



Workshop
**New Frontiers in EGS
Technology**

Friday & Saturday, September 13 & 14
*Palm Springs Convention Center, Palm Springs,
California, USA*

Organizers

<p>Sabodh K. Garg, Ph.D.</p> <p><i>Environmental Studies Chair</i></p> <p>Vice-President and Principal Reservoir Engineer, Geologica Geothermal Group, Inc.</p>	
<p>Azadeh Riahi, Ph.D.</p> <p><i>Reservoir Engineering Chair</i></p> <p>Senior Engineer, Itasca Consulting Group</p>	
<p>William M. Rickard, PE</p> <p><i>Drilling Chair</i></p> <p>President and Principal Engineer, Geothermal Resource Group, Inc.</p>	
<p>Will Pettitt, Ph.D.</p> <p>Executive Director, Geothermal Resources Council</p>	
<p>Dave R. Boden</p> <p>Workshop Chairman, Professor of Geoscience at Truckee Meadows Community College in Reno, Nevada.</p>	

High-temperature geothermal resources are the manifestations of cooling magmatic intrusions, which are vertically zoned. Beneath the low-permeability cap and the hydrothermal circulation volume, there exists a zone of limited permeability where meteoric fluid does not circulate freely, and thus engineering intervention is required to enhance permeability and fluid circulation.

It is estimated that roughly 90% of the geothermal power resource reside in Enhanced Geothermal Systems (EGS). While realization of EGS development on the 100+ GWe scale would make EGS a significant component of the renewable energy portfolio, numerous technological challenges remain in accessing and characterizing, creating, monitoring, operating, and sustaining engineered reservoirs.

Development of cost-effective EGS technology is critical to the long-term viability of the world-wide geothermal industry. This workshop is the third in a series of EGS-focused workshops sponsored by the GRC (previously held in 2012 and 2016), focusing on the latest research findings and practical experiences in geothermal reservoirs. The workshop instructors are experts from geothermal and petroleum industry, academic institutions, and U.S. national laboratories.

In addition to formal presentations, ample time will be allowed for questions/discussion between participants and workshop presenters.

Agenda - Day 1: Morning

07:30am – 08:00	Register/Coffee and Continental Breakfast	
Experimental Studies Advances in understanding of fracturing mechanisms and heat and mass transport at the laboratory (e.g. block experiments), intermediate (e.g. Collab), and field scale (FORGE) will be covered in this session.		Chaired by: Sabodh Garg
08:00 – 08:15	Welcome and Introduction	Sabodh Garg
08:15 – 08:45	Geomechanics Aspects of Reservoir Stimulation	Ahmad Ghassemi
08:45 – 09:15	Creation of permeable reservoirs under high pressure and high temperature environments: Insight from state-of-the-art laboratory experiments	Takuya Ishibashi
09:15 –10:00	The importance of data acquisition and numerical analysis for the further development of EGS	Thomas Kohl
10:00 –10:15	Coffee Break	
10:15 –11:00	The EGS Collab Project: Stimulating Crystalline Rock	Tim Kneafsey
11:00 –11:45	Characteristics of the Utah Frontier Observatory for Research in Geothermal Energy (FORGE)	Stuart Simmons
11:45 –12:00pm	Discussion	
12:00 - 1:00	Lunch (Santa Rosa Room)	



Ahmad Ghassemi is the McCasland Chair Professor in the Mewbourne School of Petroleum & Geological Engineering, OU and is the director of the Halliburton Rock Mechanics Laboratory. He has a Ph.D. in Geological Engineering and specializes in geomechanics for unconventional petroleum & geothermal reservoir development. He has been working on reservoir stimulation and high-temperature rock mechanics research for the past 25 years with emphasis on experimental and numerical modeling of hydraulic fractures, coupled geomechanics/fluid flow in naturally fractured reservoirs, wellbore stability analysis, induced seismicity, and determination of poroelastic reservoir rock properties. His teaching interests include reservoir geomechanics, numerical modeling, petrophysics, and stimulation.

Dr. Ishibashi received his Ph.D. from Tohoku University in 2014. After completion of his degree, he joined Geothermal Energy Team, FREA, AIST, Japan. He worked in the Pennsylvania State University as a visiting scholar from 2014-2016. His major is experimental rock mechanics and reservoir engineering.



Thomas Kohl holds the chair of the Division of Geothermal Energy at the Institute for Applied Geosciences and is head of the Helmholtz geothermal program at KIT. After his degree in Geophysics, he became research associate at CNRS in Paris in the field of seismology. In 1992, he got his PhD at ETH Zurich on his investigations of coupled processes in deep geothermal systems. As expert on subsurface and especially in geothermal systems, his code FRACTure on coupled hydraulic-thermal-mechanical processes used world-wide was applied to characterize fractured rock in complex subsurface terrain. As co-founder and CEO of GEOWATT AG in Zürich he was running a ETH spin-off, medium size company between 2003 and 2011. Here, he collaborated in European and national research projects also as work package leader and directed numerous geothermal projects in Switzerland, Germany, Hungary, U.S. and France. At KIT in Karlsruhe, a major research focus is on the investigation of geomechanical aspects in fractured systems. As such, the origin and impact of induced seismicity and the impact on the reservoir is of strong interest. Using the exceptional possibilities of the nearby geothermal projects, systematic data analyses in combination with the tectonic setting in the Rhine Graben are conducted. With his arrival, KIT became an internationally renowned institution in geothermal research. T. Kohl has organized several high rank workshops and is one of the initiators of the European Geothermal Workshop organized jointly with University Strasbourg. T. Kohl is member of several scientific committees in Germany and France. At KIT he has established several teaching modules and is engaged in international Master Programs. Additionally, he is editor in chief of Geothermal Energy Journal and special issues of Geothermics, member of the International Heat Flow commission IASPEI, and EERA – JPGE management board member. He gave numerous presentations and invited talks at high-level scientific conferences and is author of more than 80 reviewed manuscripts in renowned journals. He is collaborating with many worldwide industrial projects.



Timothy Kneafsey P.E., Ph.D. is a Staff Scientist at Lawrence Berkeley National Laboratory serves as the Hydrocarbon Resources Program Lead. He has bachelor's degrees in mechanical and civil engineering from the University of New Mexico, a master's degree in civil engineering from the University of California at Berkeley, and a Ph.D. in civil and environmental engineering from the University of California at Berkeley. He has led, performed, and collaborated on numerous laboratory and field studies on processes affecting heat and mass transfer and phase change in fractured and porous rock. His fields of interest include geothermal energy including enhanced geothermal systems (EGS), CO₂ sequestration, production of gas and oil from unconventional reservoirs, gas production from methane hydrate-bearing sediments, and radioactive waste disposal.



Stuart Simmons (PhD Geology, University Minnesota) is a Research Professor at EGI and the Department of Chemical Engineering, University of Utah. He has over 30 years of professional, research, and teaching experience in geothermal geoscience, having worked on projects in New Zealand, Chile, USA, Indonesia, China, Philippines, Japan, Mexico, and USA. He is a former Associate Professor and Director of the Geothermal Institute, University of Auckland and former Research Professor, Colorado School of Mines. He has published over 70 refereed papers and technical reports in a wide range of journals, including *Nature*, *Science*, *American Journal of Science*, *Geology*, *Economic Geology*, *Geothermics*, *Journal of Geophysical Research*, and *Journal of Volcanology and Geothermal Research*. He served on the editorial boards of *Geology* (Geological Society of America), *Geofluids* (Blackwell), *Geothermics* (Elsevier), and *Economic Geology* (Society of Economic Geologists). In 2014, he was awarded the Silver Medal, and in 2018, the Marsden Medal, both by the Society of Economic Geologists.

Agenda - Day 1: Afternoon

Reservoir Engineering: Common Practice And Technical Challenges		Chaired by: Azadeh Riahi
<p>This session will overview engineering approaches to some of the EGS projects. Challenges associated with site characterization, stimulation, assessment of stimulated volume, and induced microseismicity will be discussed. Simulation of EGS processes at various scales, and novel numerical techniques such as discrete element modeling, will be presented.</p>		
1:00pm – 1:40	Key Complex Process Couplings and Challenges in the Effective Recovery of Deep Geothermal Energy	Derek Elsworth
1:40 – 2:20	Using THMC modeling to inform Enhanced Geothermal System Development: Insights from Newberry, Fallon, and the Altona Site	Eric Sonnenthal
2:20 – 3:00	Informed Design of EGS Operations using Numerical Modeling Tools – Review of Fallon FORGE Numerical Modeling Efforts	Branko Damjanac
3:00 – 3:20	Coffee Break	
3:20 – 4:00	A Review of Newberry Volcano EGS Demonstration	Trenton Cladouhos
4:00 – 4:40	The Path Forward: Utah Forge Reservoir Engineering Plans	John McLennan
4:40 – 5:00	Discussion	
5:00 – 7:00	Reception (San Jacinto Room)	



Dr. Riahi is a Senior Engineer and Consultant with a Ph.D. in computational mechanics. Over the past fifteen years, she has focused on research, consulting, teaching, and software development pertinent to multi-physics problems, fluid flow in porous and fractured rock, discrete element modeling, modeling-induced microseismicity, and mathematics and numerical modeling of particulate and blocky rock using both continuum and discontinuum methods. She has applied her research to develop cutting-edge numerical modeling technologies for application to some of the most challenging problems: hydraulic fracturing in hydrocarbons, the feasibility of Enhanced Geothermal Systems (EGS), and slope stability (including those of open-pit mines and civil infrastructure). These works have led to more than 35 full-length, peer-reviewed publications on a wide range of subjects from the fundamentals of numerical modeling to practical engineering problems.

Derek Elsworth is a professor in the Departments of Energy and Mineral Engineering and of Geosciences and the Center for Geomechanics, Geofluids, and Geohazards. His interests are in the areas of computational mechanics, rock mechanics, and in the mechanical and transport characteristics of fractured rocks, with application to geothermal energy, the deep geological sequestration of radioactive wastes and of CO₂, unconventional hydrocarbons including coal-gas, tight-gas-shales and hydrates, and instability and eruption dynamics of volcanoes.



Eric Sonnenthal, Staff Geological Scientist, Geochemistry Department, Energy Geosciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720. My primary research area is in the understanding and numerical simulation of coupled thermal, hydrological, geochemical, and mechanical (THMC) processes in subsurface geological and engineered systems. As a graduate student in geochemistry, worked on trying to understand melt and volatile transport coupled to deformation in lavas and layered intrusions. Postdoctoral work was aimed at developing numerical simulators to capture pressure solution-driven sediment compaction and fracturing during basin evolution. At Berkeley Lab, work has focused on developing and applying THMC codes to coupled reactive transport, isotopic fractionation, multiphase fluid-heat flow, and geomechanics in Enhanced Geothermal Systems, geologic storage of high-level nuclear waste, mineral CO₂ sequestration, fracture stimulation in unconventional hydrocarbon reservoirs, contaminant transport/bioremediation, and hydrothermal systems. One of the primary developers of the reactive transport code TOUGHREACT and leading the development of the hybrid parallel THMC code TReactMech. Involved in DOE EGS and geothermal projects including the Newberry Volcano EGS, Fallon FORGE EGS, and the Snake River Plain Play Fairway. Currently a member of the FORGE STAT.

Branko Damjanac – BSc (Eng), MSc (Eng), PhD, Principal, Itasca Consulting Group, Inc., Minneapolis, US
Dr. Damjanac has more than 30 years of experience in application of rock mechanics to solving problems in different industries. He has been involved in design and stability analysis of underground excavations for oil storage and nuclear waste isolation, including 10 year of participation in the Yucca Mountain Project, U.S. program for underground storage of high-level nuclear waste. His experience includes stability analyses for open pit and underground mines in both hard and soft rocks. Dr. Damjanac participated in the Large Open Pit (LOP) project, funded by world’s largest mining companies, to investigate critical issues related to stability of slopes in open pit mines. In recent years he is involved in development of new numerical methodologies and their application to analysis of rock mass treatment by fluid injection in oil and gas, mining and geothermal industries. He was leading Itasca’s effort on the fundamental study, funded by U.S. Department of Energy, on viability of the enhanced geothermal systems (EGS).



Trenton Cladouhos, I am a geologist with 25 years of experience in academic research, consulting (to O&G operators, nuclear waste repository designers, and geothermal operators), and technology development for the geothermal industry. My education includes a BS in geology from Stanford University, a PhD from Cornell University based on field work in the Andes of Argentina and Bolivia, and postdoctoral research at the University of Washington on fault zone mechanics. I have taught structural geology, fractured rock hydrology, and co-supervised students on geothermal research projects at UW. Over the past decade, as Senior VP of Research & Development at AltaRock Energy, I worked on EGS projects in the USA and worldwide. I have co-led many DOE-supported projects and proposals including the Newberry EGS Demonstration, the Washington State Play Fairway Analysis, the Newberry FORGE project, and the Newberry Deep Drilling Project for SuperHot EGS. I joined Cyrq Energy in September 2018 as VP Resource and now manage the subsurface resource at Cyrq’s 6 geothermal field.



William M. "Bill" Rickard, GRG President and Principal Drilling Engineer. Bill Rickard has extensive experience in twenty-four countries, on six continents, and at more than eighty geothermal fields worldwide. He has been involved in the geothermal industry for over 40 years. He specializes in project management, drilling management, rig supervision, troubleshooting, well workovers, and problem well diagnosis. He has an established record of reducing costs through innovative engineering, and successfully managing geothermal exploration and drilling programs. Prior to starting his own company, Mr. Rickard worked almost 15 years for Unocal Geothermal where he started as a field engineer and then became district drilling manager and division drilling training coordinator. He has a Bachelor of Science degree in Petroleum Engineering from Montana Tech and has published many technical papers. Mr. Rickard is a registered Professional Engineer and is serving on the Geothermal Resources Council Board of Directors and has served on the Geothermal Energy Association Board of Directors. He is also a member of the American Association of Drilling Engineers and the Society of Petroleum Engineers.

Sam Abraham has over 26 years of experience in the geothermal and oil and gas drilling industry, exploration and appraisal wells in Indonesia (Offshore and onshore), New Zealand, Turkey, Hawaii and Caribbean Islands and onshore geothermal drilling in Kenya and Ethiopia. Sam has extensive knowledge of drilling techniques and practices on high temperature and high pressure onshore and offshore wells, especially on remote drilling and start up projects, with the ability to prioritize under pressure and to problem solve in difficult situations using an analytical approach. Sam has an in-depth understanding of the well designing, preparing drilling program and well cost AFE, HSE policy implementation, preparing RFQ, contracting and tender evaluation, permitting and logistics drill well on paper exercises and governmental regulations pertaining to drilling, and working as the project coordinator on site during the drilling project has solidified his ability to be a valuable team leader. Drilling assessment review for drilling project in Kenya and worked as the drill instructor for the drilling engineering training module with USAID/EAGP training program. Sam was on the expert panel for the US Department of State workshop, April 2014, on how to drill wells more cost effectively and the World Bank for preparing framework for drilling rules and regulations for East Africa (May 2014), presented the African Union Code of Geothermal Drilling Practices at the African Union Meeting on June 13, 2016. Performed OSHA drilling rig audits in Kenya for Akiira Project in October and November 2015.



Ernesto Rivas, Sr. Drilling Engineer and Field Supervisor. Ernesto Rivas is a fluently bilingual (Spanish/English) industrial engineer with extensive geothermadrilling engineering background. He has been with GRG since 2016. Rivas is primarily responsible for designing and engineering of geothermal wells, formulating detailed drilling and workover plans, and providing on-site supervision of domestic and multinational rotary drilling, core drilling, testing, and workover operations. Ernesto also develops and manages drilling services and equipment procurement and inventory for domestic and multinational operations. He conducts an analysis of drilling data for establishing efficient drilling practices. He has worked on various projects throughout Latin America, Philippines, Indonesia, New Zealand and Turkey.

John McLennan. Since October 2009, John McLennan has been a USTAR Associate Professor in the Department of Chemical Engineering at the University of Utah. He has been a Senior Research Scientist at the Energy & Geoscience Institute and an Adjunct Professor in the Department of Civil Engineering at the University of Utah, since January 2008. He has a Ph.D. in Civil Engineering from the University of Toronto, awarded in 1980. He has more than thirty-five years of experience with petroleum service and technology companies. He worked nine years for Dowell Schlumberger in their Denver, Tulsa and Houston facilities. Later, John was with TerraTek in Salt Lake City, Advantek International in Houston, and ASRC Energy Services in Anchorage. He has worked on projects concerned with subsurface energy recovery (hydrocarbon, geothermal) in a variety of reservoir environments, throughout the world.



Agenda - Day 2:

07:30am – 08:00	Register/Coffee and Continental Breakfast	
Drilling	Issues unique to EGS (e.g. zonal isolation) will be discussed. Topics include: casing and wellbore design considerations for EGS wells; directional drilling in extremely hard rock; use of PDC (Polycrystalline Diamond Compact) bits and MSE (Mechanical Specific Energy); Stimulation, how do we do it and what is important from a completion perspective; zonal isolation, and; cementing considerations.	Chaired by: Bill Rickard
08:00 – 08:15	Welcome and Introduction	Bill Rickard
08:15 – 08:45	Casing (material selection and premium connections) and wellbore design considerations for EGS wells	Bill Rickard
08:45 – 09:15	Directional drilling (high temperature mud motors) in extremely hard rock	Sam Abraham
09:15 – 10:00	Use of PDC bits and Mechanical Specific Energy (making use of hydraulic surface torque data collection)	Ernesto Rivas
10:00 – 10:15	Coffee Break	
10:15 – 11:00	Stimulation – how to complete a well for Stimulation and best practices	John McLennan
11:00 – 11:45	Zonal isolation and cementing (methods and formulations) considerations	Hamid Najafi
11:45 – 12:00pm	Discussion	
12:00 – 1:00	Lunch (Santa Rosa Room)	
Technical and Commercial Viability of EGS – A Panel Discussion	The technical and commercial viability of EGS is investigated in this session through objective debate across a panel of experts, and using interactive Q&A with the audience, to get to the heart of how we turn the EGS concept into commercial reality.	Chaired by: Will Pettitt
1:00 - 1:15	Session Conclusions <ul style="list-style-type: none"> 1:00 – 1:05 Sabodh Garg: Experimental Studies 1:05 – 1:10 Azadeh Riahi: Reservoir Engineering: Common Practice and Technical Challenges 1:10 – 1:15 Sam Abraham: Drilling 	
1:15 – 2:35	Panelist Presentations <ul style="list-style-type: none"> 1:15 – 1:35 TBC: What are the engineering and science research priorities for EGS to make it viable in the next 10 years? 1:35 – 1:55 Thomas Kohl: What is the international view of the importance of EGS and how can we cooperate to ensure success? 1:55 – 2:15 Trenton Cladouhos: Should we be targeting hotter reservoirs for the first operational EGS and what are the additional challenges faced? 2:15 – 2:35 Rob Podgorney: What ideas should we be considering to make EGS wells commercial? 	
2:35 – 3:05	Coffee Break	
3:05 – 3:45	<ul style="list-style-type: none"> Panelist Presentations (contd) 3:05- 3:25 Peter Meier: Is induced seismicity in EGS hydraulic treatments a friend or foe? 3:25 – 3:45 Peter Ledingham: After the past four decades of research, is EGS closer to being the game changer for geothermal? 	
3:45 – 4:55	Panel Questions and Answers	Moderator: Will Pettitt
4:55 – 5:00	Closing Remarks	Azadeh Riahi