and production processes.

Capabilities

- Allows operation down to 15,000 ft. depth, T ≥300°C and P >30,000 psi in vertical and horizontal borehole.
- Provides up to a 200-level, 3-component (600 channel) seismic sensor array for field deployment.
- Provides 3D mapping and monitoring of reservoir fluid injection to detect micro-seismic events.
- Provides high vector fidelity data with a bandwidth range 0.01 – 6,000 Hz and can detect micro-earthquakes (MEQs) with a magnitude M < - 4.0.
- Can simultaneously monitor and record temperature and fluid flow in the geothermal wells.

Benefits

Cost Savings

Reduces risk and cost associated with EGS resource development by providing accurate subsurface characterization, monitoring, and mapping for well-drilling operations.

Environment

Reduces environmental stress from minimizing additional well-drilling operations from misinterpretation of inaccurate subsurface mapping and characterization data.

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[1] Proceedings of 39th Geothermal Engineering Workshop Presentation

GeoOptics: High-Temperature Optical Seismic Sensor

Hydrothermal Resources | Commercial Technology

Sensor Enables Downhole Monitoring of Seismic Activity During EGS Stimulation

Geothermal systems occur with differing geological characteristics (e.g., marginal or hidden systems that do not have sub-surface to surface activity). Development of remote sensing technologies has been identified by GTO as critical to the discovery, characterization, and eventual use of these types of systems. Enhanced geothermal system (EGS) development require accurate mapping of rock fractures before and after stimulation and need seismic sensors at downhole depths. The temperatures encountered at these depths can reach 250°C; new seismic sensor technologies are needed to operate at these higher temperatures.

MagiQ Technologies, Inc. and Sandia National Laboratory, with funding from the U.S. Department of Energy Small Business Innovation Research grants, have developed a seismic sensor in which the temperature sensitive electronic components are eliminated from the borehole sensor. MagiQ has used fiber optic telemetry and a path-matched differential interferometer to precisely measure seismic activity generated by EGS stimulation induced microeathquakes. The sensor measures the motion of an inertial mass with better than 1 nm resolution. The signal processing electronics, including optical sources and detectors, are located in the temperature friendly environment at the surface. The sensor can also be used in other industrial applications with hazardous environments where conventional seismic or vibration measurements fail.

SNL's 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 system was tested in a borehole at SNL's Ground-Based Monitoring Research and Evaluation Center. Based on the successful evaluation of the system, MagiQ has targeted the oil and gas industry for applications of their sensor technology through a separate division called GeoOptics. MagiQ's GeoOptics sensing platform provides a modular and universal sensing platform for use in exploration and exploitation of unconventional resources such as shales and tar sands.



MagiQ's Optical Based Seismic Sensors for Resource Exploration (Top) SNL's Wellbore Sensor for Downhole Monitoring of MEQs (Bottom)

Overview

- Developed by MagiQ Technologies, Inc. and Sandia National Laboratories, MagiQ has created a focused division based on this technology called GeoOptics (www.geoopticstech.com).
- Commercialized in 2014 and available from MagiQ Technologies Inc.

Applications

Can be used for the exploration and discovery of oil, gas, and geothermal resources.

Capabilities

- Operates in high temperature (up to 300°C), in high pressure (up to 20,000 psi), and is chemically inert.
- Achieves sub-Hz to multi-kHz frequency response, <10 nano-gravity/Hz sensitivity, and sampling rates up to 10 MHz, with a dynamic range of 80 dB.
- Allows accurate measurement of seismic energy.
- Provides remote operation over long distances and high data transfer rates (real-time).
- Allows temporary or permanent installation and vertical or horizontal deployment in previously inaccessible and harsh environments.

Benefits

Cost Savings

Enables and enhances geothermal or fossil resource recovery operations and mitigates financial risk associated with natural resource discovery and exploration.

Durability

Platform uses optical fibers and optical processing technology to address and overcome the environmental and technical challenges encountered in natural resource exploration.

Flexibility

System design provides modular, expandable, and multi-variable sensing platform.

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Low Temperature & Coproduced Resources

Bottoming Binary-Cycle Power Plant Using Low-Temperature Geothermal Fluids

Power Generation from Low to Intermediate Temperature Resources

Power+ Generator™: Electrical Power Generation from Heat Co-Produced in Geothermal Fluids

Bottoming Binary-Cycle Power Plant Using Low-Temperature Geothermal Fluids

Modular System Captures Unused Energy at Geothermal Flash Plants

Geothermal flash steam power plants pump high-temperature, high-pressure brine into a flash drum, where the pressure drops and a portion of the brine flashes (vaporizes) into steam. The steam is routed through a turbine to generate electricity, while the portion of the brine that was not vaporized is injected back into the geothermal reservoir. The thermal energy contained in this re-injected brine (which is typically at temperatures of 200°F to 250°F) represents an unused resource that can be used to generate additional electricity via an Organic Rankine Cycle (ORC).

With assistance from the GTO (as part of the American Recovery and Reinvestment Act), Terra-Gen Power, LLC developed and is now operating a pair of ORC-based systems that have increased the power output from a pair of existing geothermal flash plants. Heat from the low temperature brine is used to vaporize an organic working fluid with a much lower boiling point than water (the systems operated by Terra-Gen use R-134a, which boils at -15°F under atmospheric pressure). The working fluid is then passed through a turbine to generate electricity and is condensed so that the cycle can repeat. The systems are known as bottoming binary-cycle power plants because they recover unused heat to generate additional electricity (a "bottoming" cycle system in combined-heat-and-power terminology) and have a combination of two (hence "binary") thermodynamic cycles/working fluids (the brine and the organic working fluid).

The Terra-Gen installations were manufactured and assembled by TAS Energy, Inc., which builds modular, turnkey ORC systems for waste-heat-to-power applications. The first installation, located in Beowawe, Nevada, is a 2.5 MW plant. The second installation, located in Dixie Valley, Nevada, is a 5.0 MW plant. The two installations generated 45,149 MWh of electricity in 2014 and have generated a cumulative total (through 2014) of 120,537 MWh. TAS's geothermal-to-power (G2P) systems are modular and can be scaled to the capacity requirements of a particular application.



Terra-Gen's 2.5-MW Bottoming Binary-Cycle Plant at Beowawe, Nevada

Overview

- Developed and commercialized in 2011 by Terra-Gen Power LLC in partnership with TAS Energy, Inc. (http://www.tas.com)
- Two operational installations in Nevada generated 45,149 MWh in 2014 and a cumulative total (through 2014) of 120,537 MWh.

Applications

Can be used to generate electricity by extracting heat from low temperature (200°F to 250°F) re-injected brine at geothermal flash plants.

Capabilities

- Increases the capacity of existing geothermal flash plants without additional well drilling.
- Demonstrates the commercial viability of electricity generation from low temperature geothermal fluids.
- Uses a non-flammable working fluid, which reduces the need for fire protection systems compared to other ORC systems that use a flammable hydrocarbon.

Benefits

Adaptability

Available as a modular system that is more easily assembled at the site and can be scaled to the capacity required by a particular application.

Environment

Generates electricity from a renewable resource, thereby reducing carbon emissions compared with fossil-fuel power plants.

Safety

Uses R-134a (a non-flammable working fluid).

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Power Generation from Low to Intermediate Temperature Resources

Low Temperature & Coproduced Resources | Commercial Technology

Generates Electricity From Lower Temperature Geothermal Fluids

GTO's program initiatives fund technology development and deployment for power generation using low temperature geothermal fluids. These technologies could be used in existing or new production sites and non-productive low fluid temperature injection wells. Similarly, in the oil and gas sector, significant amounts of co-produced hot water and steam are treated as waste but are warm enough to generate electricity. This mode of power generation could potentially generate over 30 GW_e in the U.S. and extend the life of mature oil and gas fields.[1]

The University of North Dakota (UND), with assistance from GTO (as part of the American Reinvestment and Recovery Act), successfully demonstrated the technical and economic feasibility of generating electricity from co-produced and low temperature geothermal resources in the oil and gas producing areas of the Williston Basin in North Dakota. UND used a binary Organic Rankine Cycle (ORC) technology from Access Energy, a wholly owned subsidiary of Calnetix Technologies, over a range of operating parameters, including geothermal fluid temperature, flow rate, and operational cost. UND's analysis found that there are few sites in North Dakota with sufficient fluid production because of the deep well depths (>3 km). There has been a recent horizontal drilling boom in the Williston Basin that has led to infill drilling that produces large volumes of geothermal fluid in the temperature range 120–130°C.[2]

Power requirement estimates for producing oil in the Williston Basin are approximately 2,600 MW and grid power is supplied by six coal-fired power plants and onsite power from gasoline, diesel, and propane-powered generators. Onsite power costs over five times more than grid power. UND's Williston Basin project demonstrated the feasibility that a distributed network of ORC engines could offset the costly and lengthy construction of new power generation infrastructure needed for oil production. [3] UND used an innovative prototype ORC design by Access Energy-Thermapower® 125XLT, which is designed for lower fluid temperatures (98°C) with 7.5% efficiency and 125 kW_e output. The integrated power module contains a turbine expander and generator that is hermetically sealed and uses magnetic bearings for high efficiency and reduced parasitic mechanical load. Currently, Calnetix have an installed capacity of over 45 MW worldwide.[4]



Access Energy's Thermapower® ORC

Overview

- Developed by University of North Dakota in collaboration with Calnetix Technologies LLC.
- Currently preparing for field demonstration start at Williston Basin, ND.

Applications

Can be used to generate electric power and/or provide supplemental heating (CHP) from waste streams or other lower temperature heat sources, including co-produced geothermal fluids.

Capabilities

- Achieves power generation using ORC with efficiencies up to 14% at T ≥120°C and 20°C cooling (similar ORC systems operate at 6–8% efficiency).
- Produces 125 kWe, 3-phase 380–480 $_{VL_L}$ at 50 Hz.
- Achieves reduced parasitic mechanical load using fewer moving parts (one) and magnetic bearings.

Benefits

Cost Savings

Reduces energy costs by offsetting grid power and costly onsite power generation methods.

Environment

Deployment of emission-free ORC power generation systems could offset the need to construct fossil fueled power plants to meet power demand, eliminating the potential for increased carbon emissions.

Installation

ORC system can be retrofitted into existing or newly developed well operations.

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[1] GTO Clean Domestic Power Factsheet
[2] Final Project Report DE0002731
[3] Geothermal Resources Council, Transactions, v. 39, 2015
[4] For more information: https://www.calnetix.com/access-energy-thermapower-orc-systems

Power+ Generator™: Electrical Power Generation from Heat Co-Produced in Geothermal Fluids

Low Temperature & Coproduced Resources | Commercial Technology

Heat Engine Generates Electricity from Waste Heat to Offset Power and Cooling Costs

GTO's program goals are to develop, demonstrate, and deploy geothermal energy production technologies and systems for generating electricity from low temperature geothermal fluids. These types of systems can be based at existing wells, newly drilled exploratory production, or injection wells to reduce capital cost. In the oil and gas sector, significant amounts of water and steam are co-produced; the water and steam are treated as waste, the majority of which is warm enough to generate electricity and could extend the life of mature oil and gas fields, while adding a steady, clean source of electricity.[1]

ElectraTherm, with assistance from GTO, has developed a micro-geothermal plant to generate electricity from heat co-produced in geothermal fluid at a mine. The plant is based on Organic Rankine Cycle (ORC) technology, a heat engine circulating a working fluid with a boiling point lower than the water-steam phase change. ElectraTherm redesigned their existing ORC waste heat recovery power unit to generate electricity from co-produced geothermal fluids. After analyzing the test site operating conditions, a system was constructed for optimized performance using a new control system, patented positive displacement screw expander, compact plate type heat exchangers, and a cleanable evaporator. The factory-built, fully integrated system has a power output up to 110kW$_e$ and is available fully packaged for ease of transportation and installation.

ElectraTherm installed an ORC system in early 2013 at the Florida Canyon mine in Imlay, Nevada that produces 50kW of electricity from the 216°F geothermal water. ElectraTherm has installed its technology in other waste heat applications besides oil and gas and mining applications (e.g., biogas and biomass processing, stationary engines, and waste incineration).[2]



ElectraTherm's ORC-Based Products

Overview

- Developed by ElectraTherm, Inc.
- Commercialized in 2013.
- 50 units installed worldwide with 300,000 hrs accumulated runtime.

Applications

Can be used to generate electric power and provide supplemental heating (CHP) from a variety of waste heat sources, including stationary engines, biomass, geothermal and co-produced fluids.

Capabilities

- Provides waste heat-to-power generation and supplemental local heating using post process waste heat.
- Achieves electricity generation (35–110 kW$_e$) using hot water flow (100–350 GPM) at temperatures in the range of 170–240°F.
- Provides siting flexibility and ease with ISO frame and skid mounted options.

Benefits

Cost Savings

Reduces energy cost by offsetting local utility power and cooling loads. Additional heat can be used for district heating or other processes.

Installation

System is easily transported (ISO frame skid), self-contained and modular, and easily retrofitted in existing plant infrastructure or new installations.

Environment

System is self-contained, fuel-free, and emissions-free and does not require EPA permitting for installation.

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[1] For more information: http://energy.gov/sites/prod/files/2014/02/f7/geothermal_fs.pdf
[2] For more information: http://electratherm.com/news/

Crosscutting

Vortex Enhanced Direct Contact Heat Exchanger for Geothermal Cooling

Vortex Enhanced Direct Contact Heat Exchanger for Geothermal Cooling

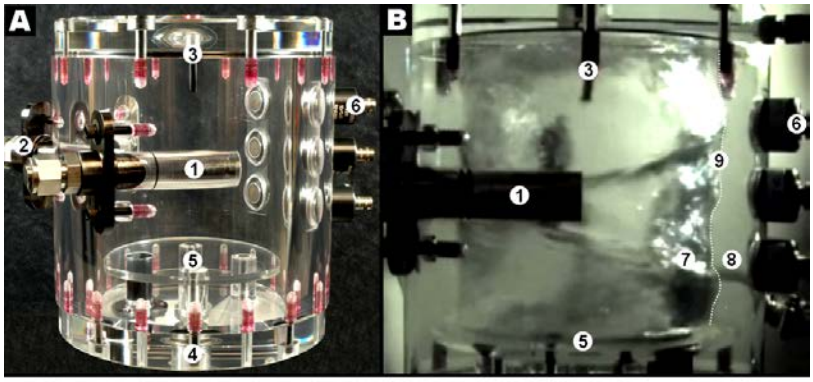
Crosscutting | Commercial Technology

Heat Exchanger with Increased Cooling Efficiency Reduces Energy Usage

Heat exchanger technology is of growing importance in the geothermal and industrial sectors as new advanced technologies require more robust thermal solutions. Conventional heat exchangers often operate using high speed rotating equipment that can be hampered by fouling, seal failures, or high maintenance requirements. This can lead to reduced product life as well as increased cost. A heat exchanger that offers improved performance and durability could reduce the cost of development for new power generation technologies.

Advanced Cooling Technologies, Inc. (ACT); with assistance from GTO, in the form of SBIR grants has used technology for microgravity two-phase systems licensed from Texas A&M University to develop a new Momentum-driven Vortex Phase Separator (MVS) for use in heat exchange applications. The MVS allows fluids and gases in the system to be separated independent of gravity, by relying on buoyancy and flow velocity. This allows the system to operate without any moving parts, reducing cost and eliminating failure modes present in conventional heat exchangers.[1] Fluids in an MVS are allowed to make direct contact with one another, increasing heat transfer rates and durability by eliminating the fouling that would occur on intermediary surfaces. Additionally, the flow rate of fluids through the MVS affects separation speeds rather than the speed of a rotating disc in the separation chamber, allowing them to achieve greater performance at smaller sizes.

ACT offers their MVS for a number of heat exchange applications in the residential and industrial HVAC, aerospace, and geothermal sectors. The MVS has demonstrated near isothermal cold plate performance, stable flow during heat load transience, and has been selected for future use in commercial space systems. In residential HVAC applications, ACT's votical-flow, direct contact heat exchanger (VDHX) provided significant energy savings over traditional ground-source and air-sorce heat pump systems (GSHPs and ASHPs) in a variety locations across the U.S.



(A) MVS designed for a microgravity two-phase system (B) during testing

Overview

- Developed by Advanced Cooling Technologies, Inc.
- Commercialized in 2017.

Applications

Can be used for high efficiency heat exchange operations.

Capabilities

- Reduces energy consumption by up to 60% compared to traditional GSHPs and up to 50% compare to ASHPs.
- Provides continuous recycling of heat transfer surface to reduced thermal resistance, increase thermal transfer rates and eliminate fouling commonly observed in gravity based systems .

Benefits

Cost Savings

Reduces costs by eliminating high speed rotating parts in favor of a fixed changer.

Efficiency

Allows direct contact heat exchange to reduce thermal resistance and eliminate fouling.

Size

Reduces unit footprint by increasing heat exchanger performance per contact area.

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[1] For more information: Phase Separation

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Emerging Technology Innovation Descriptions

Enhanced Geothermal Systems

- 300°C Capable Electronics Platform and Temperature Sensor System for Enhanced Geothermal Systems
- Abrasive Slurry Jet Drilling of Microhole Arrays in Enhanced Geothermal Systems
- Advanced Stimulation Prediction Model for Enhanced Geothermal Systems
- Controlled Pressurization for EGS Well Stimulation
- High Performance Fluoroelastomer Nanocomposite Seals for Geothermal Submersible Pumps
- High Temperature Directional Drilling System
- Imaging Fluid Flow in Geothermal Wells Using Distributed Thermal Perturbation Sensing
- Multichip Module to Enhance High-Temperature Accelerometer Measurements
- OM-300: Geothermal Drilling Navigation Instrument

Hydrothermal Resources

- Advanced Heat/Mass Exchanger Technology for Geothermal and Solar Renewable Energy Systems
- Auto Indexer for Percussive Hammers Drilling in Hard Rock Formations
- Deep Geothermal Drilling Using Millimeter Wave Technology
- El Paso County Geothermal Project at Fort Bliss
- Harsh Environment Silicon Carbide Sensor Technology for Geothermal Instrumentation
- Improved Cement for Geothermal Wells

Low Temperature & Coproduced Resources

- High-Temperature Ultracapacitors for Geothermal Exploration
- Low-Temperature Stirling Engine for Geothermal Electricity Generation
- Metal Extraction from Geothermal Fluids
- Metal Organic Heat Carrier Nanofluids for Low-Temperature Geothermal Systems
- Mineral Extraction from Geothermal Fluids
- Novel Energy Conversion Equipment for Low Temperature Geothermal Resources
- Variable Phase Turbine Power System for Low-Temperature Geothermal Resources

Enhanced Geothermal Systems

- 300°C Capable Electronics Platform and Temperature Sensor System for Enhanced Geothermal Systems
- Abrasive Slurry Jet Drilling of Microhole Arrays in Enhanced Geothermal Systems
- Advanced Stimulation Prediction Model for Enhanced Geothermal Systems
- Controlled Pressurization for EGS Well Stimulation
- High Performance Fluoroelastomer Nanocomposite Seals for Geothermal Submersible Pumps
- High Temperature Directional Drilling System
- Imaging Fluid Flow in Geothermal Wells Using Distributed Thermal Perturbation Sensing
- Multichip Module to Enhance High-Temperature Accelerometer Measurements
- OM-300: Geothermal Drilling Navigation Instrument

300°C Capable Electronics Platform and Temperature Sensor System for Enhanced Geothermal Systems

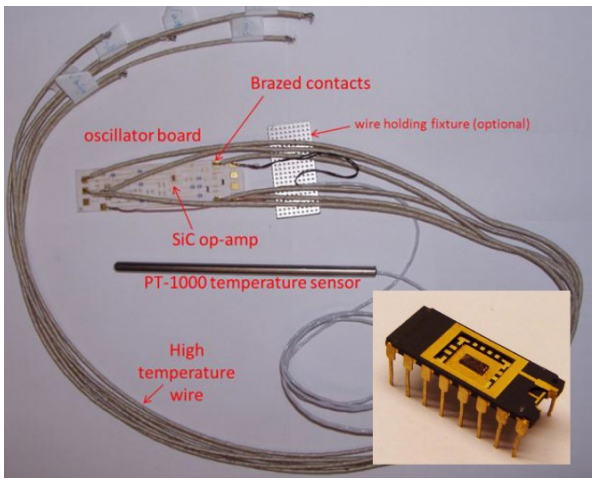
Enhanced Geothermal Systems | Emerging Technology

Electronics Withstand Harsh Environmental Conditions Encountered in Sub-Surface Operations

Exploration and development of potential geothermal resources is dependent on the acquisition of sub-surface data (e.g., temperature, pressure and seismic data). Temperature-hardened real-time monitoring sensors and logging tools are essential to generate accurate field data that tracks the hydrologic and thermal evolution of a reservoir. Those data can then be used for validating reservoir models and to characterize, validate, and determine the best approach for developing resources into enhanced geothermal systems (EGSs).[1]

With assistance from GTO, GE Global Research (in collaboration with Auburn University) is developing electronics that can operate in downhole conditions and environments (i.e., at temperatures up to 300°C and depths down to 10 km), enabling temperature, flow, pressure, and seismicity measurements in an EGS reservoir or similar applications in the oil and gas sector. Silicon carbide (SiC)-based components capable of withstanding high temperatures are being developed, including packaging and integration with the sensors and supporting electronics for data acquisition. MOSFET and JFET device technologies are being explored, as are high-temperature-capable circuit board materials, solder materials, and die attach techniques. Commercially available high-temperature-rated components are also being characterized and evaluated. Upon completion of a validated circuit design and down-selection of components, prototype circuit boards will be undergo high-temperature and electrical stress testing to evaluate and optimize the circuit design and circuit board material. Highly accelerated life testing (HALT) will be used to project component and circuit lifetimes at 300°C.[2]

Promising results have been achieved using alumina substrates (no organic or lead materials), thick gold film circuit traces, and AuSN eutectic die attach material with gold wire bonding for electrical connections. Such a circuit has operated continuously for over 1,000 hours without failure. Future work will include design improvements for near-zero drift operation, circuit board assembly, and passive component reliability.



Integrated Temperature Sensor System

Overview

- Developed by GE Global Research in collaboration with Auburn University.
- Currently improving circuit design, fabrication, and reliability in preparation for field testing.

Applications

Can be used for collecting measurement data in downhole operations such as geothermal or in gas and oil exploration.

Capabilities

- Provides electronic packaging capable of operating at temperatures up to 300°C and depths down to 10 km.
- Achieves small form factor, 4 x 1 inches and enables multiple measurement sensors per circuit board.
- Provides stable operation with near-zero drift for accurate monitoring of downhole conditions and parameters.

Benefits

Cost Savings

Reduces reservoir development and exploration cost through the use of logging tools to optimize drilling operations.

Installation

The remote sensor and measurement system is easily installed and is designed to operate in hostile environments for months; other systems require frequent withdrawal and maintenance.

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[1] GTO 2009 Project Description
[2] GTO 2011 Peer Review Presentation

Abrasive Slurry Jet Drilling of Microhole Arrays in Enhanced Geothermal Systems

Supercritical Fluid Drill Improves Heat Exchange Performance of EGS Reservoirs

Enhanced geothermal systems (EGSs—geothermal reservoirs whose permeability has been improved via engineered fracturing or drilling of the hot rock) represent a vast potential source of domestic, renewable energy for the United States. The commercial deployment of EGS would be accelerated if the cost of well drilling and reservoir development could be reduced, thereby lowering the project risk.

With assistance GTO (as part of the American Recovery and Reinvestment Act), Impact Technologies LLC is developing abrasive slurry jet (ASJ) drilling technology to drill small bores that improves the heat exchange performance of EGS reservoirs. After a large vertical wellbore (i.e., an injection well) is drilled using conventional rotary drilling, the ASJ system is used to drill several directional, microhole (<4 inch diameter) bores that intersect fractures in contact with another large vertical bore (i.e., a production well). The network of microhole bores increases the rock volume contacted by the geothermal fluid, resulting in greater heat recovery. The improved heat exchange performance allows a given power plant capacity to be obtained with fewer large vertical wells drilled, which reduces the cost and risk of the EGS installation.

Impact demonstrated that ASJ drilling with supercritical gases efficiently drills and cuts granites and hard sandstones, even at high temperatures. However, nozzle rotation and an improved slurry pump were found to be needed for efficient drilling. Those improvements are currently being developed to enable commercialization of ASJ drilling technology. Commercialization is expected to occur first in shallow drilling, and then will progress into applications at greater depths.



Impact Technologies' ASJ Drill

Overview

- Developed by Impact Technologies LLC, in partnership with Lawrence Berkeley National Laboratory and the University of Tulsa.
- Currently upgrading slurry pumps for commercialization in shallow drilling applications.

Applications

Can be used to improve the heat exchange performance of EGS reservoirs.

Capabilities

- Uses supercritical nitrogen, carbon dioxide, or steam (with entrained abrasive particles) to drill directional microhole (< 4 inch diameter) bores 4-20 times faster than conventional rotary drilling.
- Reduces short circuiting of geothermal fluid from injection wells to production wells by providing contact with an increased hot rock volume.

Benefits

Cost Savings

Reduces EGS costs and risks by improving heat exchange within the reservoir, resulting in fewer large-diameter injection wells and production wells that have to be drilled.

Environment

Enables electricity generation from a renewable resource, thereby reducing carbon emissions compared with fossil-fuel power plants.

Grid Stability

Improves the cost-competitiveness of EGS power plants, which offer dispatchable electricity generation with output that is independent of weather or time-of-day.

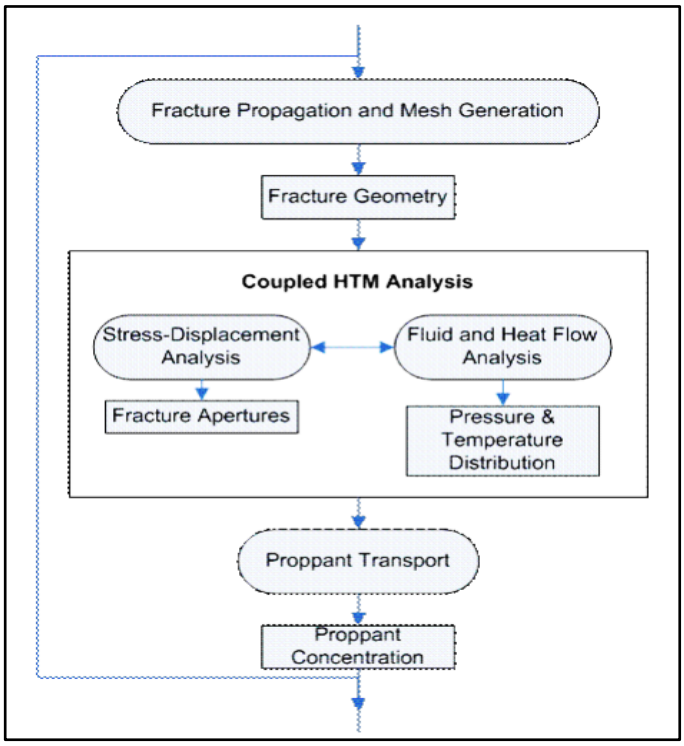
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Advanced Stimulation Prediction Model for Enhanced Geothermal Systems

Computer Model Enables Improved Planning/Design of Fracturing/Propping for EGS Reservoir Creation

Enhanced geothermal systems (EGSs) (i.e., hot rock reservoirs whose permeability has been increased via hydraulic fracturing) represent a significant potential source of domestic, renewable energy and are a key part of the research, development, and demonstration activities conducted by GTO. Of the eight research areas discussed in GTO's Technical Plan for EGS R&D,[1] reservoir creation is very important because it involves the creation and maintenance of fractures within the reservoir. The fracture network must provide enough surface area for fluid/rock heat exchange so that a sufficient amount of heat can be extracted for power production.

With funding from GTO (as part of the American Recovery and Reinvestment Act), the Colorado School of Mines (CSM) is developing a three-dimensional hydro-thermal fracturing and proppant flow/transport simulator for EGS reservoir creation.[2] The simulator will help the geothermal industry implement optimized fracturing and propping processes/techniques, resulting in increased power production from EGS reservoirs. CSM has tested and validated the simulator using laboratory-scale model tests and comparisons of simulation results with real-world data from EGS test sites in Japan. CSM is currently seeking to commercialize the completed model.



Components of CSM's Hydro-Thermal Fracturing Simulator

Overview

- Developed by CSM.
- The model has been validated using laboratory-scale model simulations of hydraulic fracturing and field data on EGS projects from Japan.
- CSM is currently seeking to commercialize the completed model.

Applications

Can be used as a tool for the planning and design of hydro-thermal fracturing and propping processes for EGS reservoir creation.

Capabilities

- Analyzes the entire process of hydraulic fracturing and proppant flow/transport and can deal with layered formations with differing rock mass.
- Considers deviated boreholes with arbitrary deviation angles and variable injection rate and proppant concentration.
- Incorporates thermally induced stresses and fracturing, temperature-dependent fluid and rock properties, and the non-Newtonian rheological behavior of the fracturing fluid and proppants.

Benefits

Cost Savings

Reduces the cost of geothermal resource development by optimizing the fracturing and propping processes involved with EGS reservoir creation.

Resource Productivity

Simulates the ability of proppants to maintain fracture volumes, which is important for maintaining a reservoir's power output.

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[1] GTO Multi-Year Research, Development and Demonstration Plan
[2] 2011 Peer Review Summary and 2011 Peer Review Presentation

Controlled Pressurization for EGS Well Stimulation

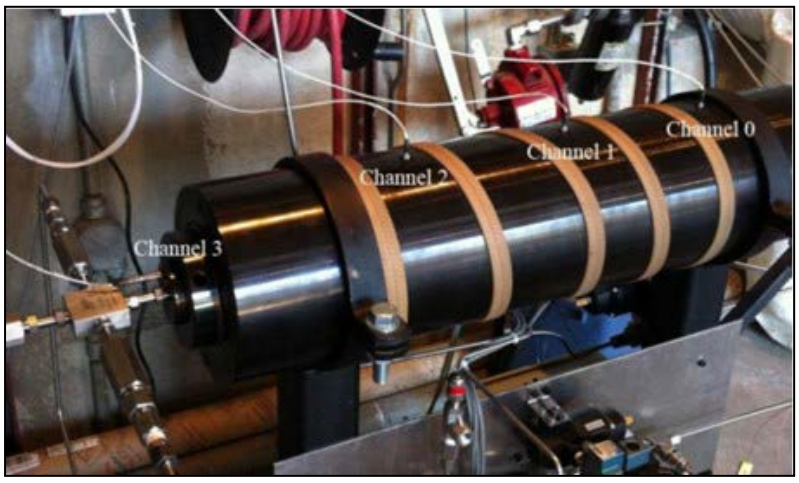
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Method Provides Greater Control and Increased Safety for EGS Fracturing Process

Enhanced geothermal systems (EGSs), which increase the permeability of hot rock formations via engineered fracturing, represent a large potential source of domestic, renewable energy for the United States. Multiple methods exist for generating a network of fractures within a formation, including hydraulic fracturing and fracturing using energetic materials (explosives). Existing fracturing methods have pressurization rates that are either too slow to achieve optimum fracture development (hydraulic methods) or are so fast/uncontained that damage can occur to the well bore (explosive methods).

With assistance from GTO, Sandia National Laboratories (SNL) is developing a method of EGS well stimulation that controls the pressurization rate so that sufficient pressure is produced to generate fractures without damaging the well bore. SNL's method involves the downhole injection, mixing, and ignition of a gaseous propellant (with ethylene as the fuel and nitrous oxide as the oxidizer).[1] The method enables customized pressurization rates and peak pressures, resulting in greater control of the fracturing process. Increased control of the fracturing process will help extend fractures to an effective length while preventing damage to the well bore, resulting in increased viability of using geothermal resources for power production.

Hardware for performing the propellant-based controlled rate pressurization has been developed and installed in shallow test wells in Socorro, NM. SNL is conducting tests on the system and looking for an industry partner to pursue commercialization.



Reactor Vessel for Measuring the Pressure Developed During a Controlled Combustion of SNL's Nitrous Oxide/Ethylene Propellant

Overview

- Developed by Sandia National Laboratories.
- Currently field testing the system in shallow test wells in Socorro, NM.

Applications

Can be used to improve the permeability of enhanced geothermal systems via a controlled pressurization that produces fractures in the formation without damaging the well bore.

Capabilities

- Controls pressure rise and peak pressure to optimally stimulate geothermal formations.
- Achieves pressurization rates on the order of 1 M psi/sec and peak pressures tailorable between 300 and 300,000 psi.

Benefits

Environment

Eliminates the wastewater produced from conventional hydraulic fracturing.

Profitability

Increases the power output that can be obtained from geothermal resources by increasing formation permeability (i.e., the amount of rock surface area available for heat exchange).

Safety

Increases safety by mixing the propellant fuel and oxidizer downhole, eliminating the surface transportation and handling of high explosives.

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[1] For additional information, see An Overview of a High Energy Stimulation Technique for Geothermal Applications, World Geothermal Congress 2015.

High Performance Fluoroelastomer Nanocomposite Seals for Geothermal Submersible Pumps

Enhanced Geothermal Systems | Emerging Technology

Nanotechnology Enhanced Additive Improves Durability and Performance of OEM Parts

In the United States, geothermal energy could potentially generate over 100 GWe. The full potential of these resources has yet to be realized. GTO is committed to developing and deploying a portfolio of innovative technologies for clean, domestic power generation. Exploration, discovery, and characterization of these resources are technically challenging and costly. Reducing these challenges and risks through improvements in exploration technologies is critical to the identification and development of geothermal resources.[1]

NEI Corporation, with assistance from GTO in the form of SBIR grants, is developing nanotechnology enhanced fluoroelastomeric materials to improve the performance and durability of electric submersible pumps (ESPs). ESPs used in geothermal and other sub-surface operations are exposed to harsh environments that include hot brine (e.g., calcium chloride), corrosive hydrogen sulfide/carbon dioxide, silica, and entrained sand, all at temperatures in the range of 300°F to 450°F. In a relatively short period of time, this environment frequently degrades the ESP's seals, causing equipment failure. NEI is developing fluoroelastomers that utilize nanoscale additives that will improve the modulus and hardness without reducing elongation. To accomplish this, NEI is formulating functionalized nanoscale additives to specifically improve the mechanical, physical, and chemical-resistance properties of the fluoroelastomer, while at the same time retaining the desirable properties required for pump seals. NEI has fabricated o-rings made from their new fluoroelastomeric material and tested them under the same harsh conditions as are found in geothermal applications, with positive results.[2]

NEI is currently optimizing the structure/size of the nanoscale additives and determining the structure/property correlation and interfacial mechanisms of the nanoscale additive in the fluoroelastomer. After comparing the nanocomposite fluoroelastomers with commercially used state-of-the-art fluoroelastomer materials, NEI will select the nanoscale additives that show the most improvement and will fabricate prototype seals for potential customer evaluation.[3]



NEI's Nanocomposite Enhanced Fluoroelastomer

Overview

- Developed by NEI Corporation.
- Currently down selecting optimized nanoadditives, setting up field tests, and in discussions with potential OEMs and customers.

Applications

Can be used in equipment applications where fluoroelastomeric materials are used and are exposed to harsh environments (e.g., geothermal operations, oil and natural gas drilling/production, and space applications).

Capabilities

- Achieves an 82% improvement in modulus and a seven point increase in Shore A hardness without decreasing the elongation at the break.
- Provides nanotechnology enhanced additive for commercially available fluoroelastomer materials.

Benefits

Cost Savings

Reduces equipment maintenance and replacement costs by improving durability of wear parts and seals.

Installation

Easily installed as OEM parts can be fabricated using the nanocomposite fluoroelastomer material.

Customizable

Tailorable to customer requirements.

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[1] GTO Clean Domestic Power Factsheet
[2] SBIR Phase I Award
[3] SBIR Phase II Award

High Temperature Directional Drilling System

Enhanced Geothermal Systems | Emerging Technology

Drilling System Enables Increased Deployment of Enhanced Geothermal Systems

Enhanced geothermal systems (EGSs) have the potential to significantly increase U.S. geothermal power production by improving the permeability (and hence, energy extraction potential) of hot rock formations that are not naturally permeable. In order to drill directional[1] injection and production wells for EGS, a drilling and steering system is needed that can perform reliably in the demanding geothermal environment (hard rock formations, high drilling vibrations, high temperatures, and high pressures).

With assistance from the GTO (as part of the American Recovery and Reinvestment Act), Baker Hughes Oilfield Operations is developing a directional drilling system that is suited to high-temperature geothermal applications. The goal of the system is to optimize the drill bit, directional drilling motor, and drilling fluid to enable 50 consecutive hours of operation in hard rock at 300°C. Drill bit mechanical face seals and bearing grease capable of achieving the desired operation at 300°C have been developed and laboratory tested. The elastomeric components of typical positive displacement directional drilling motors (a.k.a., "mud motors") would degrade under such high temperatures, so a metal-metal rotor-stator design (with wear-resistant coatings) was developed. Drilling fluids with desirable properties (e.g., density and viscosity) at 300°C has also been developed; these provide lubrication for the bit and drilling motor.

The drilling system is currently undergoing extended bench testing and early field trials. The efficiency and endurance of the motors have exceeded expectations, and the system has demonstrated the capability required to drill in the target environment.



Drill String (with Positive Displacement Directional Drilling Motor) and Drill Bits for Baker Hughes' High-Temperature Directional Drilling System

Overview

- Developed by Baker Hughes Oilfield Operations.
- Currently conducting extended bench testing and early field trials.

Applications

Can be used to create enhanced geothermal systems in challenging drilling environments (e.g., hard rock at depths of up to 10,000 meters and temperatures as high as 300°C).

Capabilities

- Provides a complete directional drilling system (including drill bit, steerable motor, drilling fluid, and measurement-while drilling navigation) that is customized for geothermal applications.
- Enables 50 consecutive hours of on-bottom operation at 300°C.

Benefits

Cost Savings

Allows faster, more economical boreholes to be drilled in lithologies that are difficult to drill in (e.g., hard, fractured formations).

Renewable Energy Development

Enables increased development of enhanced geothermal systems, a domestic source of baseload, renewable energy with reduced emissions compared with fossil-fuel-based electricity generation.

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[1] Directional wells are wells whose paths deviate from vertical. Geothermal resources that cannot be easily accessed from available surface locations can be accessed using directional drilling.

Imaging Fluid Flow in Geothermal Wells Using Distributed Thermal Perturbation Sensing

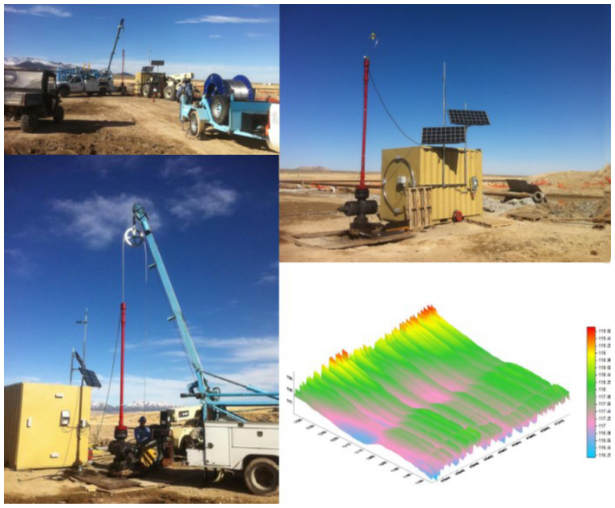
Enhanced Geothermal Systems | Emerging Technology

Wellbore Sensor System Images Fluid Flow and Reservoir Fractures in Geothermal Formations

GTO's program goals are to develop, demonstrate, and deploy energy production technologies that generate electricity from geothermal resources. Extended geothermal systems (EGSs) are man-made reservoirs where fluid is injected into hot rock formations to increase permeability and allow fluid to circulate and transport heat back to the surface for power generation. The first step in the development of an EGS is the identification and characterization of the potential site using surface, geologic, geophysical, and remote sensing exploration.[1]

Lawrence Berkeley National Laboratory (LBNL), with assistance from GTO, is developing a flow imaging tool that is robust and easily deployable for monitoring in geothermal wells. EGS development and prediction of long-term performance critically depends on how accurately wellbore conditions and coupled fluid and heat flow processes are assessed. LBNL's heat-pulse sensor and associated analysis tools can assess downhole thermal conductivity and basal heat flux, providing a high spatial and temporal resolution image of well conditions to assess potential geothermal resources. LBNL's approach is to heat the formation around the wellbore in a controlled fashion while monitoring the thermal response to this thermal perturbation (specifically during the cool-down period). This data provides information about the dominant heat transfer processes; matching temperatures to existing numerical models of these processes allows an estimation of the thermal profile along the wellbore.

LBNL collaborated with engineers at Draka Cableteq to engineer a cable that meets the demanding temperature and pressure conditions in geothermal wells. The heat-pulse design integrates the heating and fiber optic components into a single cable for rapid deployment in deep wells (>3 km depths). LBNL has field tested their heat-pulse system in several sites, including Victoria, Australia, Citronelle, Alabama, and Raft River, Idaho.[2]



Deployment of LBNL's DPTS System

Overview

- Developed by Lawrence Berkeley National Laboratory.
- Currently working on finalizing system design for commercialization partners.

Applications

Can be used to characterize and assess downhole conditions for geothermal or oil and gas resource exploration.

Capabilities

- Provides accurate, real-time monitoring of wellbore thermal conditions and properties.
- Achieves operation in extreme downhole environments T≥ 350°C and P ≤ 1080 bar.
- Provides rapid deployment in deep geothermal wells over 3 km deep.

Benefits

Accuracy

Interprets heat-pulse thermal profiles with acceptable uncertainty using a template model and analysis procedure that compares collected inversion temperature data to an inverse model of synthetic temperature data.

Cost Savings

Reduces operation costs by using an integrated single cable design that can be deployed for extended periods, potentially for the life of a well given the robustness of the fiber-optic technology.

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[1] GTO EGS Factsheet
[2] GTO 2012 Peer Review

Multichip Module to Enhance High-Temperature Accelerometer Measurements

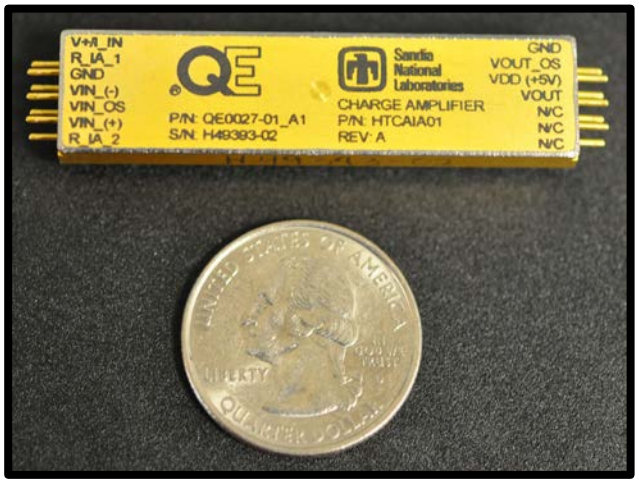
Enhanced Geothermal Systems | Emerging Technology

Electronics Package Reduces the Volume Requirement for Conditioning Accelerometer Signals

Enhanced geothermal systems (EGSs - hot rock formations whose permeability has been increased via engineered fracturing) represent a large potential source of domestic, renewable energy for the United States. Development of EGS is a primary goal of GTO.[1] In support of this goal, Sandia National Laboratories (SNL) developed a high-temperature seismic measurement tool that helps characterize potential EGS reservoirs by detecting small amounts of ground motion using a sensitive, three-axis accelerometer. A desired area for improvement in the tool was reducing the space requirement of the accelerometer signal conditioning system (which took up half of the electronics volume for the tool).

With funding from GTO, SNL is developing a high-temperature multichip module (MCM) that will reduce the volume requirement for signal conditioning accelerometer measurements.[2] The MCM integrates multiple signal conditioning devices (e.g., filters and amplifiers) into a single package, reducing the volume for performing high-temperature accelerometer sensing and filtering from 7.8 in^3 (in the current tool) to approximately 1.0–2.0 in^3. This volume reduction will enable the addition of other measurements, such as temperature and pressure, to the tool, which has the potential of creating a more cost-effective multifunctional geothermal measurement system. Placing the accelerometer electronics in an MCM also enables increased measurement sensitivity by reducing signal noise and temperature effects on the substrate material. The increased measurement sensitivity will provide higher resolution seismic data for EGS reservoir development.

The MCM has been fabricated and has undergone functional and environmental verification in the laboratory. Results show that the high temperature charge amplifier meets its design requirements at temperatures of up to 275°C. SNL is currently seeking partners for field test opportunities in order to evaluate this technology in real-world geothermal conditions.



SNL's MCM for Accelerometer Signal Conditioning

Overview

- Developed by Sandia National Laboratories with assistance from Quartzdyne, Inc.
- Currently seeking partners for field testing to evaluate the technology in real-world geothermal conditions.

Applications

Can be used to condition signals from capacitive sensors such as piezoelectric accelerometers used in seismic measurement tools and drilling diagnostic tools. In addition, with a few external components the MCM can be configured to interface with any voltage output or resistance sensitive transducer.

Capabilities

- Sensitivity: charge amplifier gain of 10 volts per g of acceleration for a 1000 picocoulomb per g accelerometer.

Benefits

Cost Savings

Enables more cost-effective multifunctional geothermal measurement packages by reducing the volume requirement of accelerometer signal conditioning electronics.

Renewable Energy Development

Improves the performance of tools associated with the exploration and development of EGS reservoirs.

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[1] For additional information, visit GTO's EGS Webpage.
[2] For additional information, visit GTO Project Webpage.

OM-300: Geothermal Drilling Navigation Instrument

Enhanced Geothermal Systems | Emerging Technology

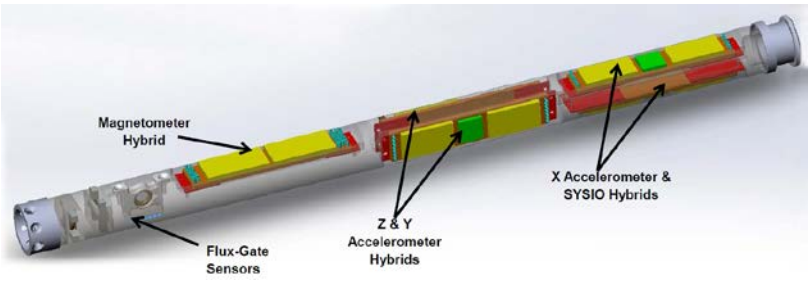
Ruggedized Instrument Enables Real-time Drill Position Monitoring in Downhole Applications

To accelerate development and deployment of clean, domestic geothermal energy, innovative technologies are needed to reduce the risks and costs of integrating geothermal resources into our nation's energy supply. GTO's technology development portfolio consists of research and development to improve identifying, accessing, and developing geothermal resources, demonstration and deployment of new geothermal technologies, and techniques for field testing and validation. Exploratory sub-surface operations encounter high temperature, pressure, and corrosive conditions as well as drilling into hard, igneous rock formations. There is an immediate need for innovative and environmentally hardened smart drilling technology to monitor and provide real-time feedback on downhole conditions.[1]

Honeywell Aerospace, with assistance from GTO (as part of the American Recovery and Reinvestment Act), is developing high temperature (up to 300°C) downhole measurements while drilling (MWD) tools.

Honeywell will use components used in oil and gas MWD tools (e.g., accelerometers and electronics) combined with a magnetometer from Applied Physics Systems to construct a directional drilling (navigation) instrument. The instrument will have three orthogonal sensors referencing gravity and magnetic vectors packaged with an optimized, purpose-specific designed temperature-hardened electronics package containing frequency based sensors and digital signal processing. The entire module will be housed in a 1 ft x 1.25 in diameter titanium tube.

Prototypes have been constructed that function correctly in the temperature range 250–300°C and enable design improvements to be identified and implemented. Honeywell is currently working toward field testing the instrument in a downhole drilling application. It is anticipated that the instrument developed here will bring directional drilling capability to geothermal applications and further potential commercialization in similar oil and gas exploration.[2]



Honeywell's OM300 MWD Instrument Concept

Overview

- Developed by Honeywell Aerospace in collaboration with Applied Physics Systems and the University of Washington.
- Continuing to optimize design for field testing and examining commercialization strategies.

Applications

Can be used for directional drilling in downhole applications in geothermal, oil, and gas exploration.

Capabilities

- Achieves environmental ruggedness, including shock and vibration, typical of existing oil/gas drilling instruments.
- Provides directional drilling capability in hot geothermal applications.
- Provides multiple user-selectable sensor ranges for navigation and for drill stick-slip and chirp detection.
- Provides user-selectable serial data communications.
- Provides drilling accuracies of 0.1° inclination and tool face 0.5° azimuth.

Benefits

Cost Savings

Reduces cost of drilling in downhole applications by providing real-time information about the drill head and avoiding impending equipment breakdowns.

Efficiency

Allows faster drilling rate by reducing equipment breakdown delays, which enables resources to be characterized sooner rather than later.

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[1] GTO FY14 Budget At-A-Glance
[2] GTO 2012 Peer Review Presentation

Hydrothermal Resources

- Advanced Heat/Mass Exchanger Technology for Geothermal and Solar Renewable Energy Systems
- Auto Indexer for Percussive Hammers Drilling in Hard Rock Formations
- Deep Geothermal Drilling Using Millimeter Wave Technology
- El Paso County Geothermal Project at Fort Bliss
- Harsh Environment Silicon Carbide Sensor Technology for Geothermal Instrumentation
- Improved Cement for Geothermal Wells

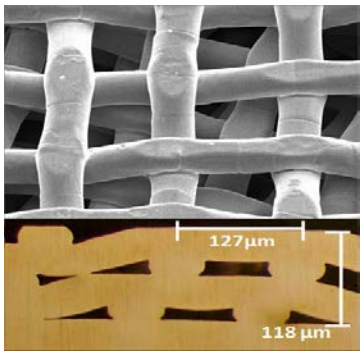
Advanced Heat/Mass Exchanger Technology for Geothermal and Solar Renewable Energy Systems

Hydrothermal Resources | Emerging Technology

Efficient Boiling Surfaces for Geothermal Power Cycles

GTO is committed to establishing clean, domestic power generation from geothermal energy as a significant contributor to America's future electricity generation. There is an estimated 30,000 MWe of undiscovered hydrothermal resources in the western United States (U.S.). In the U.S., for every barrel of oil, 10 barrels of hot water and steam are co-produced, which are then treated as waste despite being warm enough to generate electricity.[1] Geothermal power plants use steam from geothermal reservoirs to generate electricity. There are three types of technology in current use—dry steam, flash steam, and binary cycle. Binary cycle power plants use the hot geothermal fluid to heat a secondary, or "binary," fluid that has a lower boiling point than water passing through a heat exchanger. The heat transferred from the geothermal fluid causes the binary fluid to vaporize, which in turn drives the turbines to generate power. The heat transfer mechanism of the heat exchanger is a primary factor in determining the efficiency of the power plant. Existing binary cycle power plants achieve only about 30% of their ideal efficiency compared to ~60% for fossil fueled plants.[2]

The University of Nevada–Reno (UNR), with GTO funding, is developing heat exchanger surfaces that will enhance boiling and heat transfer in geothermal power cycles. This will reduce system size and improve efficiency and cost. Heat transfer is far superior when steam is saturated versus superheated; therefore, reduced superheating translates to improved power plant thermal efficiency. UNR is using applied micro/nano/molecular-scale science to optimize heat exchanger design. A significant increase in heat exchanger performance is anticipated via multiple research efforts in heat exchanger surface modification, including coatings and topology. To date, the effects of compressed laminations of a fine filament metallic screen overlaying a heat transfer surface on sub-cooled flow boiling (vapor nucleation onset) have been investigated and heat transfer rates >4.5 MW/m^2 observed. Experiments on plane and tubular, copper and steel screen-laminate surfaces have found that the higher thermal conductivity of copper filament coatings results in less super heating. Boiling performance is improved by increasing sub-cooling and flow, which results in an increase in heat transfer flux. UNR has compared their results with other research and found that increased heat transfer flux is linked to surface area enhancement. Surface area enhancement is likely to be the dominant parameter over fluid and coating material properties.[3]



UNR's Compressed Laminations of a Fine Filament Metallic Screen

Overview

- Developed by University of Nevada–Reno in collaboration with National Renewable Energy Laboratory.
- Work continues on flow-boiling experiments using best performing screen-laminate surfaces.

Applications

Can be used for geothermal power generation or other industrial applications where heat exchanger heat transfer performance is critical to system or process efficiency.

Capabilities

- Achieves a heat transfer rate of 4.5MW/m^2.
- Provides customized "tunable" heat exchanger surface enhancement using nanotechnology and other surface modifications.

Benefits

Cost Savings

Improvements in heat exchanger performance will lead to smaller, more efficient, and less costly systems.

Cross-Functionality

Processes and techniques to improve heat transfer can be used in applications other than geothermal (e.g., iron and steel processing), electronics cooling, and other energy intensive applications.

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[1] GTO Clean Domestic Power Factsheet
[2] GTO Electricity Generation
[3] 2013 GTO Peer Review Presentation

Auto Indexer for Percussive Hammers Drilling in Hard Rock Formations

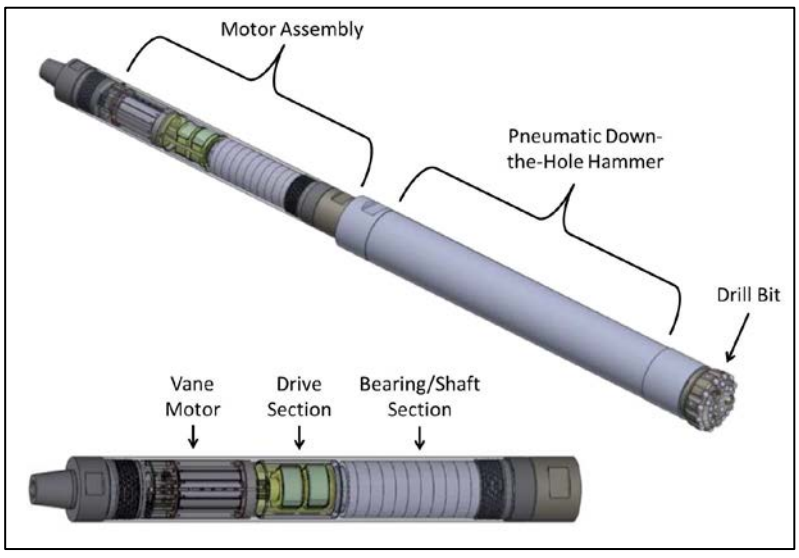
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System Enables Directional Drilling with a Percussive, Down-the-Hole Hammer

Geothermal well-drilling operations occur under challenging drilling conditions (e.g., high-temperature hard rock formations). Technologies are needed to reduce the costs associated with drilling in these difficult conditions and to enable directional drilling for accessing hard-to-reach geothermal resources.

With assistance from GTO, Sandia National Laboratories (SNL) is developing a downhole drilling system that enables directional drilling and uses a percussive hammer to improve drilling performance in hard rock formations. With percussive hammers, the bit must be indexed (rotated precisely through a certain number of degrees) between each blow for the bit to strike new material with each impact. The indexer, which is part of the bottom hole assembly, uses the same compressed air source as the percussive hammer to produce the rotational indexing required for drilling. SNL's system coordinates the bit rotation and hammering frequency to optimize drill bit life and rate of penetration.

Percussive drilling has lower weight on bit (WOB) and torque requirements than other rock reduction methods. Lower WOB improves directional stability and lower torque reduces drilling energy consumption. Both of these factors can reduce the drilling costs associated with geothermal resource development. SNL is currently working with a commercial partner to field test a version of the system in shallow horizontal drilling applications.



SNL's Auto Indexer for Percussive Hammer Drilling

Overview

- Developed by SNL.
- Working with an industry partner to test the indexer in a shallow horizontal drilling environment.

Applications

Can be used to drill wells for enhanced geothermal systems in high-temperature, hard rock formations.

Capabilities

- Enables the use of directional drilling through downhole rotation.
- Generates high peak torque in a small form factor.
- Improves drilling penetration rates in high-temperature, hard rock formations.

Benefits

Cost Savings

Reduces the cost of geothermal resource development by increasing the drilling rate of penetration in high-temperature, hard rock formations.

Durability

Overcomes the temperature-related limitations of conventional downhole motors (e.g., positive displacement motors) by eliminating the use of elastomeric components (which degrade at the high temperatures encountered in geothermal formations).

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Deep Geothermal Drilling Using Millimeter Wave Technology

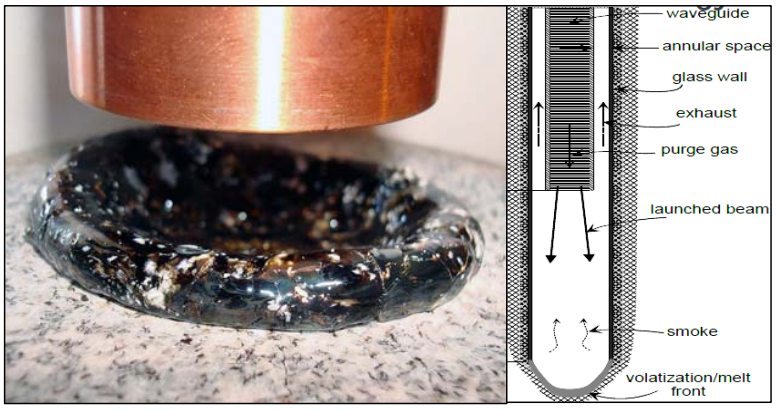
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Direct Energy Drill Increases ROP in Deep, Hard Rock Formations and Lines Wellbore While Drilling

The ability to drill through deep, hard rock formations is key to successfully accessing geothermal resources. Mechanical grinding technologies can experience a significant decrease in their rate of penetration (ROP) when drilling in deep, hard rock environments, resulting in longer drilling times and increased cost. An alternative to mechanical drilling is direct energy drilling, in which a focused beam of energy vaporizes the rock.

With assistance from GTO, Impact Technologies LLC and the Massachusetts Institute of Technology are developing a form of direct energy drilling using concentrated millimeter waves. Millimeter waves are similar to lasers, except the wavelengths are approximately 1,000 times longer. The longer wavelength reduces the problem of wave scattering (waves being deflected off-target by small particles) experienced by lasers in dirty drilling environments. When the millimeter waves are concentrated at the drilling surface, the rock is heated at temperatures of up to 3,000°C, which melts and then vaporizes the rock. During this process, the created rock melt is pushed to the sides of the well, which then cools and is vitrified (turned into glass), lining the walls of the well with a layer of glass. This rock-melt glass layer could potentially serve as a substitute for conventional steel casings that are used to stabilize the well and prevent heat exchange fluids from leaking out of the wellbore and foreign fluid entry from contaminating the heat exchange fluids.

The millimeter wave technology is currently being tested as part of a DOE Small Business Technology Transfer project with a more optimal 100 kW power and 95 GHz frequency gyrotron. High-pressure window designs and high-pressure/high-temperature millimeter wave transmission gases are also being tested.



Impact Technologies' Millimeter Wave Drill

Overview

- Developed by Impact Technologies LLC, in partnership with the Massachusetts Institute of Technology.
- Currently developing a higher power, higher frequency, millimeter wave gyrotron.

Applications

Can be used as an alternative to mechanical grinding in deep, hard rock drilling applications, such as geothermal, oil and gas, and nuclear waste storage. Can also be used to line mechanically-drilled wells with rock melt.

Capabilities

- Uses concentrated millimeter waves to melt and vaporize rock.
- Lines wellbore while drilling by melting the rock surface on the sides of the well, creating a protective, stabilizing glass layer.

Benefits

Cost Savings

Reduces drilling costs by increasing ROP compared with mechanical drilling in deep, hard rock environments (saving time and money on drilling) and eliminating the need for post-drilling installation of a steel casing.

Versatility

Provides a base millimeter wave technology that can be applied in crosscutting industrial and public applications, including subsurface fracturing.

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El Paso County Geothermal Project at Fort Bliss

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Renewable Resources Used for Power Generation as Part of "NetZero" Initiatives

To successfully develop geothermal resources, risks must be identified and minimized. Typically, a detailed resource characterization and data analysis is performed to aid in securing site funding and to reduce development cost. For power generation, hydrothermal resources must have sufficient permeability, fluid flow, and high temperature (over 300°F); analysis of these parameters will determine the economic viability of the resource.[1]

El Paso County and industry collaborators, with GTO funding (as part of the American Recovery and Reinvestment Act), are examining the heat and power generating viability of the geothermal resources at Fort Bliss Military Reservation, within the Tularosa-Hueco Basin, NM. The U.S. Army is investigating "Net Zero" energy initiatives including grid independent power generation. In 2009, Ruby Mountain, Inc. began analyzing Sandia National Laboratories' slimhole well data from the 1990s combined with new data obtained using the latest exploratory drilling technology. To mitigate risk and reduce costs, a reverse circulation drilling rig was used and produced cuttings of excellent size and quality for the analysis. Multiple data types were used to develop a new model, including petrography, hydro-thermal mapping, fault mapping from the Earth Remote Sensing Analysis Center (ERSDAC), downhole gravity, thermal gradient and cuttings analyses (thin sections, XRD), and OEMScan™ by EGI. The model determined the best location for a new production well with the required fluid temperature and flow rate to justify development for of a power plant without interfering or compromising Fort Bliss' strategic missions.[2]

The 3,030 ft production well at site #56-5 was drilled, logged, and tested in 2013 on Fort Bliss' McGregor Range in Otero County, NM. Initial testing demonstrated commercial permeability with the well having a temperature in excess of 190°F with no reversal—the highest such temperature in the vicinity. It is possible that a significant portion of Fort Bliss' power needs could be met by the geothermal power generating potential of well #56-5. This would align with the military's Net Zero objectives to the extent a functional and economically viable geothermal or combined geothermal/solar thermal project could be financed and constructed.



Drilling RMI 56-5 on the McGregor Range, Otero County, NM

Overview

- Developed by El Paso County, U.S. Army, Ruby Mountain Inc., University of Utah Energy & Geoscience Institute (EGI), and Evergreen Clean Energy Management.
- Currently testing a lower cost, lower risk geothermal exploration strategy and other deployment opportunities in geothermal, oil, and gas exploration.

Applications

Can be used for reducing power usage on grid and enabling energy independence and security.

Capabilities

- Provides field tested modeling method for analyzing and assessing geothermal resources for development.
- Allows input from different data types, including petrography, hydro-thermal mapping, fault mapping, downhole gravity, thermal gradient, and soil survey data.
- Provides optimized output for determining the best site locations with the required fluid temperature and flow rate to justify site development for power generation.

Benefits

Cost Savings

Reduces energy usage cost per kilowatt by supplementing and/or replacing grid power with onsite geothermal power generation. (Economic competiveness has yet to be determined)

Environment

The project uses detailed analysis to direct exploratory geothermal field operations, which leads to reduced cost and strain on the environment from erroneous site starts.

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[1] GTO Hydrothermal Resources Factsheet
[2] GTO 2013 Peer Review Presentation

Harsh Environment Silicon Carbide Sensor Technology for Geothermal Instrumentation

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Sensors Monitor Downhole Conditions in Sub-Surface Exploration and Development

GTO program initiatives support the exploration and development of geothermal resources and are dependent on the acquisition of sub-surface data (e.g., temperature, pressure, and seismic data). Accurate characterization of sub-surface conditions can indicate locations for potential geothermal power projects and reduce financial risks and development costs. To address these initiatives and goals, new and improved geothermal exploration technologies must be developed and validated.[1]

The University of California, San Diego (UC San Diego), with assistance from GTO (as part of the American Recovery and Reinvestment Act), are developing corrosion-resistant materials and sensors (i.e., temperature and pressure) for downhole operations. UC San Diego's sensors will be fabricated using Silicon carbide (SiC) to withstand harsh, supercritical conditions. Whereas current silicon-based sensor technology is limited to temperatures below 300°C, UC San Diego's SiC sensors have been demonstrated at 600°C and in dry steam. The pressure sensor will use a corrugated diaphragm capacitive sensing scheme for scalability, simple read-out, and survival at high burst pressures. Both sensors were designed using finite element analyses to achieve desired performance. UC San Diego developed processes to construct the sensor components and circuit boards including etching, bonding, and electroplating; vapor deposition; ion sputter deposition; reactive sputtering; and plasma etching. Ruggedized bonding processes were developed to assemble sensor arrays (solid-liquid inter-diffusion) and for attaching the arrays to casing components.[2]

Sensor materials and component exposure testing to 374°C (T_c H_2O) for up to 100 hours has shown no measureable degradation or weakened bond strength or die-shear. UC San Diego continues to work on 2nd generation sensors and improve their fabrication processes (thicker substrates) and bonding processes including a wafer cutting process to avoid wafer grinding. The 2nd generation sensors will be exposure tested in supercritical geothermal brine with casing coupler components to assess survivability. Collaborations are being explored for future field testing (geothermal reservoir monitoring) and other industry development/deployment requirements.[2]



UC's Sensor Cluster - Integrated SiC Sensors & Supporting Electronics (Power Management & Wireless Transmitter)

Overview

- Developed by UC San Diego.
- Currently developing next generation sensors, investigating potential field test sites and exploring industry partnerships.

Applications

Can be used for sub-surface data logging and monitoring in geothermal, oil, and gas exploration.

Capabilities

- Provides long term monitoring of down-hole temperature and pressure.
- Achieves operation in harsh, supercritical conditions (i.e., at a temperature of 374°C and a pressure of 220 bar for pure water).
- Provides an output signal that requires no complex signal conditioning and can be interfaced and read with simple electronics.

Benefits

Cost Savings

SiC sensor technology could provide improved geophysical data for resource modeling and direct monitoring of existing reservoirs reducing resource operation and development cost.

Durability

Constructed from chemically inert and thermally stable materials (i.e., ceramic, wide-band gap materials, and inert metals).

Manufacturability

Sensors are fabricated using semiconductor manufacturing technology.

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[1] SRA Report on Development of Geothermal Exploration Technologies
[2] GTO 2012 Peer Review Presentation

Improved Cement for Geothermal Wells

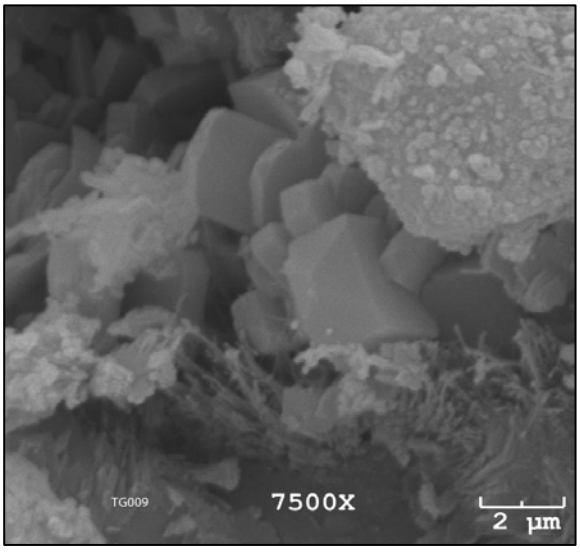
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Zeolite-Containing Cement Performs Well in Harsh Geothermal Conditions and is Easy to Use

After an oil, gas, or geothermal production well has been drilled, the well must be stabilized with a casing (i.e., sections of steel pipe that are joined together) to prevent the well walls from collapsing. The gap between the casing and the walls of the well is filled with cement, which locks the casing into place. The casing and cementing of geothermal wells is complicated by the harsh conditions of high temperature, high pressure, and a chemical environment (i.e., brines with high concentrations of carbon dioxide and sulfuric acid) that degrades conventional Portland cement.[1]

During the 1990s and early 2000s, GTO provided support for the development of fly-ash-modified calcium aluminate phosphate (CaP) cement, which offers improved resistance to degradation compared with conventional cement. However, the use of CaP cements involves some operational constraints that can increase the cost and complexity of well cementing. In some cases, CaP cements are incompatible with chemical additives commonly used to adjust cement setting time. Care must also be taken to ensure that CaP cements do not become contaminated with leftover conventional cement from pumping equipment used in conventional well cementing.

With assistance from GTO (as part of the American Recovery and Reinvestment Act), Trabits Group, LLC has developed a zeolite-containing cement that performs well in harsh geothermal conditions (thermal stability at temperatures of up to 300°C and resistance to carbonation) and is easy to use (can be easily adjusted with additives and eliminates the need to "sterilize" pumping equipment as with CaP cements). This combination of properties reduces the complexity/cost of well cementing, which will help enable the widespread development of geothermal energy in the United States. Trabits Group is currently seeking to commercialize the new cement.



Microscope Image of a Zeolite used in Trabits Group's Cement

Overview

- Developed by Trabits Group, LLC, with assistance from the University of Alaska Fairbanks.
- Completed a 1,000-ton production run of interground clinker and zeolite cement and tested the cement in six low temperature wells.

Applications

Can be used secure steel casings in geothermal wells, thereby providing structural stability to the wells.

Capabilities

- Allows for density adjustments within a single blend without adversely affecting cement slurry properties.
- Eliminates the need for separate blends for lead and tail slurries.
- Maintains accurate down-hole densities throughout the job without significant changes in viscosity.

Benefits

Cost Savings

Reduces the time and complexity of well cementing, which reduces the overall cost of well completion.

Ease-of-Use

Provides compatibility will all common additives (e.g., retarders and accelerators) and minimizes the effect of down-hole temperature fluctuation on setting time.

Environment

Reduces greenhouse gas emissions compared with Portland cement production by using naturally occurring pozzolanic zeolites.

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[1] *Advanced Cements for Geothermal Wells*, Brookhaven National Laboratory (2006), http://www.bnl.gov/isd/documents/35393.pdf

Low Temperature & Coproduced Resources

- High-Temperature Ultracapacitors for Geothermal Exploration
- Low-Temperature Stirling Engine for Geothermal Electricity Generation
- Metal Extraction from Geothermal Fluids
- Metal Organic Heat Carrier Nanofluids for Low-Temperature Geothermal Systems
- Mineral Extraction from Geothermal Fluids
- Novel Energy Conversion Equipment for Low Temperature Geothermal Resources
- Variable Phase Turbine Power System for Low-Temperature Geothermal Resources

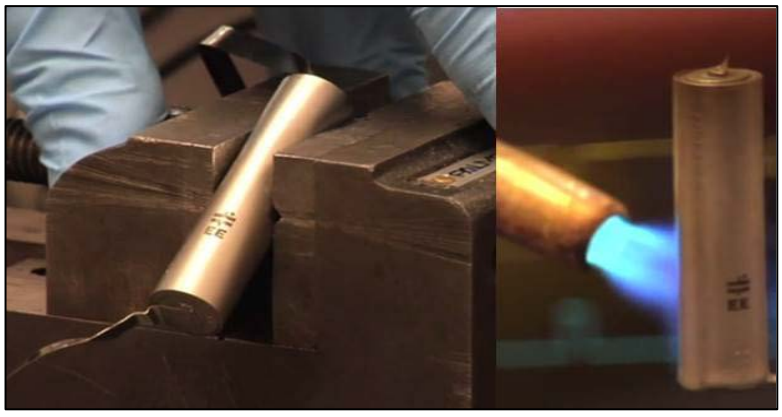
High-Temperature Ultracapacitors for Geothermal Exploration

Low Temperature & Coproduced Resources | Emerging Technology

Power System for Directional Drilling Tools Offers Increased Power and High-Temperature Operation

The ability to achieve real-time directional drilling control to access the most productive resources in a geothermal formation is a key to successful geothermal energy exploration. This control is achieved by logging-while-drilling (LWD) and measurement-while-drilling (MWD) tools, which provide feedback regarding drill bit position, drilling performance, and rock formation characteristics. The LWD/MWD tools used in geothermal drilling require electronic components (including energy supply and energy storage devices) that are capable of operating at higher temperatures (e.g., 200°C) than are typically encountered in oil and gas drilling. Today's incumbent downhole energy storage devices (lithium thionyl chloride batteries) have a safe operating temperature maximum of 200°C, are not rechargeable, and are subject to thermal runaway explosion risk in high shock, vibration, or over-temperature environments. Therefore, they are not well-suited for use in most geothermal wells, where temperatures often exceed 200°C and shock/vibration conditions can be considerably more difficult than in traditional oil and gas wells.

With assistance from GTO, FastCAP Systems Corporation has developed energy storage devices called ultracapacitors ("ultracaps") and related power systems that can operate at 250°C and offer performance characteristics that take the "best of both worlds" from traditional capacitors and batteries. Ultracaps can provide quick bursts of power (10x that of batteries), can be recharged in seconds, and can undergo more than 1,000,000 charge/discharge cycles before they wear out. Initial anticipated applications for FastCAP's ultracapacitors include providing bursts of power stored up from lithium thionyl chloride batteries. The increased power could enable the use of electromagnetic telemetry in applications such as deep wells in rock formations with high electrical resistivity, where currently available downhole power cannot generate a signal that is strong enough to reach the surface.



FastCAP's High-Temperature Ultracapacitors Undergoing Mechanical and Thermal Stress Testing

Overview

- Developed by FastCAP Systems Corporation.
- 200°C and 250°C prototypes have been successfully validated at Sandia National Laboratories in 2014 and 2015, respectively.

Applications

Can be used as a power system and rechargeable energy storage device for downhole LWD/MWD tools in the geothermal and oil and gas industries.

Capabilities

- Delivers up to 10x more power than the lithium thionyl chloride batteries currently used in drilling.
- Operates safely and reliably at temperatures of up to 250°C (more than 3x the temperature of commercially available ultracaps).

Benefits

Cost Savings

Enables the expanded use of directional drilling tools in high-temperature geothermal environments, helping to reduce the cost and risk of geothermal exploration.

Performance

Increases available downhole power compared with battery-based systems, enabling the expanded use of electromagnetic telemetry.

Safety

Does not pose an explosion risk (like lithium-based batteries) when exposed to extreme temperatures, physical damage, shock, or vibration.

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Low-Temperature Stirling Engine for Geothermal Electricity Generation

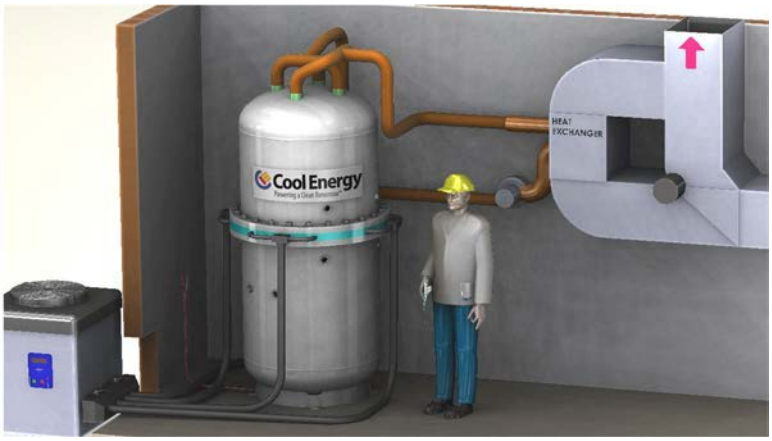
Low Temperature & Coproduced Resources | Emerging Technology

Heat Engine Generates Electricity From Waste Heat in Low Temperature Co-Produced Geothermal Fluids

Low temperature resources are hydrothermal resources with temperatures below 150°C and developing applications of these resources for power generation, heating, aquaculture, and agriculture, and drying is being sought. Similarly, co-produced hot fluids, a common by-product of oil, gas, and other hydrocarbon production, are being used to generate electricity. It is estimated that 25 billion barrels of hot water are produced annually by oil and gas fields alone. It is estimated that there is potential for up to 2,700 terawatt-hours of geothermal power generation in the U.S., with efficiency being dependent on the water volume and temperature.[1,2]

Cool Energy, Inc. (CEI), with assistance from GTO in the form of SBIR grants, is adapting and developing their Stirling cycle based power conversion technology for use with geothermal heat sources. CEI's technology was originally intended for waste heat recovery applications, but the temperatures required for operation are similar and applicable to geothermal applications. In addition to the $3kW_e$ engines previously developed, CEI is developing a 25 kW_e version (rated at 400°C), which will use custom self- lubricating, low-wear-rate bearing surfaces, metallic or non- metallic regenerators, high-effectiveness heat exchangers, and a rotary transmission to transfer the mechanical work of the engine to the electric generator built into the engine housing. The initial phase of CEI's efforts analyzed data from oil and gas wells to model electric power generation using heat from coproduced liquids to drive a Stirling engine. Subsequently, CEI estimated the power generating potential from geothermal energy in oil and gas wells and has designed an engine to operate in the temperature ranges supplied by these co-produced liquids. It is expected that the engine unit will produce 10–15 kWe from each co-produced fluid site.

CEI has begun fabrication and construction of a 25 kWe prototype, which will be marketed as the GeoHeart®. The unit will be used to generate electricity from co-produced liquids at oil and gas wells and recoverable heat from pumps and compressors. CEI will also apply this technology to study the potential of using spent wells that are no longer producing.



CEI's 25kWe GeoHeart® Stirling Cycle Based Heat Engine

Overview

- Developed by Cool Energy, Inc.
- Currently fabricating prototypes and evaluating market strategies.

Applications

Can be used to generate electric power from low temperature heat sources, including stationary plant equipment (engines, pumps, and compressors) and geothermal and co-produced fluids.

Capabilities

- Provides waste heat-to-power generation and supplemental local heating using post process waste heat.
- Achieves 5–15 kWe electricity generation while operating in the temperature range between 100°C and 200°C.
- Achieves thermal conversion efficiency of up to 20%.

Benefits

Cost Savings

Reduces energy cost by offsetting local utility power loads.

Installation

System is easily transported and easily retrofits into existing plant infrastructure or new installations.

Environment

System is self-contained, fuel-free, and emissions-free.

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[1] GTO Low Temperature and Coproduced Resources Fact Sheet
[2] Cool Energy SBIR II Award

Metal Extraction from Geothermal Fluids

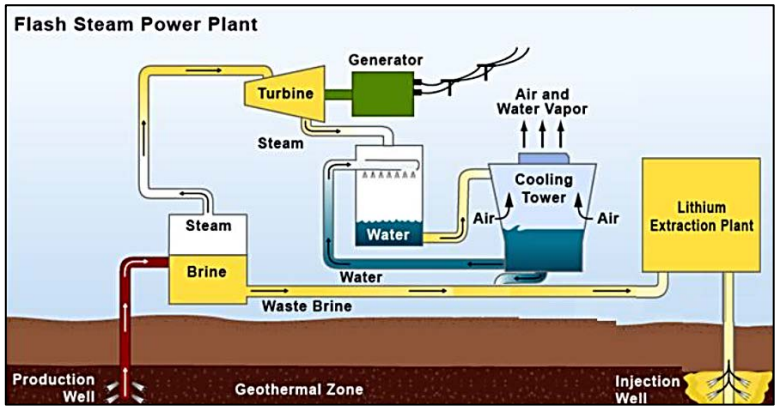
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Process Captures Valuable Metals from Geothermal Brine and Transforms them into Marketable Products

Geothermal flash steam power plants pump brine under high pressure from a geothermal reservoir into a flash drum, where the pressure drops and a portion of the brine flashes i.e., vaporizes into steam. The steam is routed through a turbine to generate electricity, condensed, and injected back into the geothermal reservoir. The unflashed brine, which is typically viewed as not having any value, has a high concentration of metals that could be captured and transformed into marketable products.

With assistance GTO (as part of the American Recovery and Reinvestment Act), Simbol, Inc. (now owned by Alger Alternative Energy LLC), has developed processes to extract these valuable metals from the brine before it is injected back into the geothermal reservoir. Simbol is focusing on the extraction of lithium, manganese, zinc, and potassium. Lithium and manganese are two of the elements included in DOE's Critical Materials Strategy because of their use in batteries for hybrid and all-electric vehicles.[1] Further, lithium is used in rechargeable batteries for high-draw portable electronic devices with high levels of use (e.g., smartphones, laptop computers, and digital cameras). Zinc and manganese (in the form of manganese dioxide) are the active materials in alkaline batteries, which are most commonly used in low-draw electronic devices (e.g., alarm clocks, toys, and radios). In addition, zinc and manganese are increasingly used as micronutrients—in the form of chlorides and sulfates—for crops. Finally, potassium (in the form of potassium chloride, or potash) is used as an agricultural fertilizer.

Simbol estimates that metal extraction/transformation from the brine used by a 50-MW geothermal plant could annually yield 15,000 tonnes of lithium carbonate, 24,000 tonnes of manganese dioxide, 8,000 tonnes of zinc metal, and 410,000 tonnes of potash. Royalties from the sale of these products would provide an additional revenue stream to geothermal plant operators, improving geothermal project economics and accelerating the development of geothermal energy in the United States.



Simbol's Metal Extraction Plant Recovering Lithium and other Strategic Metals from Geothermal Flash Plant Brine

Overview

- Developed by Simbol, Inc., now owned by Alger Alternative Energy LLC.
- Operating a demonstration plant at the EnergySource LLC, John L. Featherstone geothermal power plant in Calipatria, CA.

Applications

Can be used to extract valuable metals (e.g., lithium, manganese, zinc, and potassium) from geothermal brine and transform the raw extracted materials into marketable products.

Capabilities

- Produces high-value metals and metal-containing compounds that are used in hybrid and all-electric vehicle batteries.
- Produces potash (potassium chloride), an important agricultural fertilizer.

Benefits

Additional Revenue

Improves geothermal project economics by creating a new revenue stream (i.e., royalties from the sale of extracted mineral byproducts) for the geothermal plant operator.

O&M Cost Savings

Removes potential fouling agents from geothermal brine, thereby reducing injection well operation and maintenance costs.

Domestic Resource Development

Provides a domestic source of lithium and other metals that are key components of batteries for electric vehicles, consumer electronics, and energy storage technologies.

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Website: http://www.simbolmaterials.com

[1] For more information: http://energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf

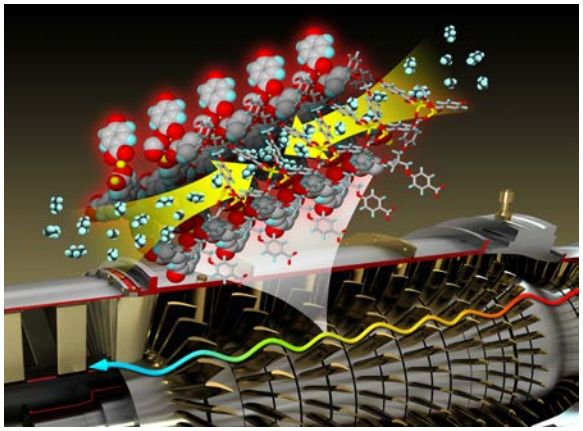
Metal Organic Heat Carrier Nanofluids for Low-Temperature Geothermal Systems

Low Temperature & Coproduced Resources | Emerging Technology

Nanotechnology Based Additive Improves Thermodynamic Properties at Fluid-Vapor Transition

GTO facilitates research, development, and demonstrations to enable economic power generation using low-temperature resources, which is technically challenging because system efficiency is strongly dependent on temperature.[1] Low temperature and coproduced geothermal resources is a growing sector, with development work extending into sedimentary basins and resources co-located within oil and natural gas fields. There are three types of geothermal power plants—dry steam, flash steam, and binary cycle. Binary plants typically use an Organic Rankine Cycle (ORC) heat engine circulating a working fluid with a boiling point lower than the water-steam phase change. The heat from the geothermal fluid vaporizes the working fluid ("binary" fluid) in a heat exchanger to drive the power generating turbines.

Pacific Northwest National Laboratory (PNNL), with initial funding from the American Recovery and Reinvestment Act and currently through GTO's Low Temperature and Coproduced Geothermal Resources Program, is developing a new type of nanotechnology additive using microporous metal-organic solids to improve the heat carrying capacity of working fluids in an ORC. These metal-organic heat carrier (MOHC) nanofluids may overcome the cycle efficiency limitations imposed by the bulk thermodynamic properties of the working fluid (e.g., boiling point, latent heat of vaporization, density, and heat capacity). In particular, the constraints imposed by these properties can limit heat transfer above the vapor transition where the vapor's thermal conductivity and heat capacity are lower. PNNL is investigating nanoporous organic or metal-organic solids that interact at the molecular level in a working fluid and offer the potential to improve ORC system efficiency without modifying the core equipment or operating conditions. To date, PNNL has completed tests on nanofluid vapor-liquid transition in both a single-pass capillary and coiled tubing heat exchanger. Calculations suggest the potential to improve cycle efficiency by up to 15% with MOHCs. PNNL's advances in molecular dynamics simulation of MOHC nanofluids have harmonized materials design and engineering performance requirements, which will enable further development of MOHC nanofluids for geothermal systems. Discussions with potential industry partners are underway on the application of MOHCs in small ORC systems, solar thermal power, and ocean thermal power.[2]



Operating Principle of PNNL's MOHC Nanofluid in a Turbine

Overview

- Developed by Pacific Northwest National Laboratory.
- Continuing development and simulation work on MOHCs, exploring industry partnerships and applications.

Applications

Can be used to improve Organic Rankine Cycle heat engine efficiency in applied electric power generation using low temperature (< 300°F) geothermal, solar, or ocean resources.

Capabilities

- Achieves increased heat extracting of working fluid by up to 15%.
- Achieves tunable binding energy for compatibility with existing working fluids and refrigerants.
- Adaptable to improve efficiency of solar thermal collectors.
- Provides increased high heat uptake and high structural and thermal stability up to 350°C.

Benefits

Efficiency

Heat extraction rates of working fluids are improved by up to 15% by the addition of MOHCs nanofluid leading to improved ORC system efficiency.

Installation

MOHC nanofluids are compatible with most currently available working fluids and refrigerants with little modification to existing equipment or operating conditions.

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[1] 2014 GTO Low-Temperature and Coproduced Geothermal Resources Factsheet
[2] 2012 GTO Peer Review Presentation

Mineral Extraction from Geothermal Fluids

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Process Generates Revenue Stream by Removing Damaging Minerals for Use in Other Industries

GTO is committed to developing and deploying technologies for clean, domestic power generation and establishing geothermal energy as a significant contributor to the U.S. energy portfolio. There is an estimated 100–500 GWe of potential geothermal power generating resources and another ~100 million barrels of hot water produced daily by the oil industry that is treated as waste.[1] Power is generated from hot geothermal fluids by converting heat to electricity using a closed loop binary cycle that produces steam to drive turbines. These fluids contain minerals and other contaminants, which can cause deposits–silica scaling–in critical power plant components (e.g., heat exchangers and pumps), reducing overall efficiency and reliability.

Lawrence Livermore National Laboratory (LLNL), with assistance from GTO, is developing technology that could extract these minerals from geothermal brine and prevent issues from silica scaling. Other valuable minerals and metals are present in geothermal brine and could also be processed for extraction and recovery. LLNL, in collaboration with Mammoth Pacific, LP (MPLP), a subsidiary of Ormat Technologies Inc., built a cost effective plant-scale process using reverse osmosis (RO) and subsequent agglomeration and filtration for extracting silica as a by-product. Increasing the silica concentration using RO increased the polymerization rate of silica, which lowered overall process costs. The properties of the silica produced can be controlled and the post extraction RO permeate used for cooling the power plant's working fluid. Removing the silica allows other valuable minerals and metals in the post extraction water (e.g., lithium, cesium, and rubidium) to be extracted using ion exchange resins. The MPLP work demonstrated that mineral extraction could improve plant operations and additional revenues increased the profitability of geothermal power production. The process can also be easily adapted for other geothermal fluid compositions.[2]

In 2014, Environmetals, Ltd. (now Geo40, Ltd.) commissioned a mineral extraction plant at Wairakei geothermal power station in New Zealand. This plant was based on LLNL's previous success at Mammoth Lakes and builds upon LLNL's process. EM's plant can process 150 tonnes (approx. 40,000 gals) of geothermal fluid per day. At a recent GNS Science geothermal energy workshop, it was estimated that the global market for silica is growing at 5% per year and has a multi-billion dollar value.[3]



Mammoth Lakes and Wairakei Power Plants and Silica Scaling (RHS)

Overview

- Developed by Lawrence Livermore National Laboratory.
- Currently developing next generation pilot scale plant with Geo40 Ltd.

Applications

Can be used to extract silica and other minerals for improved geothermal power plant efficiency and operation as well as additional revenue generation.

Capabilities

- Achieves improved heat transfer by removing potential scalants from geothermal brine prior to heat extraction.
- Provides adaptable and controllable extraction process for the various types of geothermal brine chemistries encountered in geothermal operations.
- Provides additional revenue from silica and other element extraction (lithium, tungsten, cesium, and rubidium) for use in industries outside geothermal power generation.

Benefits

Cost Savings

Reduces operating and maintenance costs by eliminating issues and impact of plant shut downs caused by silica scaling.

Environment

Extraction technique uses fewer chemical additives, minimizing environmental impact.

Installation

System can be easily retrofitted in existing plant infrastructure or new installations.

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[1] GTO Clean Domestic Power Factsheet
[2] PIER Project Final REPORT – Mammoth Lakes
[3] GNS Science Workshop July 2015

Novel Energy Conversion Equipment for Low Temperature Geothermal Resources

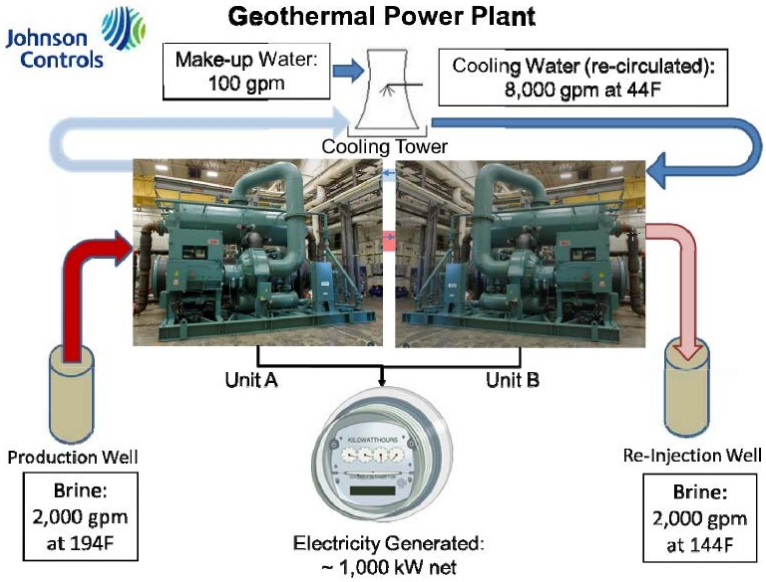
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Heat Engine Generates Electricity at Reduced Cost and Improved Performance

Low temperature and coproduced resources, where the fluid temperature can be below 150°C (300°F), represent a growing sector of hydrothermal development in the geothermal industry. GTO's program has directed focus on developing low temperature resource applications to enable electricity generation instead of using these resources for heating, fisheries, and industrial processes.[1]

Johnson Controls, Inc. (JCI), with assistance from GTO (as part of the American Recovery and Reinvestment Act), developed technology to convert low temperature geothermal heat to electricity with a 20% lower cost than currently available technologies. JCI, using their existing technology portfolio, identified the optimal components by comparing different thermodynamic cycles with various working fluids to produce the best results economically and environmentally. A multi-unit series counter-flow configuration was developed that optimized the conversion efficiencies of the thermodynamic cycle for low temperature resources.[2]

JCI constructed two units (750 kW & 1 MW), giving a total capacity of 1.75 MW for installation at a geothermal well at the Oregon Institute of Technology (OIT) in Klamath Falls. Prior to installation, JCI performed extensive performance and failure modes and effects analysis (FMEA). This determined the system's flexibility in adapting to changes in source temperature and that it met JCI's power generation capacity predictions. The system is currently undergoing a two year demonstration at OIT where operation and maintenance cost data are being gathered. Based on the results so far, JCI believes that this is a good first step toward eventual commercialization of this technology.[2]



JCI's Series Geothermal Plant at Oregon Institute of Technology

Overview

- Developed by Johnson Controls, Inc., in collaboration with Barber-Nichols and Oregon Institute of Technology.
- Field demonstration in progress and currently investigating commercial opportunities.

Applications

Can be used to generate electric power from low temperature geothermal resources or waste heat from industrial processes.

Capabilities

- Achieves power generation using lower temperature fluids (T <200°F).
- Achieves 1 MW net electricity generation using hot water flow (1500 GPM) at temperatures in the range of 196°F.
- Achieves working fluid temperature glide using refrigerant R245fa instead of a mixture.

Benefits

Cost Savings

Reduces thermal energy to electricity generation costs by 20% compared to the current state of the art with improved performance.

Environment

Generates near-emission free electricity from geothermal fluid and can enable end user to "export" electricity.

Flexibility

System design is based on the worst case, most technically challenging scenario of low temperature resources; however, the system can adapt to different source temperatures.

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[1] GTO Low Temperature Co-Produced Resources Factsheet
[2] EE0002858 - Johnson Controls Final Report

Variable Phase Turbine Power System for Low-Temperature Geothermal Resources

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System Increases Power Output from Low-Temperature Geothermal Resources

Low temperature (less than 300°F) geothermal resources and residual brine from geothermal flash plants represent large sources of thermal energy that historically have not been used for electricity generation. The lower temperature of these geothermal fluids increases the capital cost ($/kW) of the power plants used to generate electricity (all else equal, a larger plant is needed to obtain a given power output than would be necessary with a higher-temperature resource). A system that could extract more energy from a given amount of low-temperature fluid would improve project economics and enable the expansion of geothermal power across the United States.

With assistance from GTO, Energent Corporation has developed a variable phase turbine power system that increases power output from low-temperature geothermal resources. The system uses a variable phase cycle (also known as a trilateral (triangular) flash cycle) in which a pressurized liquid working fluid is heated by geothermal brine in a heat exchanger and then expanded through a nozzle and turbine as a liquid/gas mixture.[1] The two-phase expansion differs from the Organic Rankine Cycle (ORC—a commonly-used method for converting waste heat to electricity), in which a working fluid is boiled in a heat exchanger before being expanded through a turbine as a gas. Elimination of the phase change (boiling) during the heating portion of the cycle results in better-matched temperature profiles for the brine and the working fluid in the heat exchanger. By avoiding the "pinch point" (point of minimal temperature difference between the brine and the working fluid) caused by boiling, the temperature of the brine can be reduced further than in an ORC, thereby increasing the amount of energy extracted from the brine. Energent has identified a 30% improvement in power output from low-temperature geothermal resources compared with an ORC.

Energent has operated a 1 MW variable phase turbine test plant (using brine from an existing flash plant in the Coso, California geothermal area) since early 2012. The test plant generated 38 MWh of electricity in 2014 and has generated a cumulative total (through 2014) of 700 MWh.



Energent's 1-MW Variable Phase Turbine Power Plant

Overview

- Developed by Energent Corporation.
- Operating a 1 MW test plant in the Coso geothermal area of California.
- Generated 38 MWh of electricity in 2014 and 700 MWh through 2014.

Applications

Can be used to generate electricity from low-temperature geothermal resources, residual brine from geothermal flash plants, or other sources of waste heat (e.g., waste heat recovery from large engines).

Capabilities

- Increases the power output from low-temperature geothermal resources by 30% compared with an ORC.
- Reduces the capital cost compared with other low-temperature systems by using a liquid-to-liquid heat exchanger to heat the working fluid (instead of a boiler/separator) and by directly driving the generator (eliminating the gearbox).

Benefits

Cost Savings

Reduces the capital cost ($/kW) of geothermal projects by generating more power from the developed resource.

Environment

Enables the expansion of renewable electricity generation (reducing emissions compared with fossil-fuel-based power plants) to low-temperature geothermal resources (which are abundant in the United States).

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[1]For additional information regarding the variable phase cycle, two-phase nozzle/turbine, and Energent's Coso, California power plant, see http://pubs.geothermal-library.org/lib/grc/1030641.pdf

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