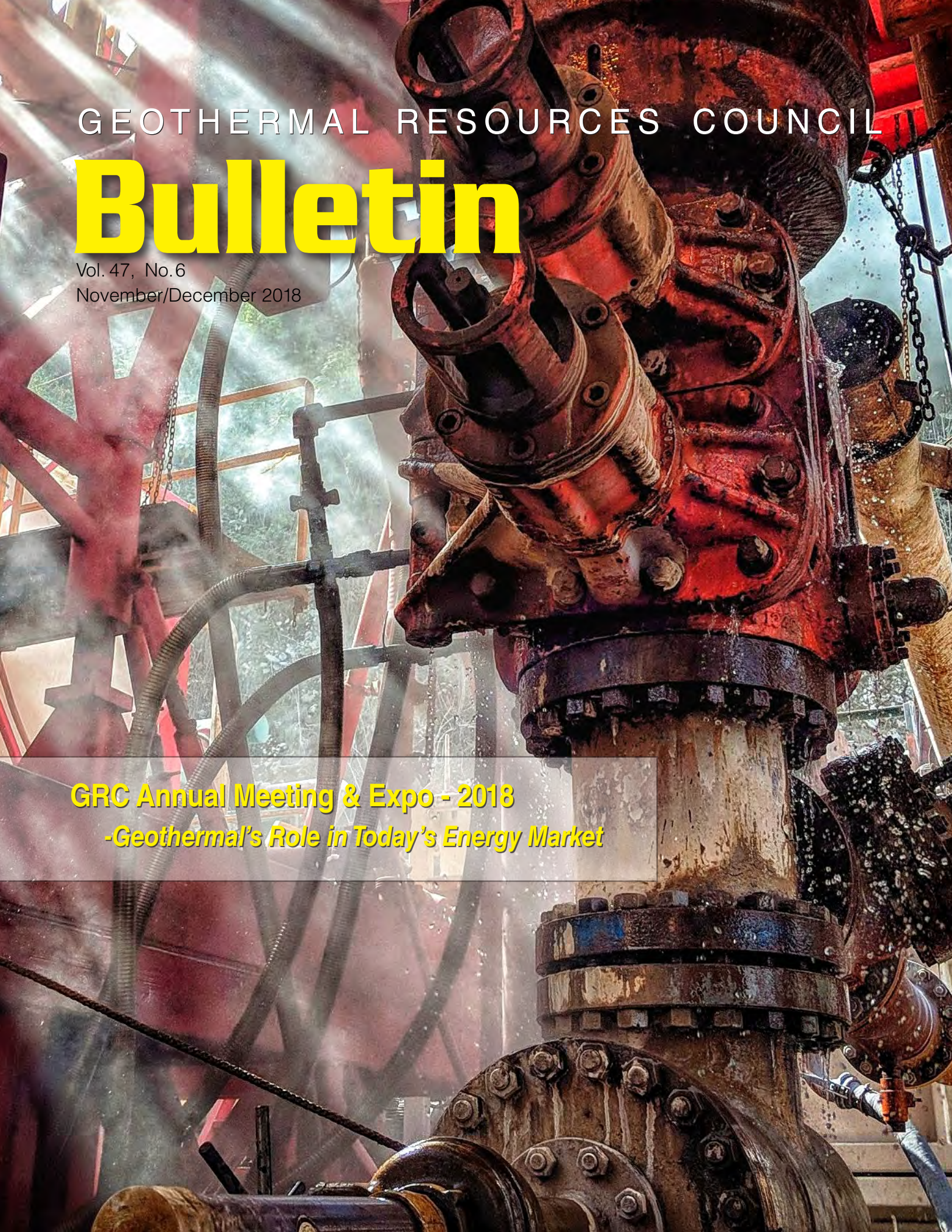
GEOTHERMAL RESOURCES COUNCIL

# Bulletin

Vol. 47, No. 6
November/December 2018



## GRC Annual Meeting & Expo - 2018

*-Geothermal's Role in Today's Energy Market*

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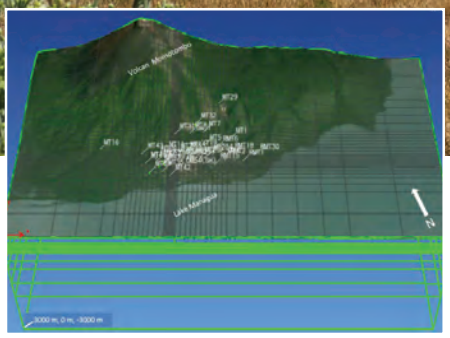

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# Bulletin

Vol. 47, No.6
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**Geothermal Resources Council**

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The Geothermal Resources Council (GRC) *Bulletin* (ISSN No. 01607782) is published as a service to its members and the public, with six issues per annual volume. The GRC is an international, non-profit educational association whose purpose is to encourage research and environmentally sound exploration, development, and utilization of geothermal-energy resources worldwide through cooperation with governmental agencies, academic institutions, and the private sector. The GRC *Bulletin* provides a forum for information transfer to the public and among professionals in many fields related to geothermal resources, including geology, exploration, development, electric-power production, and direct-use technologies. The views and opinions expressed by authors in this publication do not necessarily reflect those of the GRC or its members. For changes of address or membership information, please contact us.





COVER: *Ray of Steam, by* ***Piyush Bakane****, Reno, Nevada, USA. First Place in the 2018 GRC Geothermal Photo Contest.*

# RENEW YOUR MEMBERSHIP


## RENEWAL IS EASY!

www.geothermal.org/membership.html

# President's Message

by Maria Richards

## *Making a List*

GRC Members, know that your Board Directors hear you and bring your voice into the discussions. They volunteer their time to build this organization and community for you. Your way to thank them is to keep talking, sharing, exploring ways to improve and then assist them in completing the task/activity. As your involvement increases, the synergies of our different backgrounds create energy, and we all know the power of geothermal energy!

Paul Brophy, Richard Campbell, Louis Capuano Jr., and Joe Moore are four long-term Board leaders not running again. Please thank them for their decades of service to the geothermal community. Now it is even more important to contribute and assist those elected this Fall.

Looking at the roomful of members during the opening session of the 2018 GRC Annual Meeting and Expo, so many faces were of those who had mentored me over my 24 years in the geothermal community, Thank You!. Mentoring is multi-directional. An example is how I've learned Latin American policy and business knowledge from Gustavo Cuellar Sr. & Jr. and removing the concept of barriers from Nataly Castillo as she developed the Columbian Geothermal Association. One outcome of their mentoring is the 2018 opening of the GRC LATAM Representative Bogota office with the Dewhurst Group's assistance. The Board just voted in October to expand it's activities in 2019. If you'd like to be more involved in the region, contact the GRC office in Davis, CA or Bogota, Columbia.

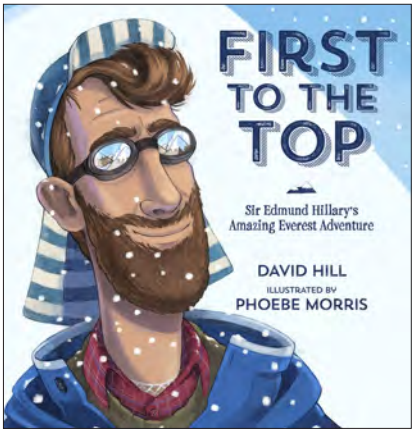
The Annual Meeting included the International Geothermal Association (IGA) and GRC Boards spending time together. This allowed us to get to know each other better and to find more ways to increase our communication. As a large international organization, GRC wants to work with IGA and assist them in building the "one voice" message for the geothermal community and then to increase the conversations between geothermal organizations and our individual members. We believe that this will provide new opportunities for stronger research, companies, and development teams. With U.S. Dept of Energy Geothermal Technologies Program announcing the increase of 2019 funding, we want every dollar spent to progress the U.S. and world geothermal projects.

Being President often feels like an honor, as it starts with you electing me to the Geothermal Resources Council (GRC) Board, then the Board electing me to be President. After the Board voted for me, a realization swept the room: Maria will be the first female President. Their awareness felt initially a surprise, then excitement, then empowerment. Empowerment to do be courageous in our thinking. In accepting the position, I requested their guidance and support. Everyone of them gave it to me, not just when they agreed with me, rather even more so by being courageous enough to disagree. The most important decisions we made, did not vote in the direction I wanted walking into the meeting, rather through thought-provocative discussions, we found our decisions. I'm very grateful to have worked with these Directors.

Each GRC Member is a reason for the President to strive and achieve more goals for our organization. Andy Sabin is the next President of the Board. He will be looking for your suggestions, concerns, and support over the next two years. I'll be passing on the GRCPres@geothermal.org email address to him to make it easy for you to keep contributing your input. I've learned there is not enough time for me to call you, therefore emails can be a way to hear the community voice. Please continue to exchange emails and calls with Andy.

For me, I have one last request: please help accomplish my goal of starting a GRC Gift and Estate Planning option and then sign-up for it. From establishing a large-scale marketing campaign to increasing funding for student research, they all take money. With the skills and drive of our new Executive Director, Will Pettitt, we can accomplish extraordinary progress for the GRC and the geothermal community in the next few years. Let's make it happen, together.

First to the Top: Sir Edmund Hillary's Amazing Everest Adventure by David Hill and Phoebe Morris, is a children's book about Sir Edmund Hillary, who is the first known person to climb Mt Everest. While in New Zealand for the 2016 Geothermal Workshop, I discovered this book exploring Auckland and was inspired by this sparkling-snowy covered man willing to pull himself up the highest peak on Earth. As the first female President of the Board, it provided a reference of reaching beyond a person's comfort zone and using creativity to keep going. It wasn't a book though that kept me going, it was you, the members. Whether I know you personally or by your name in our directory, you inspired me as someone who joined GRC to gain personally and as part of a community.




Over the next two years as the Past President, I'm looking to create more with you and strengthen our community. My contact information in January changes to SMU Geothermal Laboratory Coordinator, (w) 214-768-1975, email: mrichard@smu.edu ■

# Executive Director's Message

by Will Pettitt, PhD

## *Speaking with One Global Voice for Geothermal Energy*

During our 2018 Annual Meeting and Expo in Reno in October the term "Speaking with One Global Voice" suddenly took off. It appeared in conversations everywhere and clearly struck a deep-seated chord in the imagination of the community. I first used that term in an interview published online and then in my opening address to the meeting. The language has probably been used many times before and I discovered its significance during earlier discussions with Dr. Kate Young about the GRC's Ambassador Program that she has led. It seems that our community is saying the time is right for us to speak with one global voice.

Speaking with one global voice does not mean there is only one speaker. Nor does it mean that we are focusing on the international arena. The use of the term "one global voice" instead means that we are finding a comprehensive voice, built by consensus, that can be communicated everywhere by everybody (Definition of *global* according to online Oxford Dictionaries: *Relating to or encompassing the whole of something, or of a group of things*). What we aim to achieve is as many speakers as possible, millions if we can get them, all communicating consistent messages for geothermal energy. How do we achieve that?

This lofty goal is achieved by getting geothermal energy rooted into the public conscience. It speaks directly to our mission in Figure 1 and the goal for geothermal energy to be synonymous with renewable energy (described in Executive Director's Message in the July/August 2018 *Bulletin*: "The GRC at once Advocates, Facilitates and Educates"). To execute on this goal, we need to be successful in a number of practical steps:

- Unite our industry;
- Find the messages;
- Play the political game;
- Educate the public and our leaders;
- Work with others;
- Invest in our future and what's right, and;
- Find a million voices!


*Figure 1: Our mission is to help elevate the geothermal community by raising the recognition and acceptance of geothermal energy across the spectrum of society, in government, industry, academia and the general public, in both the US and internationally.*

We are working on all of these steps in parallel.

One reason I think the community is energized about speaking with one global voice is that recent public opinion has united behind climate change and the need for renewable, "carbon-free", energy. High-profile public figures have become vocal advocates for renewable energy (for example,

https://www.gatesnotes.com/Energy/My-plan-for-fighting-climate-change). Along with technological advances, and favorable policy and economic environments, then public opinion puts renewable energy onto a realistic trajectory for replacing carbon-emitting sources of power. There is clearly a movement in public opinion that geothermal energy needs to be a part of and can't afford to miss.

There are also many things going on in our industry right now that enables the practical steps towards achieving our goal of getting more into the public conscience. For instance, the reunification of the GEA and GRC in the USA, and the creation of the GRC's Policy Committee, now means that the GRC speaks with one voice for the geothermal community across the spectrum of society. This means that your one association can, for example, support R&D through networking and dissemination of high-end geothermal innovation (such as the work on EGS described later in this *Bulletin*), whilst at the same time advocating for policy improvements that would facilitate greater application of power-producing projects and more resource development.

Bringing together people from these often-different parts of our community can lead to efficient synergies such as the collective desire to produce a clear and simple messaging for the benefits of geothermal energy. A draft of an "elevator pitch" is given in Figure 2, which is an output of thought leaders coming together in our Ambassador Program. Through both conventional media channels and new channels such as social media, marketing and communication professionals within our industry can help all of us in our community connect these messages with millions of voices in the general public. It's these voices that will persuade our government leaders that geothermal energy has a legitimate and bright future within the world-wide renewable-energy mix.

If you want to talk about our association and the geothermal energy community you can contact me at wpettitt@geothermal.org or 916.758.2360 ext. 103. ■


*Figure 2: Draft "Elevator Pitch" for geothermal power. Assembled from: "Talking Points for Geothermal Today" presented by Paul Thomsen, and; "PowEARTHful – Renewable. Reliable. Always available. Geothermal Energy" presented by Kate Young, at the Ambassador Workshop, GRC Annual Meeting and Expo, Reno, October 2018.*

# Communication from the GRC

by Ian Crawford
Director of Communications

## The Global Geothermal Energy Community Comes Together in Reno

The 42nd version of the **GRC Annual Meeting & Expo** was held at our old stomping ground of the **Peppermill Resort Spa & Casino** in **Reno, Nevada**. It proved to be a celebration for the geothermal community, full of fun and some optimism for the future of the industry.

**More than 1,000 attendees**, about a third of them from overseas, gathered for the largest annual meeting of the global geothermal energy community.

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*1. GRC President Maria Richards and GRC Executive Director William Pettitt prepare to cut the ribbon to open the 42nd GRC Annual Meeting & Expo. Holding the ribbon are Warren Dewhurst (left) and Louis Capuano, Jr. (right). GRC Conference Manager Estela Smith supervises from stage right!*

*2. GRC Librarian Brian Schmidt (in red shirt) welcomes attendees at the registration counter.*

*3. The Opening Reception is one of the many opportunities for networking at the meeting. Here is the place to meet new friends and catch-up with old acquaintances.*

*4. More than 70 exhibitors enjoyed meeting - and doing business with attendees in the Expo.*

*5. The GRC Annual Charity Golf Tournament was held on a brisk, bright morning at the Sunridge Golf Club.*

*6. GRC Executive Director William Pettitt welcomes attendees to one of the two workshops held just before the meeting. Held over two days each the workshops offered expert knowledge on Project Development Strategy and Economic and Investment Evaluations and Evolution of Geothermal Resource Models: From Surface Exploration to Field Development and Reservoir Management.*

*7. Gene Suemnicht (in red baseball cap) led a fascinating three day fieldtrip to the Long Valley Caldera before the main event. Photo by Dr Thomas Borrmann of the School of Chemical and Physical Sciences at Victoria University of Wellington, New Zealand. Other fieldtrips visited the Steamboat Springs Geothermal Field, toured the Geothermal Direct Use System of the Peppermill Resort and another visited western Nevada to understand the use of Play Fairway Analysis in the Gabbs Valley.*

*8. A happy group after a visit to the Steamboat Springs geothermal field just south of Reno.*

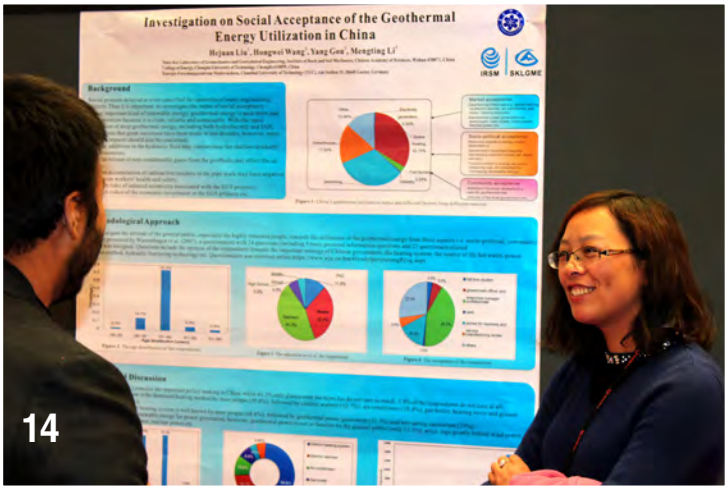
*9. More than 500 attendees packed the Capri Ballroom to hear nearly four hours of geothermal energy news and opinion.*

*10. Gene Suemnicht (left) congratulates Toshihiro Uchida on the 40th anniversary of the Japan Geothermal Research Society. According to Gene, Japan is one of the oldest and most diligent international participants in the GRC with no fewer than 30 members on the GRC roster and consistently sending a number of people to attend the annual meeting and deliver papers. Year after year, they contribute more than any other international contingent.*

*11. Jonathan A. Hernandez, of the Dewhurst Group addressed a special Spanish language workshop on behalf of the GRC Latin America Section.*

*12. On his return to Japan Toshihiro presented the plaque seen in the photo 10 above to Hideshi Kaieda, the newly appointed President of the Geothermal Research Society of Japan. He commented "We, members of GRSJ appreciate very much the GRC's thoughtfulness. Please give our best regards to GRC and the president."*

*13. Nearly 200 papers were presented at the GRC Annual Meeting & Expo for a total of over 66 hours of high quality technical information.*







*14. More than 30 posters offered opportunities for good networking and good scientific discussions.*

*15. The winners of the prestigious GRC Awards. (from left to right) Ron Barr (Joseph W. Aidlin Award); Peter Rose (Henry J. Ramey Jr. Award); Kasumi Yasukawa (Geothermal Special Achievement Award); Roy Baria (Geothermal Special Achievement Award); Zvi Krieger (Geothermal Pioneer Award), and Virgil Welch (Geothermal Special Achievement Award).*

*16. Marcelo DeCamargo (center) celebrates the success of his GeothermEx Enthalpians team in the Trivia Night Mixer with Ann Robertson-Tait (right) as Gene Suemnicht (left) moves in to congratulate. The GRC Student Committee did an excellent job of organizing the fun event.*

*17. New this year was an ending reception to celebrate a successful event. A wine and cheese social proved very popular!*

**The next GRC Annual Meeting & Expo will be held in Palm Springs, California, USA, September 15-18, 2019. Let's get together again!**

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*All photos by Ian Crawford.*

More than 700 photos from the GRC Annual Meeting & Expo can be viewed on the GRC Flicker website.....

## 2019 GRC Annual Meeting & Expo

**Reservations can now be made for hotel rooms for next year's GRC Annual Meeting & Expo in Palm Springs, California, USA, September 15-18, 2019.**

**Palm Springs** has a new dynamic downtown with stylish hotels, new fashionable restaurants, new chic shops and boutiques, new fun entertainment venues as well as welcoming public spaces for gathering, celebrating and relaxing.

With 360 days of sun-kissed weather and gorgeous scenery, **Palm Springs is like no place else** and experiencing a comeback as Hollywood's playground with a growing nightlife, burgeoning art scene and edgy vibe.

The surrounding area is a natural paradise with mountains and box canyons just outside of town and the Joshua Tree National Park just 12 miles away. Farther afield the cities of Los Angeles and San Diego are only two hours from Palm Springs.
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The GRC Annual Meeting & Expo will be held in the **Palm Springs Convention Center** and the contracted hotels are either connected to the convention center or just a short walk away.

The GRC has contracted for a discounted block of rooms at two host hotels. The **Renaissance Palm Springs Hotel** is attached to the convention center and the **Hilton Palm Springs** is just one block away.

*The luxurious surroundings of the Renaissance Palm Springs Hotel.*

*The Hilton Palm Springs is just one block from the convention center.*

Attendees can make their reservations on a secure website prepared specially for the GRC. The links will be available from the GRC Annual Meeting website at: www.geothermal.org/meet-new.html.

Exhibitors who desire a booth at the Expo should contact the GRC. Contact Anh Lay at alay@geothermal.org or (530) 758-2360 for more information. All the essential information will also be available on the GRC Annual Meeting website at: www.geothermal.org/meet-new.html.

*All the events at the GRC Annual Meeting & Expo will be held in the Palm Springs Convention Center. (Courtesy Palm Springs Bureau of Tourism)*

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## GRC Membership

**It's time to renew your GRC membership!**

Notices were sent out in November. Please complete the form and send it back as soon as possible. Alternatively, you can go online on the my.geothermal website and renew your membership quickly and easily. There is also a PDF file of the Membership Application form to download and print.

### Have Your Say!

If you would like to comment on any column or article in the *GRC Bulletin* or have an opinion on a topical subject that will interest our readers, please email the editor, **Ian Crawford** at icrawford@geothermal.org or mail to Geothermal Resources Council P.O. Box 1350, Davis, CA 95617-1350.



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## The Geysers Geothermal Association is now The Geysers NorCal Section of the GRC

GRC Executive Director **Will Pettitt** attended The **Geysers Geothermal Association (GGA)** fall dinner in November where he gave a talk on the GRC… "Representing our Community, Finding One Global Voice". The GGA is now **GRC's Geysers Northern California Section.**

There were about 30 people present - a mixture of industry and non-industry folk, who provided some really valuable feedback.

Will included an interactive challenge for all the guests and went around the room at the end of the presentation asking for: "3 things that would most improve the geothermal industry… in the U.S. over the next 3 years?"

The top three that resonated to Will were:

- Help with K-12 education, bringing geothermal energy into the curriculum in schools;
- Advertise to the general public to raise their awareness of geothermal energy;
- Help more to facilitate power purchase agreements.

*The GRC meets the folks of The GRC Geysers NorCal Section (from left to right):* **Dorothy Beebee** *(board member),* **Danielle Matthews Seperas** *(President),* **Will Pettitt** *(GRC ED),* **Jay Hepper** *(2nd Vice President),* **Mark Dellinger** *(Vice President).*

## The SUEZ Foundation and Calcite Crystals

by Susan Fox Hodgson

The **SUEZ Foundation** exhibited at the GRC Annual Meeting & Expo in Reno, Nevada. According to the website, the foundation has the world's largest research and development program for water technology. **SUEZ North America** and its global partners "…. strive to find new and smarter ways to conserve natural resources and protect the environment."

I stopped by the booth because the display caught my eye. I was mesmerized by the sight of short lengths (maybe 4 to 5 inches) of extracted casing from a geothermal well in Calistoga, California, the insides of which were evenly coated with calcite crystals (photo lower left). **Alper Tunga Dost** said a nearby art gallery purchases these pipe lengths from the company and sells them for up to $1,200 apiece, that some customers even implant them in coffee tables. Mr. Dost is the SUEZ Water Technologies & Solutions, Power Vertical, Growth Sales Leader, Europe. ■


*The short lengths of crystal-coated pipeline are in the lower, left-hand corner of the photo.*

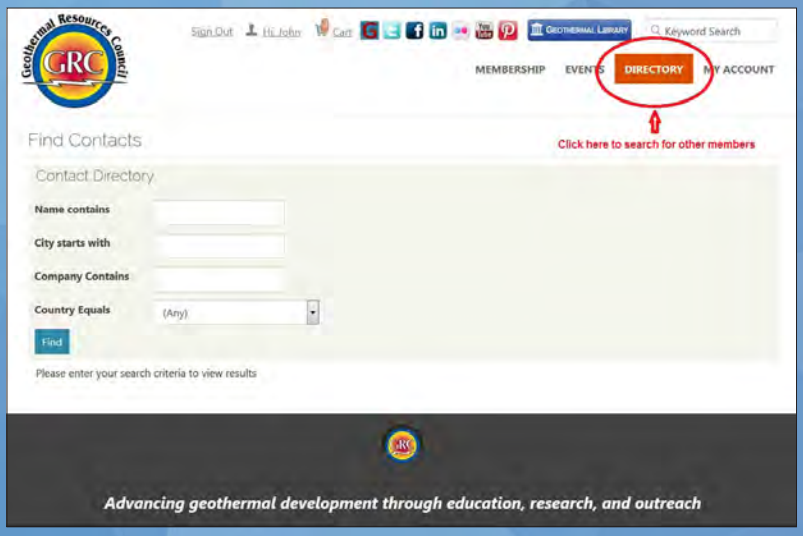
# The GRC Membership Directory At Your Fingertips

www.my.geothermal.org

**The online membership directory provides the most up to date contact information for all GRC members at your fingertips.**

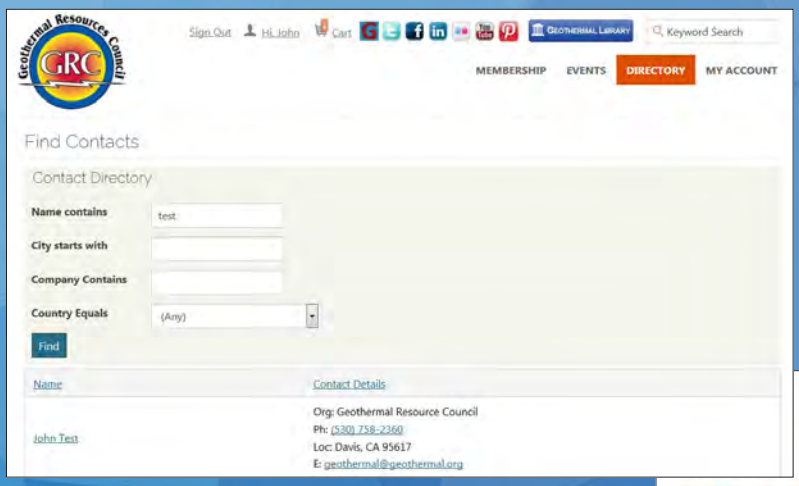
**Step 1**

**Login to the GRC Membership website: my.geothermal.org**
***(Tip: Bookmark this webpage on your smart phone for easy access)***




**Step 2**

**Click on the Directory Tab**

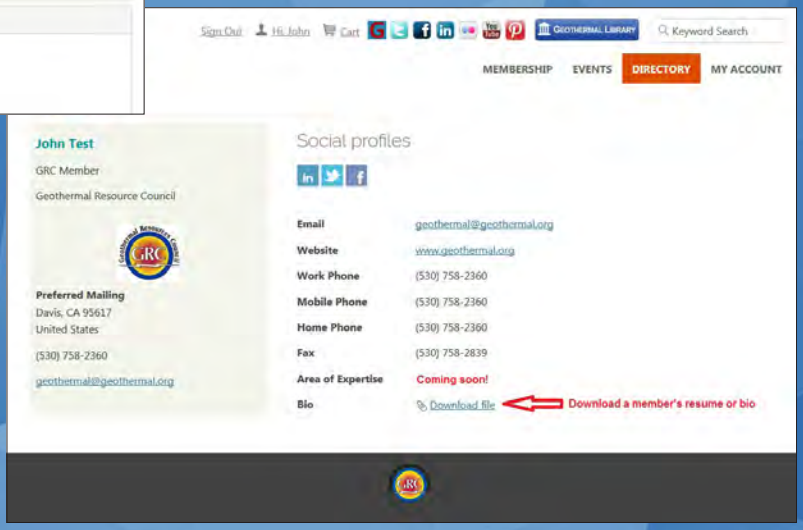



**Step 3**

**Search by Name, City, Company, or Country**
***(Coming soon: search by Expertise)***

**Step 4**

**Click on the name of the person and view their public profile.**




This feature is only available to current GRC members. If you have not renewed, please contact Anh Lay at alay@geothermal.org to renew your membership and update your profile!

# Inside Geothermal

**Dr. Susan Hamm** *addresses the large audience at the Opening Session of the 2018 GRC Annual Meeting & Expo in Reno, Nevada on October 15.*

### International Geothermal Association Extends Term of Office of Board Members by Six Months

The **International Geothermal Association (IGA)** has announced that its membership has voted to **extend the term of the current board for an additional six months.**

This will allow the new IGA board elected in 2019 to meet for the first time at the **2020 World Geothermal Congress** in Iceland. Contact the IGA if you are interested in being elected - nominations will open soon. At the last election in 2016 eight members of the GRC were elected. *Global Geothermal News.....*

## NORTH AMERICA

### Increased Budget for Geothermal Technologies Office

**Dr. Susan Hamm**, Director of the **Geothermal Technologies Office (GTO)** at the U.S. Department of Energy (DOE) Office of Energy Efficiency & Renewable Energy (EERE), gave an update on GTO activities at the GRC Annual Meeting in Reno, Nevada.

In the enacted budget for the 2019 financial year, the **spending on Enhanced Geothermal Systems increased slightly** but there was a reduction in the budget for the hydrothermal program. Spending on Low Temperature & Coproduced Resources and Systems Analysis enjoyed increases. *Download the complete GTO presentation.....*

| Dollars in Thousands USD ('000) | FY 2016 Enacted | FY 2017 Enacted | FY 2018 Enacted | FY 2019 Enacted |
|---|---|---|---|---|
| Geothermal Technologies Office | 71,500 | 69,500 | 80,910 | 84,000 |
| - Enhanced Geothermal Systems | 45,000 | 42,700 | 50,790 | 53,000 |
| - Hydrothermal | 13,850 | 14,150 | 18,420 | 15,000 |
| - Low Temperature & Coproduced Resources | 8,000 | 8,000 | 8,000 | 10,000 |
| - Systems Analysis | 3,700 | 3,700 | 3,700 | 6,000 |

*GTO Budget Overview*

### DOE Announces USD 11.4 Million for New Projects to Advance Efficient Drilling for Geothermal Energy

The U.S. **Department of Energy (DOE)** has announced the selection of **seven projects** totaling nearly **USD 11.4 million** to accelerate the research and development (R&D) of innovative geothermal energy technologies in the U.S.

*U.S. Secretary of Energy Rick Perry*

"Geothermal energy is a clean and efficient base-load energy resource, making it **an important part of our nation's diverse energy portfolio**," U.S. Secretary of Energy **Rick Perry** commented. "Developing new, efficient drilling technologies will reduce these costs and increase the availability of this domestic renewable energy resource."

Technological innovation is necessary to economically convert these resources into cost-effective energy resources. The awardees will focus on early-stage R&D projects **exploring innovative technologies for drilling geothermal wells** that show the ability to reduce non-drilling time, improve rates of penetration, and identify methods to accelerate the transfer of geothermal drilling and related technologies from the laboratory to the marketplace.

The selected projects include:

- **Argonne National Laboratory** (Argonne, Illinois): Developing more advanced, low-cost materials using superhard nano-composites combined with ultrafast surface treatment to create new drill bits with tunable properties capable of doubling rates of penetration (ROP) for drilling geothermal wells.
- **General Electric Company, GE Global Research** (Niskayuna, New York): Developing and

testing a new directional drilling orientation sensor capable of operating at 300°C for 1000 hours; this will enable measurement-while-drilling (MWD) at the significantly higher temperatures needed for geothermal drilling than current tools.

• **Oklahoma State University** (Stillwater, Oklahoma): Developing a new detailed model for common drill bits (PDC) based on tracking cutter wear from rock/bit interactions and then design a system to optimize geothermal drilling based on real-time data from that model.

• **Sandia National Laboratories** (Albuquerque, New Mexico): Developing sensing tools, algorithms, and actuators for an intelligent drilling architecture which optimizes how deep the drill cutter goes in real-time, leading to longer life for down-hole drilling components, reduced unplanned trips, and more consistent drilling rates.

• **Sandia National Laboratories** (Albuquerque, New Mexico): Developing and testing a new all-metal down-hole motor that turns drilling fluid flow into torque; this motor will remove current temperature limitations, reduce vibrations, and enable directional drilling into high-temperature geothermal reservoirs.

• **Texas A&M Engineering Experiment Station** (College Station, Texas): Developing and testing a new drill bit system that uses nanosecond micro-plasma discharge to create localized shock waves which initiate micro-cracks ahead of the bit, making it easier to cut rock; this system is capable of doubling ROP for drilling in geothermal wells.

• **University of Oklahoma** (Norman, Oklahoma): Developing and testing smart lost circulation materials (LCM) that use shape memory polymers activated by geothermal temperature to prevent the loss of fluid into fractured rock next to the drilled wellbore; the smart LCM expands within the fractures to reduce non-drilling time (NDT) and strengthen the wellbore in high temperature geothermal drilling operations. *Global Geothermal News.....*

## Controlled Thermal Resources Announces Partnership to Produce Lithium at Hell's Kitchen Geothermal Project

**Controlled Thermal Resources (CTR)**, led by Chief Executive Officer & Founding Director **Rod Colwell**, a GRC Member, has announced the launch of the company's USD 1.8-billion Hell's Kitchen Lithium-Geothermal 1 (HKLG1) project on the shores of the Salton Sea in Southern California.

The project's available **lithium carbonate equivalent (LCE)** is estimated at approximately **76,000 tonnes per annum** and will use 100 percent renewable baseload geothermal power, estimated at **up to 275 MW capacity**.

According to the CTR website, the project will utilize carbon dioxide contained in the geothermal brine for the lithium carbonate process. With no environmentally hazardous evaporation ponds, **geothermal steam will be used** to concentrate lithium carbonate products in real-time, making this development an environmentally friendly and socially responsible, world-leading facility.

On completion of HKLG1, CTR plans to expand the development in 3 additional stages of LCE production, providing **a total resource capacity of more than 300,000 tonnes per annum of LCE** -the largest known lithium resource and LCE production facility worldwide. There will be enough lithium to produce batteries for over 6,000,000 electric vehicles per year.

**Hatch**, a global multidisciplinary management, engineering and development consultancy founded in **Toronto, Canada**, will continue to support the project's technology development and will provide engineering and project execution services.

The project is located within the **Salton Sea Known Geothermal Resource Area (SSKGRA)** in the Imperial Valley, California, USA. **Commercial operation is anticipated by late 2022**. *Global Geothermal News.....*

*"Hell's Kitchen Geothermal Fields" by* **Darrell Comett.** *Third place in the 2017 GRC Photo Contest.*

## Company Announces Plans to Build Four Geothermal Power Plants in Imperial Valley

In another possible boon for geothermal in the Imperial Valley, a company called **Hy-Power Industries Inc.** has announced it has acquired 1,317 acres in the Salton Sea area for the development of **four geothermal energy plants.**

"On behalf of Hy-Power Industries, we are pleased to announce our acquisition of 1,317 acres in an area of the Salton Sea for the production. We will develop four plants for the production of electricity and minerals within the property of hydrogen and lithium which, we believe, is critical to advance energy production for a greener environment and a step forward in the battle against climate warming," said **Alan Painter**, chief executive officer of Hy-Power Industries.

**R. Gerald "Jerry" Bailey, Ph.D., P.E.**, previously president of Exxon Arabian Gulf, and adviser to the company on technical issues, said, "The Hy-Power geothermal project at the Salton Sea will utilize latest technologies for a very efficient and environmentally friendly facility. It will enhance the public power grid, while providing local employment and positive economic development in the area."

"Hy-Power Industries is currently evaluating its options for development of the property," Painter added. "Discussions are underway with **Kenneth Davlin**, president of **Oscar Larson & Associates**, Civil Engineers to engage for project planning, permitting and engineering." *Global Geothermal News.....*

## New Community Choice Aggregator for San Diego Could Offer Opportunities to Geothermal Energy Industry

The city of **San Diego has** announced it will create an alternative to the area's investor-owned utility, **San Diego Gas and Electric (SDG & E).** The city says the government-run **Community Choice Aggregator (CGA)** program will increase competition, lower electricity rates by as much as 5 percent and ensure that the city reaches its goal of 100 percent carbon-free electricity by 2035, 10 years ahead of the state's mandate.

The move makes San Diego the largest city in California to embrace the CGA program in which residents essentially band together to buy power in bulk.

San Diego's program is expected to be in place by 2022, and utility customers will be automatically enrolled in it, though they can also choose to stay with SDG & E.

*The New York Times*, reporting on the story, states that San Diego's coastal winds aren't suitable for offshore turbines, but the city plans to tap solar arrays, land-based wind farms **and geothermal power** to meet its goals. *Global Geothermal News.....*


*San Diego is just 90 miles from one of the largest geothermal energy resources in the world at the Salton Sea.*

## 20 MW Bear Canyon Geothermal Power Plant Receives Permit Extension

The **20 MW Bear Canyon geothermal power plant** in **The Geysers** has been approved by the **Lake County Planning Commission** for a use permit extension which will endure for the entire productive life of the project.

The Bear Canyon Power Plant is owned by **Calpine Corporation** and has been out of service since 2015. Calpine is currently undecided about whether or not the plant will be put back into service, but as Regional Manager **Bruce Carlsen** suggested, a "life of project" permit is better for business than a time-restricted one. "We think 'life of the project' is really good for our business," Carlsen said. *Global Geothermal News.....*

## Nevada Utility Requests Proposals for up to 350 MW Including Renewable Energy

**NV Energy** is seeking up to **350 MW of additional long-term renewable energy** and supplemental battery energy storage systems in a new *Request for Proposals.*

Key highlights of the **Fall 2018 Renewable Energy Request for Proposals** are:

- **Deadline for bids was December 10, 2018;**
- NV Energy is seeking proposals for renewable generation, including dispatchable renewable generation;
- Projects can range in size from 20 MW up to 350 MW;
- Projects must be capable of delivering energy to serve load in NV Energy's retail service territory;
- Projects must be located within the state of Nevada;
- The projects must be approved by the Public Utilities Commission of Nevada; and
- Project proposals must allow for **a commercial operation date on or before December 31, 2023.** *Global Geothermal News.....*

## Nevada BLM Receives Bids for Two Geothermal Leases

The **U.S. Bureau of Land Management (BLM)** received bids on geothermal leases in Nevada that brought in **USD 26,422** in total receipts during an online auction held on October 23.

Ten parcels totaling 27,136.48 acres were offered during the lease sale. Bids were received on two parcels, totaling 2,321.05 acres. The parcels are located in the **BLM Carson City District.**

The largest amount received, **USD 21,445** was from **Federal Abstract Company** for 1,520 acre parcel in **Lyon County**. The highest bid was for USD 12 per acre.

Geothermal leases are for an initial 10-year period with the opportunity to extend if diligent exploration and development occur.

Fifty percent of the funds collected as bids, rent and royalties are disbursed to the state, 25 percent disbursed to the county the lease is located in and 25 percent to the U.S. Department of the Treasury. *Global Geothermal News.....*

## Reno to Further Exploit Geothermal Resources

**Reno City Council** has unanimously approved moving forward with development of the **Moana Springs Aquatics Complex** in south Reno.

The Moana site sits on an active geothermal spring and historically hosted mineral baths. The geothermal reservoir also provides the heat for the nearby P**eppermill Resort Spa & Casino**, the regular host for the **GRC Annual Meeting & Expo.** *Global Geothermal News.....*

## Seismic Survey to Begin at Cornell Enhanced Geothermal System Project

**Cornell University**, in upstate **New York**, is taking the next step in a geothermal district heating project.

During September, faculty and students from **Cornell Engineering** conducted geological characterization of rock formations under campus and adjacent land to establish **baseline seismicity**, as part of the university's study of **Earth Source Heat (ESH),** a proposed enhanced geothermal system (EGS) to heat the **Ithaca** campus. *Global Geothermal News.....*

## New Reports Assess Viability for Geothermal Development in British Columbia

Two new geothermal research reports released by **Geoscience BC** provide relevant and valuable new information by evaluating locations and assessing the viability for geothermal energy development in northeastern **British Columbia (BC), Canada.**

In *Techno-Economic assessment of Geothermal Energy Resources in the Sedimentary Basin in Northeastern British Columbia, Canada*, researchers from The **University of Victoria** evaluated four areas favorable for geothermal development. The sites are at Horn River, Clarke Lake, Prophet River and Jedney.

In the *Clarke Lake Gas Field Reservoir Characterization* report, researchers from the **University of Alberta** analyzed the potential of the depleted Clarke Lake natural gas field in northeast BC for its potential as a geothermal reservoir. *Global Geothermal News.....*

## Lithium Extraction Pilot Plant will Source Geothermal Brine from Leduc Reservoir in Alberta

**E3 Metals Corp.** of **Calgary, Alberta, Canada** has announced it has begun the development of its field pilot plant which will incorporate E3's proprietary concentration technology to further validate the lithium extraction component of the process flow sheet.

The company states on its website that **a binary geothermal energy plant** could power the lithium extraction facility in **Leduc, Alberta.** *Global Geothermal News.....*

### Project Seeks to Develop the Geothermal Potential of the Leeward Islands

A geothermal and digital interconnection hub project for the **Leeward Islands** area in the **Eastern Caribbean** has been announced.

Financed by the **European Commission Interreg Caribbean** program the project initially provides for the initiation of pre-feasibility studies on potential geothermal resources on the islands of **Saba, St. Eustatius and St. Kitts,** and on electricity and digital interconnection with the establishment of a partnership between the islands. *Global Geothermal News.....*

### More Funding Made Available for Montserrat Geothermal Power Plant Project

The United Kingdom **Department for International Development (DFID)** has agreed to fund the next phase in the development of a geothermal power plant on **Montserrat.**

According to the Hon. Minister of Energy **Paul Lewis,** the agency will source the funding to engage experts to move the geothermal plant development forward. "This expertise could take the form of a "**Client Engineer**" that will aid in the formulation of turnkey service for the project," a release from Lewis' ministry stated. *Global Geothermal News.....*

## CENTRAL & SOUTH AMERICA

### Latin America Geothermal Development Facility Grants Awards to Seven Projects

The **Geothermal Development Facility for Latin America's (GDF)** second call has concluded with an announcement of grant awards.

The GDF has announced seven grantees from Central and South America. As a result of this initiative, surface studies in amounts of up to **EUR 600K** will be funded in **Chile, Peru, Nicaragua**, and **Guatemala**, while exploratory drilling campaigns up to **EUR 5.8M** will be funded in **Chile** and **Guatemala**.

The **EUR 13M** in total grant awards approved during this second call comprises approximately 23 percent of the GDF's original EUR 55M fund, which is expected to catalyze **EUR 1.6B** in future geothermal investments in Latin America. The total anticipated amount of energy generation supported through the first and second calls is expected to reach **520 MW.**

**A new, third call for applications is scheduled for December 2018.** *Global Geothermal News.....*

### Ormat Receives OPIC Loan for Honduras Geothermal Power Plant

**Ormat Technologies Inc.** has announced that its wholly owned subsidiary has completed the financial closing of Tranche I under the previously announced *Finance Agreement* totaling up to **USD 124.7 million** for the **35 MW Platanares geothermal power plant** in **Honduras**, with the **Overseas Private Investment Corporation (OPIC)**, United States government's development finance institution, as the sole lender.

Following the closing, Ormat received a disbursement of **USD 114.7 million** representing the full amount of Tranche I of the OPIC non-recourse project finance loan that will carry a fixed interest rate of **7.02% per annum** with a maturity of approximately **14 years**. The closing of the second tranche of up to **USD 10 million** is expected during the first half of 2019. *Global Geothermal News.....*

### Enel Chile Monitors and Manages its Renewable Plants from One Control Room

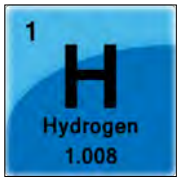
**Enel Chile** has inaugurated a renewable energy control room in the company's headquarters in **Santiago, Chile**, where it will monitor and manage all four renewable energy sources it manages in the country: hydropower, solar, wind and **48 MW of geothermal.** *Global Geothermal News.....*

### IDB Loan Could Boost Geothermal Energy Development in Bolivia

The I**nter-American Development Bank (IDB)** has granted a **USD 51.6m loan** to Bolivia to promote geothermal, solar and wind power in the nation, which currently produces 80% of its electricity demand from fossil fuels. *Global Geothermal News.....*

## AUSTRALASIA

### New Zealand and Japan to Cooperate on Hydrogen Production - Possibly Using Geothermal Power




New Zealand and Japan have signed of a *Memorandum of Cooperation* on manufacturing **hydrogen (H2)**, says New Zealand Energy and Resources Minister **Megan Woods.**

A project to pilot the commercial production of hydrogen using renewable geothermal energy had previously been announced by Taupō-based **Tuaropaki Trust** and Japanese construction company **Obayashi Corporation** using energy from the **113 MW Tuaropaki geothermal power station** in New Zealand. *Global Geothermal News.....*

### Te Ahi O Maui Geothermal Power Plant Enters Commissioning Phase

Commissioning has begun at the **25 MW Te Ahi O Maui geothermal power plant** in **Kawerau** in the **Bay of Plenty region** of the North Island of **New Zealand.**

**Initial heating up** of the plant began at the end of September, with the first synchronization of the plant to the national grid expected to follow. A reliability run followed an extensive testing regime, which was conducted with the help of **Ormat Technologies Inc.**

The Te Ahi O Maui facility consists of **three geothermal production wells, two geothermal injection wells,** an **Ormat binary power station** and a transmission connection to the national grid.

Consents allow for the **extraction of 15,000 tonnes of geothermal fluid** daily from the Kawerau geothermal reservoir **for the next 35 years.** Nearly 100% of this fluid will be injected back into the reservoir, **ensuring the operation is sustainable.**

Initially considered a 22 MW plant, the **Te Ahi O Maui plant is now expected to achieve around 25 MW** – enough to power over 25,000 average homes. The increase in output has improved the plant construction cost, including drilling, to **$5.45m/MW.** *Global Geothermal News.....*

### Testing Begins at 28 MW Ngāwhā Geothermal Power Plant Extension Project

Far North power company **Top Energy** has begun testing at the **28 MW Ngāwhā Geothermal Power Plant Extension Project.**

The plant could eventually make the Far North of New Zealand self-sufficient in electricity and even an energy exporter.

The company already operates a 25 MW geothermal power plant at Ngāwhā. The new plant will more than double the capacity **to 53 MW**. *Global Geothermal News.....*

## ASIA

### Short-Term Flow Tests Carried Out at Akita Geothermal Energy Project

**INPEX Corporation** has announced short-term flow tests to gauge the capacity of exploratory wells it has drilled at the **Akita geothermal energy project** in the **Oyasu** region of **Akita Prefecture, Japan.**

The short-term flow tests will be conducted on two exploratory wells drilled during the current fiscal year. The tests will evaluate production capacity based on a constant flow over a 1~2 week period using wells similar in size to actual production wells. *Global Geothermal News.....*

### New Toyota Fund Will Target Geothermal and Other Renewable Energies

**Toyota Motor** will be a key investor in a **Sparx Group** renewable-energy fund, aiming to **reduce carbon emissions** from its auto factories and dealerships.

The **Mirai Renewable Energy Fund** will aim to raise **30 billion yen (USD 267 million)** in capital, with Toyota supplying 10 billion yen. Sparx will manage the fund starting November and solicit other investors.

The fund will target a variety of facilities, such as solar, wind, biomass and **geothermal power plants.** Rather than investing in existing facilities, it will target new ones to be involved in from the initial stages. Power generated may be sent to Toyota factories or dealerships. *Global Geothermal News.....*

## Inside Geothermal

### Chinese and Japanese Companies to Cooperate on Developing Geothermal Power Systems

P**ower Construction Corporation of China, Ltd.** and **Toshiba Corporation** have signed a *Strategic Cooperation Agreement* covering areas such as hydro, **geothermal** and thermal power systems, to cooperate in investments and arrangement of finances for projects to further expand businesses opportunities. *Global Geothermal News.....*

### Asian Development Bank Loan to Help Develop Geothermal District Heating Resources in China

Iceland's **Arctic Green Energy Corporation** and China's **Sinopec (SNPMF)** have secured a **USD 250 million** loan from the **Asian Development Bank** to help develop geothermal resources in China.

The loan, which has been granted to a joint venture between the two companies, will be used to **expand geothermal district heating** in cities near **Beijing** and reduce the area's reliance on coal.

The plan envisions that geothermal energy will **replace 70 million tons of coal** by 2020. *Global Geothermal News.....*

### Coca-Cola Production in Philippines to be Powered by Geothermal

**Coca-Cola Femsa Philippines Inc.**, the current licensed bottler of Coca-Cola products in the country, has signed an agreement with **First Gen Corp.'s** retail electricity arms—**First Gen Energy Solutions Inc.** and **Bac-Man Geothermal Inc.**—for the supply of electricity from renewable energy sources to power Coca-Cola's bottling facilities in **Ilocos, Pangasinan, Pampanga** and **Cebu.**

Coca-Cola Femsa said in a statement that it strived to make clean energy a more prominent part of its global manufacturing processes, in keeping with its long-standing commitment to reduce its carbon footprint and to achieve sustainable operations through the use of renewable energy sources and the adoption of new technologies to further enhance operational efficiency. *Global Geothermal News.....*

### Drilling at 100 MW Kalinga Geothermal Project to Start in 2019

Drilling at the **Kalinga geothermal power project** is targeted to start next year. A consortium of **Aragorn Power and Energy Corporation, Guidance Management Corporation** and **Allfirst Kalinga Ltd.,** have been given a two-year extension for its exploration permit for the projected **100 MW** capacity project in the province of **Kalinga**, in **North Luzon, Philippines.** It has contracts in place with **First Balfour** as general contractor and **Drill Corp.** for drilling. It has also completed community development projects in four of eight ancestral domains. *Global Geothermal News.....*

### Philippines Government Expands Search for Geothermal Resources

The Philippines **Department of Energy (DoE)** has held preliminary meetings on the geothermal viability of the area around **Mt. Malindang** in the province of **Misamis Occidental.** *Global Geothermal News.....*

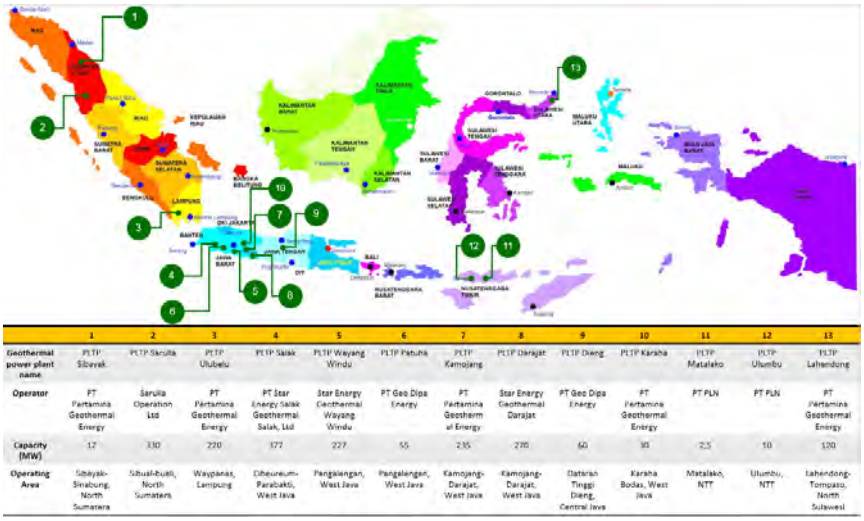
In addition, DoE is undertaking a study on the potential of the **Mati-Lupon-Tarragona geothermal field** in **Davao Oriental**. *Global Geothermal News.....*

### ABB to Upgrade 6 Units at Palinpinon 1 & 2 Geothermal Power Plants

**ABB**, headquartered in **Zurich, Switzerland**, has won a multi-million-dollar order from **Energy Development Corporation (EDC)** and its subsidiary **Green Core Geothermal, Inc.** for a major retrofit to upgrade six geothermal units at **Palinpinon 1** and **Palinpinon 2 geothermal power plants in Valencia, Negros,** the **Philippines.** ABB will also deliver a new **Control System Integration (CSI)** solution for these plants and an area control center facility.

The aim of the project is to deliver a modern control system integrated across all plants that can be easily upgraded over time to take advantage of the latest digital technology as it develops.

The new solution will increase operational and maintenance efficiency and assist management decision-making by providing improved access to better operational information. It will also facilitate central control and remote monitoring of the power plants and steam fields from one location. *Global Geothermal News.....*



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Geothermal power plant name | PLTP Sibayak | PLTP Sarulla | PLTP Ulubelu | PLTP Salak | PLTP Wayang Windu | PLTP Patuha | PLTP Kamojang | PLTP Darajat | PLTP Dieng | PLTP Karaha | PLTP Mataloko | PLTP Ulumbu | PLTP Lahendong |
| Operator | PT Pertamina Geothermal Energy | Sarulla Operation Ltd | PT Pertamina Geothermal Energy | PT Star Energy Salak Geothermal Salak, Ltd | Star Energy Geothermal Wayang Windu | PT Geo Dipa Energy | PT Pertamina Geotherm al Energy | Star Energy Geothermal Darajat | PT Geo Dipa Energy | PT Pertamina Geothermal Energy | PT PLN | PT PLN | PT Pertamina Geothermal Energy |
| Capacity (MW) | 12 | 330 | 220 | 377 | 227 | 55 | 235 | 270 | 60 | 30 | 2.5 | 10 | 120 |
| Operating Area | Sibayak-Sinabung, North Sumatera | Sibual-buali, North Sumatera | Waypanas, Lampung | Cibeureum-Parabakti, West Java | Pangalengan, West Java | Pangalengan, West Java | Kamojang-Darajat, West Java | Kamojang-Darajat, West Java | Dataran Tinggi Dieng, Central Java | Karaha Bodas, West Java | Mataloko, NTT | Ulumbu, NTT | Lahendong-Tompaso, North Sulawesi |

## EDC Receives Renewable Energy Service Contract for Geothermal Exploration in Sumatra

Philippines company **Energy Development Corporation (EDC)** has been wanting to increase its geothermal presence in neighboring Indonesia. Now, EDC President and Chief Operating Officer **Richard B. Tantoco** has disclosed that the company has secured *Preliminary Survey Assignments Plus Exploration* (PSPE) for geothermal prospects it has been eyeing in **Sumatra.**

Tantoco noted that the company is still "doing road constructability surveys, so probably if all goes well, **we will have drilling in 18-24 months**." *Global Geothermal News.....*

## Green Climate Fund Awards USD 100 million for Geothermal Resource Risk Mitigation Project in Indonesia

The Board of the **Green Climate Fund (GCF)** has approved over one billion dollars of new projects and programs to support climate action in developing countries, and formally launched the Fund's first replenishment.

GREEN CLIMATE FUND

Funding for the 19 new projects include **USD 100 million** for the **Indonesia Geothermal Resource Risk Mitigation Project in** cooperation with the **World Bank.** *Global Geothermal News.....*

## Installed Geothermal Power Generation in Indonesia is 1,948 MW

As of October 2018, installed geothermal power generation in Indonesia is **1,948 MW** from **13 geothermal power plants** in **11 geothermal working areas.** (Thanks to **Rifka Aisyah** for the information) *Global Geothermal News.....*

## Dutch University to Help Survey for Geothermal Energy Resources on Flores Island

The Faculty of Geo-Information Science and Earth Observation (ITC) of the **University of Twente** in the **Netherlands** has joined up with the Faculty of Engineering of the **Universitas Gadjah Mada (UGM)** in Yogyakarta, Indonesia and the commercial Indonesian LiDAR services provider **PT ASI Pudjiastuti Geosurvey (PT. APG)** to fly an airborne survey over areas with geothermal potential near **Bajawa, Flores Island** in **East Nusa Tenggara Province** of **Indonesia.**

The main goal of the survey is to acquire for the first time in Indonesia a combined airborne dataset of high precision LiDAR terrain data with surface temperature data to map surface expressions of the underlying geothermal potential. *Global Geothermal News.....*

## Inside Geothermal

### Partnership Formed to Develop 10 MW Dieng Geothermal Power Plant

State-owned geothermal company **PT Geo Dipa Energi (Geo Dipa)** is to collaborate with the state-owned financing company, **PT Sarana Multi Infrastruktur (SMI)**, to develop the **10 MW Dieng geothermal power plant** in **Central Java**, Indonesia. *Global Geothermal News.....*

### Progress at 30 MW Armenian Geothermal Power Plant Project

**Sumec GeoPower AG**, the Swiss-based division of Chinese company **SUMEC Group Corporation,** has announced plans to build the **30 to 50 MW Karkar geothermal power plant** in **Armenia** in western Asia.

Armenia's partner in developing geothermal energy is the **International Bank for Reconstruction and Development (IBRD),** a division of the **World Bank**, which in 2016 signed an agreement to fund the geothermal exploration drilling program. A feasibility study has been ongoing since 2017. *Global Geothermal News.....*

*"Environmentally Friendly" by* **Raditya Mahendra Yasa,** *Semarang, Central Java, Indonesia - Environmentally friendly-farmers working on potato farms around the geothermal installation on the Dieng Plateau, Central Java, Indonesia. GRC Photo Contest 2013.*

## AFRICA

### East Africa Geothermal Risk Mitigation Facility Awards Seven Projects

Seven projects qualified for a grant award in the 5th **Geothermal Risk Mitigation Facility (GRMF)** Application Round (AR 5).

Four surface studies from **Uganda** and **Tanzania** and three drilling programs from **Ethiopia** and **Tanzania** will get funds. (see table below). *Global Geothermal News.....*

| No. | Applicant | Country of Bidder | Project Name | Activity |
|---|---|---|---|---|
| 1 | GIDS Consult Ltd. | Uganda | **Buranga** | Surface Study |
| 2 | Department of Geological Survey and Mines | Uganda | **Kibiro** | Surface Study |
| 3 | Tanzania Geothermal Development Company Ltd. (TGDC) | Tanzania | **Natron** | Surface Study |
| 4 | Department of Geological Survey and Mines | Uganda | **Panyimur** | Surface Study |
| 5 | Orpower 12, Inc. | Ethiopia | **Dofan** | Drilling Programme |
| 6 | Tanzania Geothermal Development Company Ltd. (TGDC) | Tanzania | **Kiejo-Mbaka** | Drilling Programme |
| 7 | TM Geothermal Operations PLC (TMGO) | Ethiopia | **Tulu-Moye** | Drilling Programme |

### Contract Signed to Develop 50 MW Tulu Moye Geothermal Power Plant

**M-V,** a company jointly owned by Icelandic companies **Mannvit** and **Verkís,** has signed a consulting agreement with **Tulu Moye Geothermal (TMGO)** for **Owner's Engineer Services** concerning the development of the **Tulu Moye** geothermal power plant in **Ethiopia.**

M-V will assist TMGO in the development stages, including the building of access roads, well pads, drilling and testing of wells and the development of the steam field. M-V is collaborating with **Landsvirkjun Power, ÍSOR** and **MGM Consult** on this project.

In a first phase of four, TMGO aims at developing a **50 MW power plant** with up to **12 production and reinjection wells,** with a **final target of 520 MW** by the end of the project. *Global Geothermal News.....*

## Cyrq Energy Plans 330 MW Geothermal Power Plant in Kenya

US-based renewable energy tech firm **Cyrq Energy has announced** it will spend Sh30 billion in building a **330 MW geothermal power plant** in the **Suswa** area, **Narok County**, between Nairobi and Olkaria, in **Kenya**.

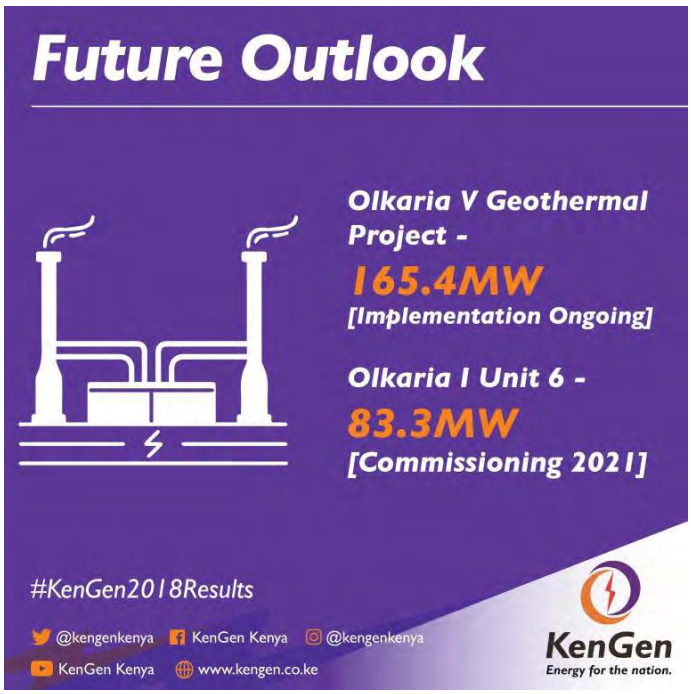
Chief executive **Nicholas Goodman** said applications for approval had been sent out to regulatory agencies in Kenya after feasibility studies conducted at the site confirmed availability of adequate thermal energy to power the project.

Mr. Goodman said upon award of permits, the project will be implemented within two years with the **first phase expected to generate 75 MW**. The other phases will raise the **total output to 330 MW.** *Global Geothermal News.....*

## First 82 MW Unit of Olkaria V Geothermal Project Scheduled for Commissioning in April 2019

State-owned **Kenya Electricity Generating Company (KenGen)** has released year-end financial results and reported on future developments.

**Joseph Njoroge**, principal secretary at the Ministry of Energy, gave an update on the **164.5 MW Olkaria V geothermal project.**




"The **first unit of 82 MW** is scheduled for **commissioning in April 2019**, while the second one is set for commissioning in July 2019. Also in the pipeline is **Olkaria 1 Unit 6 (83 MW) geothermal project**, which has commenced," Njoroge said.

**Rebecca Miano**, CEO of KenGen, said that **revenue** generated from KenGen's geothermal power plants **increased** from 161 million dollars in 2017 **to 171 million dollars** in 2018, **a growth of 6 percent.** *Global Geothermal News.....*

## KenGen to Apply "Internet of Things" Technologies to the Olkaria Geothermal Power Project

**KenGen** has signed a joint declaration with the **United Nations Industrial Development Organization (UNIDO)** and the **Japan International Cooperation Agency (JICA)** to improve security and efficiency in geothermal power generation with **Internet of Things (IoT)** technologies.

The technology will bring together all the O&M stakeholders for the **Olkaria geothermal power project,** creating a platform for dialogue between the industry, manufacturers, policy makers and investors. The aim is to jointly build capacity and promote sharing of expertise with a view to improving efficiency. *Global Geothermal News.....*

## Exploration Drilling at Baringo-Silali Geothermal Project Commences

As of the time of writing, exploration drilling was to have started at the **Baringo-Silali geothermal project** in central Kenya.

**Geothermal Development Company (GDC)** MD & CEO Eng. **Johnson P. Ole Nchoe** said "We are on course in the development of the Baringo-Silali Project. The completion of the water points will allow GDC to commence exploration drilling in November". *Global Geothermal News.....*

## Akiira Geothermal Ltd Confident of Commercial Operation of 70 MW First Phase in 2022

**Akiira Geothermal Ltd (AGL)** has announced the company is carrying out further drilling at the **70 MW Akiira One geothermal power project** in the Kenyan Rift Valley before the end of this year and **will complete exploratory drilling by the end of 2019.**

AGL is in advanced stages of organizing the project financing from various lenders and the award process for both the *Engineering, Procurement and Construction*(EPC) and *Operations*

*and Management* (O&M) contracts is expected to be finalized with financial close of the project.

The company anticipates that it will commence production drilling and power plant construction for the **first 70 MW phase in early 2020** and achieve **commercial operation in early 2022.**

The **second 70 MW phase is planned for 2020** with exploratory studies and drilling with **commercial operation planned for 2024.** *Global Geothermal News.....*

### 5 MW Geothermal Power Project in Tanzania to Start Next Year

**Tanzania Geothermal Development Company Limited (TGDC)** has announced plans to start exploration drilling in the **Mbeya Region** next year. The company hopes to **generate 200 MW by 2025.**

TGDC General Manager **Kato Kabaka** said the company plans to generate **5 MW by 2020** and **20 MW by 2022.** *Global Geothermal News.....*

## EUROPE

### European Consortium Receives Funding for "Geothermal Emission COntrol" project

**Reykjavík Energy** and a group of 17 partners across Europe have received a **EUR 16 Million grant** from the **Horizon 2020 Research and Innovation program** for the **Geothermal Emission COntrol (GECO) project.**

The project will advance the provision of cleaner and cost-effective geothermal energy in Europe and around the World with reduced emissions of carbon and sulphur. The core of this project is the application of an innovative technology, recently developed and successfully demonstrated at a **pilot-scale plant in Iceland,** which can **limit the emissions from geothermal plants** by condensing and re-injecting gases in the subsurface or turning them into commercial products.

GECO aims to increase public acceptance and generalize this novel approach. To that end, the reinjection method will be applied in four distinct geothermal systems in four European countries:

1. a high temperature basaltic reservoir in **Iceland**;
2. a high temperature gneiss reservoir in Italy;
3. a high temperature volcano-clastic reservoir in **Turkey**; and
4. a low temperature sedimentary reservoir in **Germany**.

*Global Geothermal News.....*

### Drilling Starts at Cornish Geothermal Power Plant

**Geothermal Engineering Ltd. (GEL)** has announced that drilling has started to build the UK's first deep geothermal electricity plant at the **United Downs** Industrial Estate near St Day in **Cornwall, United Kingdom.**

The aim of the initiative is to demonstrate the potential of the geothermal resource in the UK to produce electricity and renewable heat. The plant will **supply up to 3 MWe** of electricity which is enough energy to power 3000 homes.

The global engineering consultancy, **Arup**, has signed an agreement to purchase **renewable energy guarantee of origin certificates** (REGOs) from GEL equating to 9,000 MWh/year. *(Continued on page 28)*

*The United Downs geothermal power project site. (Courtesy Geothermal Engineering Ltd.)*

# Icelandic Geothermal Workshops

by Wilfred Elders, Research Professor, University of California, Riverside

From 12-15th November, four days of intensive presentations and discussions on geothermal resources took place in Reykjavik, Iceland. Although Iceland has a population of only about 350,000, this volcanic island situated on the Mid-Atlantic Ridge, just south of the Arctic Circle, is among the world leaders in geothermal developments. It has an installed geothermal generating capacity of 752 MWe, and 96 percent of its buildings benefit from geothermal space heating. Furthermore, at this meeting a new estimate by ISOR, the Iceland Geosurvey, of its available geothermal reserves indicated that its potential geothermal generating capacity is almost 36 GWe.

The 752 MWe of geothermal generation represents 26 percent of the total of Iceland's installed generating capacity, the rest being hydropower. The low cost of this "green" electricity has attracted energy intensive industries such as aluminum smelting and the manufacture of ferrosilicon. Iceland's geothermal industry is also a leader in sequestering the $CO_2$ separated from geothermal steam by injecting it into disposal wells.

Iceland's geothermal industry has espoused an aggressive program of research and development, epitomized by the Iceland Deep Drilling Project (IDDP). The IDDP aims to investigate, and eventually use, supercritical and superhot geothermal resources. Because of the higher enthalpy and enhanced flow characteristics of supercritical water, a well producing from a supercritical reservoir should have an order of magnitude higher power output relative to that produced by typical hot geothermal wells today. The well IDDP-1, drilled at Krafla in NE Iceland, in 2009, failed to reach its supercritical target when it penetrated a rhyolite magma at only 2.1 km depth.

The Power of Thor, by Robert Zierenberg, Davis, California, USA. The lighthouse on the Reykjanes Peninsula, Iceland, showing the way to safe passage at sea, and the drill rig Thor at the IDDP-2 supercritical drill hole, showing the way to the future of geothermal power. Taken *September 2017*

However, when the well was completed to produce from the highly permeable formation just above the intrusion, it flowed for 10 months with a wellhead temperature of ~450°C and a pressure of 140 bars, equivalent to a power output of ~36 MWe. Unfortunately, the IDDP-1 had to be quenched due to failure in the well-head valves. In 2017 the IDDP-2 well, drilled at the Reykjanes geothermal field, in SW Iceland, became the first well in the world to successfully reach supercritical conditions, with a bottom hole temperature of ~600°C at a depth of 4.5 km.

KMT
KRAFLA MAGMA TESTBED

The first two of the four workshop days in Reykjavik were devoted to the Krafla Magma Testbed workshop. KMT (KMT), an international collaboration of volcanologists, headed by Freysteinn Sigmundsson and John Eichelberger, now proposes to drill a well at Krafla dedicated to study the rhyolite magma discovered by the IDDP-1. Their concept is to make this a long-term magma testbed for monitoring volcanic hazards, and as a portal into investigation of magma dynamics, and magma-hydrothermal coupling.

As this multiyear project would require a budget of about 100 Million USD, much of the discussions on the first day of the KMT workshop concerned funding and organization, whereas the second day mainly focused on technical issues of casing and cementing superhot wells which were the main challenges encountered in drilling the IDDP-1, IDDP-2, and well Venelle 2 in Lardarello, Italy, which are projects within the DEEPEGS program supported by the European Union H2020 initiative. One improvement proposed would be to use flexible couplings enabling casing to withstand

thermal expansion and contraction during heating and cooling of the well and thereby reduce the risk of structural damages. This new technology is presently under development within H2020 supported projects.

GEORG, the Icelandic geothermal consortium, held its workshop on the third and fourth days of the meeting and so the topics discussed were more widely ranging. However, updates on the status of the IDDP-2/DEEPEGS well were featured in one special session. Long-term injection tests to improve the permeability of the deep supercritical zone have been concluded successfully and the well is now heating preparatory to flow tests scheduled to begin in April 2019.

A plenary session during the GEORG workshop discussed the role that geothermal resources must play in future in response to the two existential global threats of population growth and climate change. Many different aspects of the geothermal industry will be involved in mitigating these challenges, ranging from providing environmentally benign alternative energy, to reducing greenhouse gas emissions, improving food security, producing metals such as lithium and manganese needed for storage batteries, and producing hydrogen by electrolysis, both for a transportation fuel and as a means of balancing fluctuations in the supply/demand ratio of the electric grid.

GEORG plans to put all the presentations from the 4-day meeting online at: http://www.georg.cluster.is

## Inside Geothermal

*(Continued from page 26)*

**"It's a make or break moment for geothermal power in the UK," Ryan Law**, managing director of GEL, told the *Financial Times* of the project. "If this one doesn't produce I don't think we'll see any others for some time."

"It is a demonstration plant of a concept. And if that concept works we know we've got similar geology in many, many other sites across Devon and Cornwall," said Mr Law. If it works he wants to create more joint direct heat and power generating plants in the region. *Global Geothermal News.....*

### Crowd-funding for Geothermal-Heated Jubilee Pool Raises More than Enough

A Crowdfunder campaign to raise funds to help create a geothermal-heated spa at the **Jubilee Pool** in **Penzance, Cornwall**, has reached its minimum target of GBP 350k, allowing the project to go ahead. **Drilling has now begun.** *Global Geothermal News.....*

### Largest Danish Bet On Geothermal District Heating To Date

**Aarhus Municipality** and **A.P. Moller Holding** have joined forces to clear the way for what would be the largest Danish geothermal district heating project to date.

Geothermal studies have shown that the subsurface below **Aarhus**, located on the Jutland peninsula's east coast, is well-suited for using geothermal energy for district heating. *Global Geothermal News.....*

In other Danish news, **WellPerform** of **Holte**, Denmark has completed the Thisted-5 injection well and connected it to the **Thisted geothermal district heating plant** in the **North Denmark** Region. *Global Geothermal News.....*

### Exploration for Dutch Ultra-Deep Geothermal Energy Project Begins

In June 2017, seven consortia, together with the government, **EBN** and **TNO**, signed the so-called **Green Deal Ultra-Deep Geothermal Energy (UDG)**, to increase knowledge about ultra-deep geothermal energy (heat extraction at a depth of more than 4 km) in the Netherlands.

The consortium members **UDG Leeuwarden, GOLD** (Utrecht), **UDG Renkum, Geothermal Heat Oost Brabant, UDG Schiedam** and **UDG Port of Rotterdam** are now taking the next step with an **Exploration Working Programme** and the exploration for ultra-deep geothermal heat in the Netherlands.

The program involves, among other things, detailed geological research, research into drilling techniques, risk inventory & management and careful environmental management.

Preparations for possible drilling will only start in the next phase if it is safe and responsible, and economically viable. It is expected that this decision can be taken **by the end of 2019** at the earliest. *Global Geothermal News.....*

## Oil Company Applies for a Permit to Drill for Geothermal Resources in Rotterdam

**Shell** has submitted a permit application to **the Ministry of Economic Affairs and Climate (EZK)** for the development of geothermal energy in the **Rotterdam** region. With its knowledge and expertise, and in cooperation with customers, companies and the (local) government, Shell thinks that it can make a positive contribution to the role of geothermal energy in the Dutch energy transition.

If the license is granted, Shell will map the geothermal potential which could lead to **test drilling by the end of 2020,** and further drilling in the following years. *Global Geothermal News.....*

## Progress at German Geothermal Projects

**Geysir Europe GmbH,** a subsidiary of **Daldrup & Söhne AG**, has been granted the concession for exploration for the **Neuried geothermal district heating project** in the district of **Ortenau** in **Baden-Württemberg, Germany**. Daldrup already owns the premises for the operations so drilling operations will be able to begin. *Global Geothermal News.....*

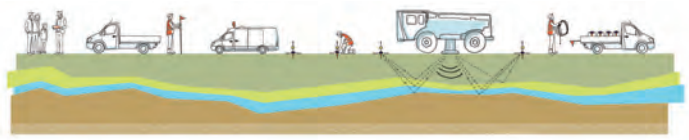
Also, **Silenos Energy** has completed the first geothermal deep well in **Garching ad Alz** in **Bavaria**. At **a depth of 3,832 meters**, the company encountered hot thermal water in the Malm formation of the Bavarian south-east Molasse. After a two-week test phase, Silenos Energy was able to present the first results of this drilling.

"The funding test showed that we were right with our forecasts. We encountered about **125°C** hot thermal water. As far as the output from the drilling is concerned, we were able to reach our target at **105 liters per second**, "said **Oliver Friedlaender**, Managing Director of Silenos Energy. *Global Geothermal News.....*

## Austrian Geothermal District Heating Projects Advance

The **GeoTief Vienna geothermal district heating project** is surveying the geology in the eastern area of **Vienna**, **Austria** for shallow geothermal resources. After initial investigation during the past year, detailed 3D seismic measurements now follow. *Global Geothermal News.....*

In addition, drilling for a third well at the **Ried geothermal district heating project**, located north of **Salzburg**, **Austria** has begun. *Global Geothermal News.....*



*Courtesy GeoTief Vienna.*

## More Funding for Polish Geothermal District Heating Projects

The Polish **National Fund for Environmental Protection and Water Management** has announced more funding for geothermal heating projects in 7 municipalities. The funding will cover initial research drilling to determine the potential geothermal resources. *Global Geothermal News.....*

## Tender to Drill New Wells at Azores Geothermal Power Plants to Open in January

**EDA Renováveis, S.A.** is to announce a drilling tender in January 2019 to award the provision of drilling services for geothermal wells in **Ribeira Grande Geothermal Field** (São Miguel Island) and **Pico Alto Geothermal Field** (Terceira Island), **Azores, Portugal.**

EDA Renováveis, S.A. is an affiliated company of the regional electric utility **EDA – Electricidade dos Açores, S.A.** and operates three geothermal power plants: **Ribeira Grande** and **Pico Vermelho** plants on São Miguel Island, with a combined net capacity of **23 MW** and representing 43% of the electricity consumed on the Island and **Pico Alto** power plant, located on **Terceira** Island, with a net

*Ribeira Grande geothermal power plant on São Miguel Island in the Azores. Courtesy EDA Renováveis, S.A.*

capacity of **3.5 MW** representing about 12% of the electric consumption of the Island.

The campaign is designed to **drill up to 8 geothermal wells:** 3 production wells to saturate the power capacity installed at Ribeira Grande power plant (13 MW), 2 geothermal production wells to expand the power capacity of Pico Vermelho power plant to 15 MW and 3 geothermal production wells to saturate the actual power capacity installed in Pico Alto power plant and accommodate a possible expansion. *Global Geothermal News.....*

## SCIENCE & TECHNOLOGY

### Bacteria that Lives in Geothermal Zones Could Have Antibiotic Properties

*Colorful thermophiles - heat loving bacteria - at the Grand Prismatic Springs in Yellowstone National Park, Wyoming, USA. Taken by* **Ian Crawford**, *GRC Fieldtrip 2015.*

**Antimicrobial resistance** is one of the biggest threats to global health and the race is on to find new molecules with **antibiotic properties.** One way scientists try to find these molecules is to study proteins produced by microorganisms themselves, as the bacteria often uses these to fight off other competing bugs.

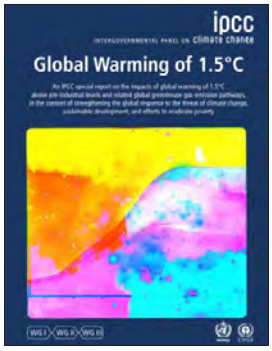
Scientists analyze the microorganism's genetic make-up – its genome – looking for sequences of code that correspond to types of proteins known to have antibiotic properties. One group of such proteins are called **lanthipeptides** that have a particular structure known to be effective at fighting off bacteria.

Researchers in New Zealand recently applied this process, known as **'genome mining'**, to a strain of **Thermogemmatispora** – a type of bacteria that lives in extreme conditions in the heated soil of New Zealand's **Taupo geothermal zone.** They discovered a new type of **lanthipeptide,** called **tikitericin**, which they believe is part of the microorganism's host defense system. *Global Geothermal News.....*

*Genome mining, isolation, chemical synthesis and biological evaluation of a novel lanthipeptide, tikitericin, from the extremophilic microorganism Thermogemmatispora strain T81*, by Buzhe Xu et al. *Chemical Science*, 2018, Accepted Manuscript. DOI: 10.1039/C8SC02170H

## CLIMATE CHANGE

### "Limiting global warming to 1.5°C would require 'rapid and far-reaching' transitions in energy" - Report



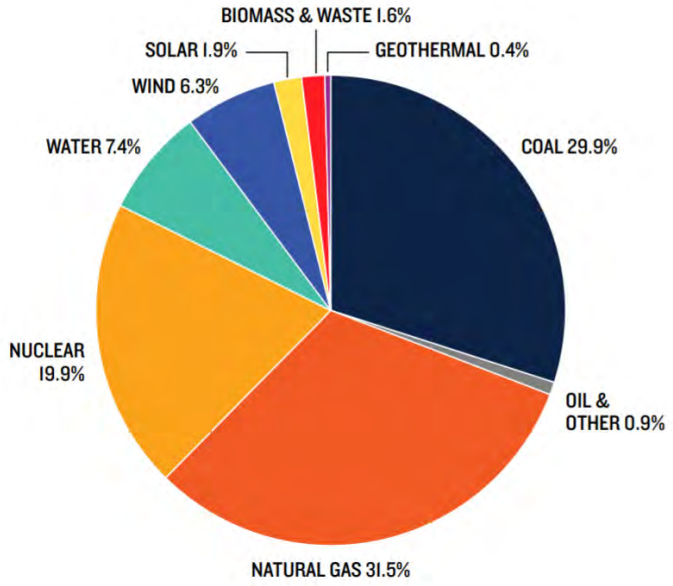

According to a new report that **the world may have as few as 12 years to stave off the worst of climate change.**

Published by the **Intergovernmental Panel on Climate Change (IPCC)**, an intergovernmental body of the United Nations, the report assesses the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

The report warns that limiting global warming to 1.5°C would require rapid, far-reaching and unprecedented changes in all aspects of society including **'rapid and far-reaching' transitions in energy**. With clear benefits to people and natural ecosystems, limiting global warming to 1.5°C compared to 2°C could go hand in hand with ensuring a more sustainable and equitable society. *Global Geothermal News.....*

## USA Must Greatly Accelerate Clean Energy Progress to Help Avert Climate Disaster - Report

The United States is light years ahead of 10-year government projections for renewable energy, energy efficiency, and carbon pollution cuts but **must greatly accelerate clean energy progress** to help avert climate disaster, according to a new report from the **Natural Resources Defense Council (NRDC).**




Less than three weeks after the urgent warning from the Intergovernmental Panel on Climate Change (IPCC) - see above - that the world may have as few as 12 years to stave off the worst of climate change, *America's Climate Crossroads: Pushing Clean Energy Higher & Faster* notes the nation made huge clean energy strides in the past year and a half and far outpaced the U.S. Department of Energy's (DOE) 2007 predictions for 2017 energy use. However, the country is not yet on track to meet the IPCC's climate targets.

The U.S. power industry has seen a remarkable shift as nuclear and coal struggles to compete with energy efficiency, renewable energy resources, cheap fracked gas, and the rising need for a more flexible energy system.

**Renewables now account for 16 percent of U.S. power generation**, a substantial increase even from 2016 levels, when renewable energy provided 14 percent of U.S. power. More than half of that—8.1 percent—came from wind and solar, with **geothermal providing 0.4%.** (See Figure left). *Global Geothermal News.....*

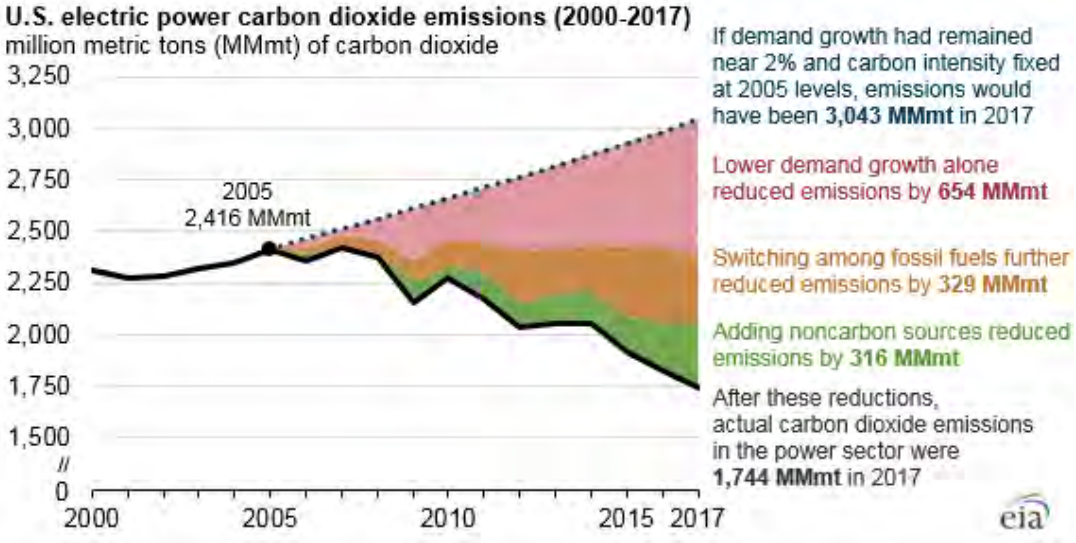
## Renewable Energies Help Reduce Carbon Dioxide Emissions in USA

U.S. electric power sector carbon dioxide emissions ($CO_2$) have declined 28% since 2005 because of slower electricity demand growth and **changes in the mix of fuels used to generate electricity.**

The U.S. **Energy Information Administration (EIA)** has calculated that $CO_2$ emissions from the electric power sector totaled 1,744 million metric tons (MMmt) in 2017, the lowest level since 1987.

In the United States, **most of the changes in energy-related $CO_2$ emissions have been in the power sector.** Since 2005, as power sector $CO_2$ emissions fell by 28%, $CO_2$ emissions from all other energy sectors fell by only 5%. Slower electricity demand growth and changes in the electricity generation mix have played nearly equal roles in reducing U.S. power sector $CO_2$ emissions.

The power sector has become less carbon intensive as natural gas-fired generation displaced coal-fired and petroleum-fired generation and as the noncarbon sources of electricity generation—**especially renewables**—have grown. *Global Geothermal News.....* ■



# Geothermal History in the Making

by Ian Crawford, Director of Communications

*In 2022, the Geothermal Resources Council, the GRC, will be celebrating its 50-year anniversary. Our association was established in 1972 "to encourage development of geothermal resources worldwide." To mark our golden anniversary, we are running a series of articles looking back on the history of geothermal energy around the world over these past decades.*

*In this issue we look back to 2001 and how geothermal aquaculture successfully established alligators as a new cash crop in the USA!*

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## Gators in the Sage

**GRC *Bulletin*, Volume 30, No. 6, November/ December 2001**


*Alligators were raised at the farm for just 10 years. From the original GRC Bulletin article in 2001.*

The high-desert country of the Snake River Plain is a far cry from the lush subtropical swamps of the U.S. Gulf Coast, but with a perfect combination of sparkling geothermal water and abundant food from local fish farms, captive American alligators thrive in the harsh climate of Idaho.

For 50 miles along the Thousand Springs Scenic Byway in the southern part of the state, life-giving geothermal water reaches the surface in scores of seeps along the Snake River. It is here, near Buhl, where Leo Ray started his successful Fish Breeders of Idaho with his first geothermal well over 25 years ago. His pioneering efforts brought geothermal fish farming to Idaho in the early 1970s, and now promise to usher in a unique growth industry in alligator meat and hides.

A tall, lanky outdoorsman, Ray was born and raised on a farm in Oklahoma. He earned a BS degree in zoology at the University of Oklahoma in 1963, and has continued his studies with more than 100 hours of courses in the sciences and fisheries. By the late 1960s, Ray was running a successful aquaculture operation for African tilapia at the Salton Sea in southern California. It was there that he first learned about the advantages of geothermal waters for aquaculture.

Ray's Fish Breeders of Idaho, Inc. is located on 170 acres in the Western Snake River Plain geologic province, slashed by the Snake River Canyon from central Idaho west to the Oregon border. The region is thought to be the trace of a "hot spot" now found at Yellowstone National Park, hundreds of miles to the east.

"This area's got the best geothermal potential, but some of the poorest farm land in the state," says Ray, who laments the fact that most owners of geothermal wells in the area consider the heat a nuisance. Indeed, most geothermal water produced around Ray's operations is used for irrigation and livestock, demanding that it be cooled before it can be used. But with over 800 geothermal springs and wells in the state," he continues, "farmers could switch from low-value irrigated crops to high-value aquaculture crops that thrive in hot water."

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**2018: An update:** The website for Fish Breeders of Idaho Fish Processors, Inc. & Big Bend Trout, Inc. [https://www.fishbreedersofidaho.com/] has a wealth of information on current operations at the farm on the Western Snake River Plain.

Unfortunately, the raising of alligators only lasted until 2002. However, the farm now sells Trout, Catfish, Tilapia and Sturgeon - or more specifically - caviar.

Read the original article "Gators in the Sage" from the November/December 2001 *Bulletin*..... ■


*Instead of alligator meat the aquaculture farm now produces some of the best caviar in the world!* Courtesy Fish Breeders of Idaho.


*Leo and Judith Ray.* Courtesy Fish Breeders of Idaho.

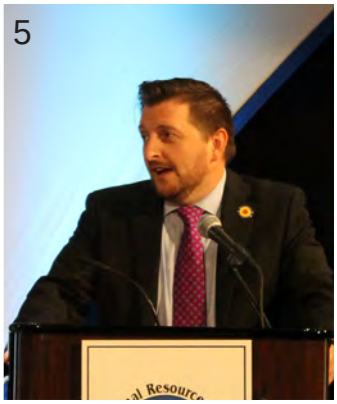
# GRC Annual Meeting & Expo 2018

*We start our overview of the 43rd Annual Meeting of the Geothermal Resources Council (GRC) with a photo essay of the Opening Session, Annual Charity Golf Tournament, Photo Contest (page 38) and the Poster Session. Following this section is an important technical paper by the student poster winner. Elsewhere, (page 54) Sue Hodgson reports on a fieldtrip to Gabbs Valley to see at first hand the application of Play Fairway Analysis to exploration of geothermal resources in central Nevada.*

*In the next issue of the GRC Bulletin we will report on the GRC Awards, more Fieldtrips, the Mixer - Trivia Night!, the International Lunch and Session and the Expo.*

## Opening Session

The opening plenary session always serves up fascinating discussion of the industry's major topics by federal, state, and local government representatives, from key players in the energy market, and from the leading lights of the geothermal industry. The big audience gathered at the Peppermill Resort Spa & Casino on October 15 were not disappointed with this year's offering.






*1. More than 500 attendees packed the Capri Ballroom to hear nearly four hours of geothermal energy news and opinion.*

*2. Reno City Councilwoman Naomi Duerr welcomed everyone to the "Biggest Little City in the World". She announced that Cyrq Energy had plans to build the "biggest little geothermal district heating network" in Reno.*

*3. GRC President Maria Richards reports on a successful year for the association including the conclusion of the merger with the Geothermal Energy Association (GEA).*

*4. Attendees pay rapt attention to speakers.*

*5. GRC Executive Director William Pettitt reported a healthy attendance of over a thousand for the meeting including over a third from overseas. He said that the GRC Annual Meeting & Expo brings together the international community every year which advances collaboration among the various groups, helping the community to speak with one voice.*






*6. Governor of Idaho Clement Leroy "Butch" Otter made a pitch for the GRC Annual Meeting & Expo to come to Boise, Idaho. He said the state has a long history of utilizing geothermal resources. Governor Otter told a story of how growing up his family used geothermal waters to cook pigs for food! He never realized then that the same hot water could be used to light a bulb!*

*7. Dr. Susan Hamm, Director of the Geothermal Technologies Office (GTO) at the U.S. Department of Energy (DOE) Office of Energy Efficiency & Renewable Energy (EERE), gave an update on GTO activities at the GRC Annual Meeting in Reno, Nevada. See the item "Increased Budget for Geothermal Technologies Office" in the Inside Geothermal section of this issue (page 16) for details from her presentation.*

*8. Paul Thomsen, chair of the GRC Policy Committee (seen at the podium) moderated a very interesting panel discussion on New Energy Markets.*

*9. The panelists at the New Energy Markets discussion: (from left to right) Sam Enoka, CEO/Founder, Greensparc Inc., Sam Castor, Executive Vice President, Policy, Switch and Chris Benson, Program Manager, Sustainability & Energy, University of Utah.*

*10. Sam Castor, Executive Vice President, Policy, Switch agreed with his fellow panelists that there was a coming "Tsunami" of demand for electricity. He stated that geothermal energy has an important part to play in meeting this demand. He said that corporations in Nevada that use over 1 MW of electricity, can procure their own supply - but none do from geothermal...yet. He thinks that corporations should cooperate to buy electricity collectively with help from a "wise helper". However, the companies should also volunteer to subsidize electricity supply to private customers.*

*All photos by Ian Crawford.*

More photos from the Opening Session.....

## Annual Charity Golf Tournament

More than 70 players turned up in beautiful conditions at the Sunridge Golf Club near Carson City. There was an autumnal crispness to the air but bright sunshine kept everyone warm. Everyone had a great time playing and networking!





*1.There were a few water hazards at the Sunridge Golf Club and the spectacular scenery distracted some golfers - that was their excuse, anyway!*

*2. Players were treated to a breakfast provided by GEODEEP, the French geothermal cluster for heat and power, before lining up to sign-in.*

*3. More than 70 players try to squeeze in for a group photo!*

*4. Robert Winsloe (left) and Paul Cairns (right) of Eavor Technologies Inc celebrate a 1st place finish! Photo by Paul Cairns.*

*5. Putting practice with a view of the eastern escarpment of the Sierra Nevada.*

*All photos by Ian Crawford except where mentioned.*
More photos from the Annual Charity Golf Tournament.....

## GRC Annual Photo Contest

**1st Place:** *Ray of Steam* - **Piyush Bakane**, Reno, Nevada, USA

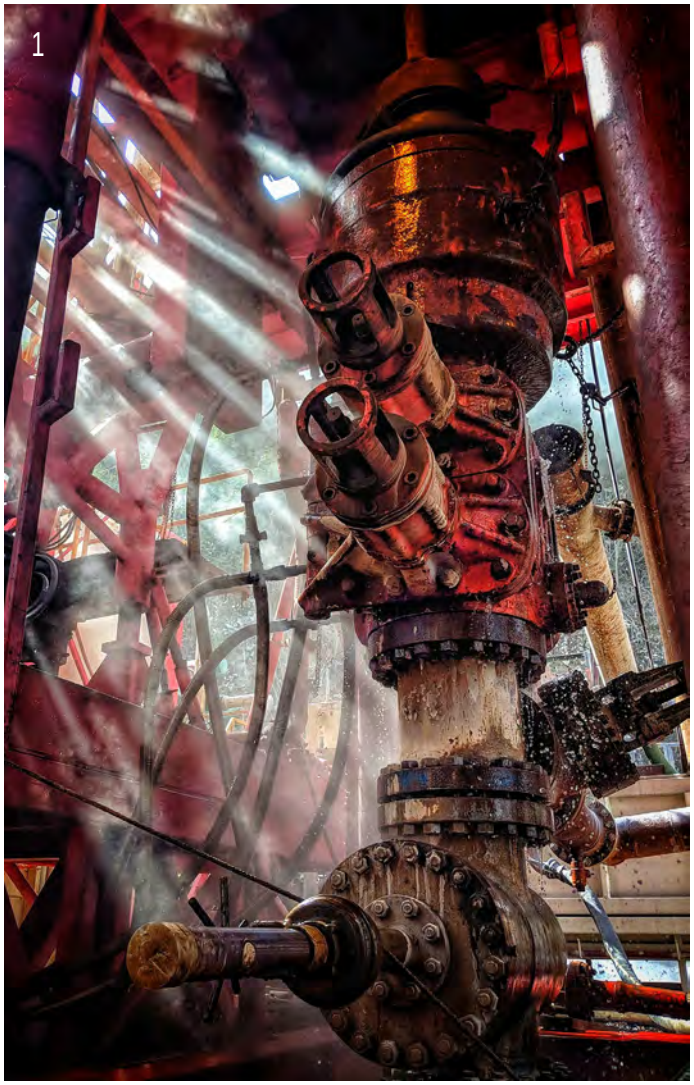
**2nd Place:** *Cooling Tower, Theistareykir Power Station* - **Hreinn Hjartarson,** Reykjavik, Iceland

**3rd Place:** *Zunil Geothermal Plant* - **Steven Fercho**, Reno, Nevada, USA

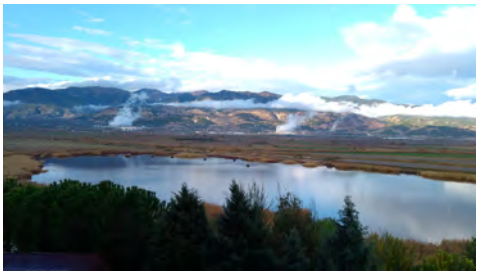
**Honorable Mention:**

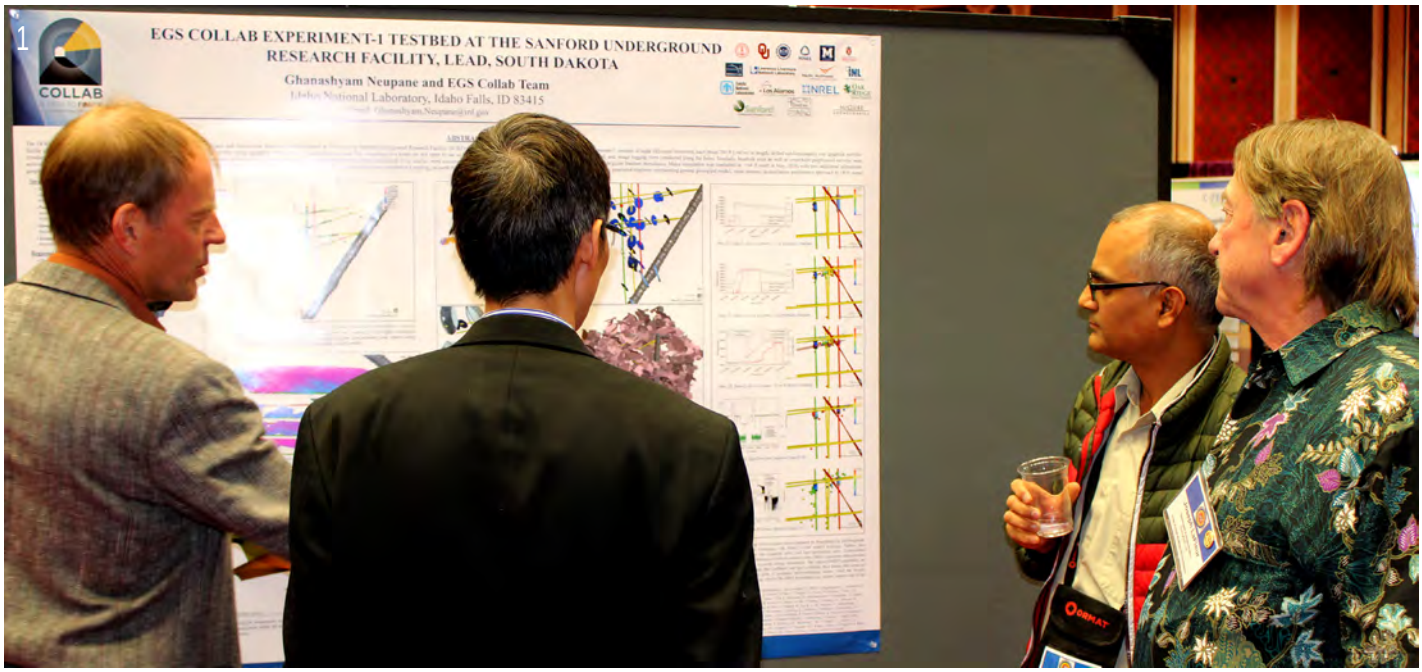
- *Krafla Power Station* - **Hreinn Hjartarson**, Reykjavik Iceland (H1)
- *Light Snow* - **Giulia Bonifazi**, Brescia Italy (H2)
- *Kizildere Clouds* - **Umut Destegul Solaroglu**, Istanbul Turkey (H3)

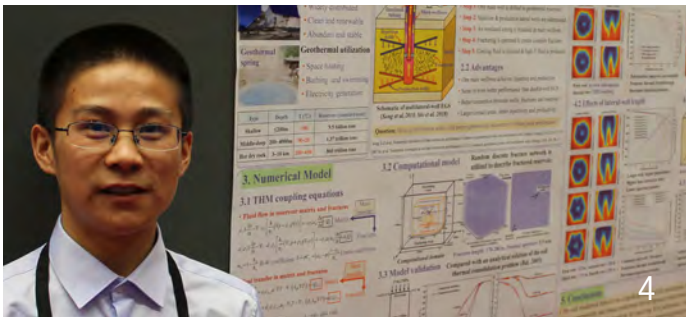
See all 66 entries in the GRC Photo Contest.....








*1. As always the Poster Session Networking reception offered a chance to talk to the authors and discuss important developments in geothermal energy.*

***Best Professional Poster Award***
*Geophysical Investigations of a Blind Geothermal System in Southern Gabbs Valley, Nevada (Tait Earney et al., including William Schermerhorn)*

*2. William Schermerhorn (left) is congratulated by GRC Poster Session chair Roland Horne.*

***Best Student Poster Award***
*Numerical Simulation of Effects of Multilateral Wells on Thermal Characteristics of a Fractured EGS Based on a Thermal-hydraulic-mechanical Coupling Model (Yu Shi et al.)*

*3. (From left to right) GRC Executive Director William Pettitt, Student Poster WInner - Yu Shi, GRC President Maria Richards and Roland Horne, Poster Session chair.*

*4. Yu Shi with his winning poster.*

All photos by Ian Crawford.
More photos from the Poster Session and Networking Reception.....

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The winner of the Student Poster Award, Yu Shi impressed the judges with his poster. They were struck by the innovative design for a lateral well with the proper geometrical parameters to obtain better performance of an EGS well.

To celebrate this achievement, the GRC is pleased to publish the Technical Paper associated with Yu Shi's poster - turn to the next page for the complete article..... ■
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*As part of an ongoing series of articles, we present the Technical Papers associated with the best presentations made at the last GRC Annual Meeting. This paper is from the session on Superhot Geothermal Systems.*

# Numerical Simulation of Effects of Multilateral Wells on Thermal Characteristics of a Fractured EGS Based on a Thermal-hydraulic-mechanical Coupling Model

Yu Shi [1], Xianzhi Song [1], Yiqun Zhang [1], Gensheng Li [1], Christopher Pain [2], Jiacheng Li [1], Feixu YuLong [1]
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Keywords
- Geothermal energy
- Enhanced geothermal system
- Multilateral wells
- Heat extraction performance
- Thermal-hydraulic-mechanical coupling
- Discrete fractures

**ABSTRACT**

A novel enhanced geothermal system (EGS) with multilateral wells is presented to exploit geothermal energy. The EGS includes one main wellbore with an inner insulated tubing, several upper injection lateral wells and lower production lateral wells. The working fluid is injected into the reservoir through the annulus, and produced from the insulated inner tubing. Hence, this EGS can achieve the injection and production through one main wellbore instead of double wells. A thermal-hydraulic-mechanical (THM) coupling model with discrete fractures is established to investigate thermal characteristics of multilateral-well EGS. The model is verified by an analytical solution of a thermal consolidation problem. Based on the model, the effects of rock mechanical behavior on the heat extraction performance are analyzed. The influences of geometrical parameters of multilateral wells, including well length, number, spacing and diameter, on the EGS performance are studied. The results indicate that the effective stress of rock induced by variations of temperature and pore pressure can increase the fracture permeability and promote the thermal breakthrough. Besides, the longer lateral well and larger well spacing are beneficial for enhancing the EGS performance. The well number has a complicated effect on the heat extraction process, which needs to be further optimized. The influence of the lateral-well diameter on the EGS performance can be ignored. The results of this study provide good guidance for the lateral wells design of the multilateral-well EGS.

## 1. Introduction

Geothermal energy is one of the promising and clean renewable resources to replace the fossil fuels. Geothermal energy is abundant and stable, especially the heat stored in the deep hot dry rock (HDR). The enhanced geothermal system (EGS) is designed to exploit the deep hot dry rock for electricity generation.

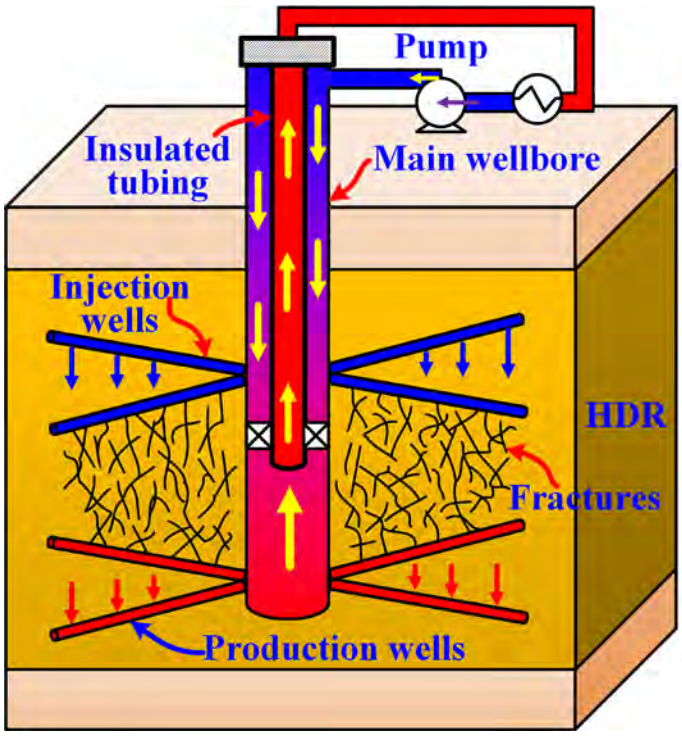


*Figure 1: Schematic of heat extraction for multilateral-well EGS (Song et al. 2018)*

We proposed a novel EGS with multilateral wells in the previous study (Song et al. 2018), which achieves injection and production simultaneously through one main wellbore. The schematic of multilateral-well EGS is shown in **Figure 1**. One main wellbore is drilled to the HDR, from which several upper injection and lower production lateral wells are sidetracked. Finally, an insulated tubing is installed in the main wellbore and the annulus between the tubing and wellbore is sealed by the packer. The low temperature working fluid is injected from the annulus and injection wells into the geothermal reservoir to extract heat. After that, the working fluid is produced from production wells and returns to the surface through the insulated tubing for electricity generation. The previous study (Song et al. 2018) showed that compared with conventional double-well EGS, multilateral-well EGS could extract heat from the most part of the geothermal reservoir and has a better heat extraction performance. The average production temperature, output thermal power and heat extraction ratio of multilateral-well EGS is higher than those of conventional double-well EGS. Besides, in 2008, the field application of multilateral wells technology at Klaipėda geothermal field indicated that 12 multilateral wells with a length of around 40 m obtained an improvement in injectivity of about 14% (Nair et al. 2017). Hence, it demonstrates that the multilateral wells technology has enormous potential to acquire great heat extraction performance in geothermal development.

Although Song et.al (2018) have investigated the thermal characteristics of multilateral-well EGS through a 3D fluid flow and heat transfer model. The effects of multilateral-well geometrical parameters on the heat extraction performance of the EGS were not studied, and the effects of rock mechanical behavior and fracture patterns on the thermal characteristics of the EGS were not taken into consideration in the model. However, many studies indicated that the effects of thermal stress induced by cooling working fluid on the heat extraction process could not be ignored (Ghassemi et al. 2011; Ghassemi et al. 2007; Rawal and Ghassemi 2014). For example, McDermott et al. (2006) and McDermott and Kolditz (2006) studied the heat extraction from a crystalline rock reservoir through a thermal-hydraulic-mechanical (THM) coupling model. They demonstrated that the variation of normal stress could lead to the changes of fractures aperture, which would induce the major evolution of reservoir permeability. Zhao et al. (2015) presented a THM model to study the EGS performance, and found that the flow resistance of working fluid gradually decreased during the heat extraction process, showing great effects of mechanical behavior on EGS operation. Based on THM model, Cao et al. (2016) found that the increased effective stress could enhance the heat extraction but reduce the life expectancy of EGS, and that the lower injection temperature and higher injection pressure could improve the effects of mechanical behavior. Pandey et al. (2017) investigated the evolution of fracture aperture and the deformation of reservoir under different rock properties. Sun et al. (2017) and Yao et al. (2018) presented a THM coupling model to study the heat extraction of a fractured reservoir based on a 2D and 3D model, respectively. The results indicated that under effects of temperature drawdown and pore pressure variation, the fracture permeability could increase above 4 times.

The fractured reservoir of EGS are generally represented by equivalent continuous porous media model and discrete fracture network (DFN)

model in numerical simulation (Kazuo et al. 1999; O'Sullivan et al. 2001; Botros et al. 2008). For the equivalent continuous porous media model, individual fractures are implicitly homogenized within the porous media, and their thermal and fluid transport properties are equivalently calculated. The DFN model is a more realistic model in which each fracture is described explicitly as a parallel plate. The fracture properties including length, aperture, orientation and density are taken into consideration in the model through measured data or statistical distributions (Lee et al. 2017). Therefore, the effects of fracture pattern on the heat extraction of EGS can be studied by DFN model. For example, Qu et al. (2017) studied the influence of fracture morphology on the CO2-EGS performance based on a DFN model implemented in COMSOL and found that more complex fracture network is favorable for heat extraction. Fu et al. (2016) established a 2D THM coupling model based on a discrete fracture network to study the effects of fracture parameters on EGS performance. The results indicated that fracture intensity has a significant effect on the overall hydraulic impedance of the geothermal reservoir but the heat extraction performance cannot be improved by increasing fracture intensity.

The previous studies have shown that the evolution of rock effective stress induced by the temperature drawdown and pore pressure variation has a major effect on the heat extraction of EGS, and that the DFN model can reveal the actual thermal process in EGS reservoir. Therefore, based on the previous model (Song et al. 2018), we take the mechanical behavior and discrete fracture network into consideration, and establish a 3D THM coupling model with a fractured reservoir for the multilateral-well EGS. The THM coupling process of the presented model is verified by an analytical solution. Based on the model, the effects of mechanical behavior of reservoir rock on the heat extraction are investigated. The effects of multilateral wells geometrical parameters, including lateral well number, well length, well diameter and well spacing, on EGS performance are studied. The results of this study provide good guidance for the lateral wells design of the multilateral-well EGS.

## 2. Model description

### *2.1 Model assumption*

In this paper, the supercritical $CO_2$ (SCCO2) is set as the working fluid, because according to references (Brown 2000; Pruess 2006; Pruess 2008; Pan et al. 2015; Cao et al. 2016), $CO_2$-EGS has several advantages. For example, under the operation conditions of EGS (the pressure and temperature are above 7.38 MPa and 31.1 °C, respectively), $CO_2$ is in a supercritical state. $SCCO_2$ has gas-like viscosity, large diffusivity and zero surface tension, and is considered as a favorable working fluid for mass and heat transfer. $SCCO_2$ is unable to dissolve and transport minerals, which avoids the degradation of heat extraction performance and scaling problem. Because of the working fluid loss in the reservoir (Cheng et al. 2016), $CO_2$-EGS is able to achieve the $CO_2$ geological storage and reduce $CO_2$ emissions. Besides, in this model, we assume that the fluid flow of $SCCO_2$ in the reservoir obeys Darcy's Law. The reservoir rock is homogeneous and isotropic and its physical properties are independent of temperature and pressure.

### *2.2 $CO_2$ properties*

Because the physical properties of $SCCO_2$ vary dramatically with pressure and temperature, the $SCCO_2$ properties should be accurately calculated for the numerical simulation of $CO_2$-EGS. The equation of state for $CO_2$ proposed by Span and Wagner (S-W EOS) (Span and Wagner 1996) is widely used to calculate the density and heat capacity of $CO_2$, which has a wide applicable range (216.95 K< $T$ < 1100 K, 0.52 MPa < $p$ < 800 MPa) and high calculation accuracy. In this study, S-W EOS is adopted to calculate the density and heat capacity of $CO_2$, the detailed equations could be found in Span and Wagner (1996). The viscosity and thermal conductivity of $CO_2$ is explicitly expressed by Equations shown in Heidaryan et al. (2011) and Jarrahian et al. (2012).

### *2.3 Governing equations*

The mass conservation equation of the fluid flow in the porous media is written as (Biot 1962)

$$\rho_f S\frac{\partial p}{\partial t}-\nabla\cdot\rho_f\left[\frac{k}{\eta_f}\left(\nabla p+\rho_f g\nabla z\right)\right]=-\rho_f\alpha_B\frac{\partial e}{\partial t}-Q_f \quad (1)$$

The mass conservation equation of the fluid flow in the fracture is written as

$$d_f \rho_f S \frac{\partial p}{\partial t} - \nabla_T \cdot d_f \rho_f \left[ \frac{k_f}{\eta_f} \left( \nabla_T p + \rho_f g \nabla_T z \right) \right] = -d_f \rho_f \alpha_B \frac{\partial e}{\partial t} + d_f Q_f \quad (2)$$

where the parameter $\rho f$ (kg/m$^3$) is the fluid density and $p$ (Pa) is the pore pressure. $t$ (s) is time and $\eta f$ (Pa•s) is the fluid viscosity. $k$ and $kf$ (m$^2$) are the permeabilities of reservoir and fracture, respectively. $df$ (m) is the fracture aperture. $e$ denotes the volumetric strain induced by the rock deformation, which is determined by the equilibrium equation. $\alpha_B$ is Biot-Willis coefficient (Biot 1962) and is defined in terms of the drained and solid bulk modulus as

$$\alpha_B = 1 - \frac{K_d}{K_s} \quad (3)$$

where $K_s$ (Pa) is the bulk modulus of a homogeneous block of the solid material, while $K_d$ (Pa) is the drained bulk modulus of the porous matrix of the same material. S (Pa$^{-1}$) is the storage coefficient that considers the fluid and rock compressibility. The parameter is calculated by

$$S = \varphi C_f + (\alpha_B - \varphi) \frac{1 - \alpha_B}{K_d} \quad (4)$$

where $Cf$ (Pa$^{-1}$) and $\phi$ represent the fluid compressibility and reservoir porosity, respectively. The parameter $Qf$ in Eqs. (1) and (2) indicates the mass transfer between the rock matrix and fractures.

In this paper, the assumption of local thermal equilibrium is used to describe the temperature field and the energy conservation equation and is expressed by

$$\left(\rho c_p\right)_{eff} \frac{\partial T}{\partial t} + \rho_f c_{p,f} u \cdot \nabla T - \nabla \cdot \left( \lambda_{eff} \nabla T \right) = -Q_{f,E} \quad (5)$$

where $T$ (K) and $C_{pf}$ (J/(kg·K)) are the reservoir temperature and the heat capacity of the working fluid. $(\rho c_p)_{eff}$ and $\lambda_{eff}$ are the effective volumetric capacity and the effective thermal conductivity, respectively, which are determined by

$$\left(\rho c_p\right)_{eff} = (1-\varphi) \rho_s c_{p,s} + \varphi \rho_f c_{p,f} \quad (6)$$

$$\lambda_{eff} = (1-\varphi) \lambda_s + \varphi \lambda_f \quad (7)$$

where $\rho s$ (kg/m$^3$), $C_{p,s}$ (J/(kg·K)) and $\lambda s$ (W/(m•K)) represent the density, heat capacity and thermal conductivity of the solid part in the reservoir, respectively. Similarly, the energy conservation equation in fracture is written as

$$d_f \left(\rho c_p\right)_{eff} \frac{\partial T}{\partial t} + d_f \rho_f c_{p,f} u_f \cdot \nabla_T T - \nabla_T \cdot \left( d_f \lambda_{eff} \nabla T \right) = d_f Q_{f,E} \quad (8)$$

The parameter $Q_{f,E}$ in the Eqs. (5) and (8) indicates the heat transfer between the porous media and fractures.

The rock deformation induced by the variations of temperature and pore pressure is determined by the equilibrium equation.

$$\mu u_{i,jj} + (\lambda + \mu) u_{j,ji} - \alpha_B p_{,i} - 3K_d \alpha_T \Delta T_{,i} + F_i = 0 \quad (9)$$

where $u$ (m) represents the displacement. $\lambda$ (Pa) and μ (Pa) are Lamé parameters and expressed by elastic modulus $E$ (Pa) and Poisson's ratio $\nu$, i.e. $\lambda = E\nu/[(1+\nu)(1-2\nu)]$, $\mu = E/[2(1+\nu)]$. The third term denotes the effect of pore pressure that couples with the fluid flow in the reservoir. The fourth term represents the thermal stress induced by the temperature drawdown that is linked with the temperature field. $\Delta T = T - T_i$, where $T_i$ (K) represents the initial temperature of the reservoir. $K_d$ (Pa) can be expressed as $K_d = E/[3(1-2\nu)]$. $\alpha_T$ (K$^{-1}$) is the coefficient of thermal expansion. $F^i$ is the body force per unit volume in the i-coordinate.

The rock deformation could cause the variation of the fracture aperture, which induces the evolution of the fracture permeability. Actually, many empirical correlations between the effective stress and the reservoir permeability studies have been obtained by the previous studies (Zou et al. 2013; Davies et al. 2001; Miller 2015; Rice 1992). In this paper, the correlation in the references (Miller 2015; Rice 1992) is used to describe the variation of fracture permeability.

$$k_f = k_0 e^{-\left(\sigma_n' / \sigma^*\right)} \quad (10)$$

where $k_0$ (m$^2$) is the initial permeability when $\sigma'_n = 0$. $\sigma^*$ is a normalizing constant and set as -10 MPa (Sun et al. 2017; Yao et al. 2018; Miller 2015). $\sigma'_n$ is the effective normal stress imposed on the fracture plane and expressed by

$$\sigma_n' = K_n \left( u_n - d_f \alpha_T \Delta T \right) \quad (11)$$

where $u_n$ (m) is the normal displacement of fractures. $K_n$ (Pa/m) is the stiffness of fractures and considered as 400 GPa/m (Sun et al. 2017; Yao et al. 2018). The correlation between the effective stress ($\sigma'_n$) and total stress ($\sigma_n$) is $\sigma'_n=\sigma_n+\alpha_B p$, where we assume that the tensile stress is positive and compressive stress is negative. Besides, it is worth noting that the permeability of rock matrix also changes during the heat extraction. However, the variation of matrix permeability is ignored, because it is much smaller than that of fractures.

### *2.4 Model verification*

**Table 1 Physical properties of reservoir rock**

| Items | Values |
|---|---|
| Soil elastic modulus | 60 MPa |
| Soil Poisson's ratio | 0.4 |
| Thermal expansion coefficient | $3\times10^{-7}$ |
| Porosity | 0.4 |
| Hydraulic conductivity | $1\times10^{-9}$ m/s |
| Overall thermal conductivity of rock and water | 0.5 W/(m·K) |
| Heat capacity of soil | 800 J/(kg·K) |
| Heat capacity of water | 4200 J/(kg·K) |
| Biot-Willis coefficient | 1.0 |
| Water density | 1000 kg/m$^3$ |
| Soil density | 2600 kg/m$^3$ |

The governing equations combined with the initial and boundary conditions comprise the THM coupling model of the heat extraction process of EGS. The model is implemented in the finite element solver COMSOL. In our previous study (Song et al. 2018), the TH coupling process has been verified by an analytical solution of the fluid flow and heat transfer in a 2D single-fracture system. Similarly, the THM coupling process is also verified by a simple problem that an accurate analytical solution could solve, i.e. the thermal consolidation process of the saturated porous media (Sun et al. 2017; Bai 2005). **Figure 2** illustrates the thermal consolidation problem of a soil column (Sun et al. 2017) and the analytical solution is presented in the reference (Bai 2005). The height of the soil column is 1 m with the initial temperature of 283.15 K and initial pressure of 0.1 MPa. The vertical compressive load of 0.1 MPa is imposed on the top surface, where the temperature and pore pressure are fixed at 333.15 K and 0 MPa, respectively. The side and bottom boundaries are considered as impervious and insulated, where the displacements are constrained normally. The properties of the soil and fluid utilized in the numerical model are the same as those in the analytical model and listed in Table 1.

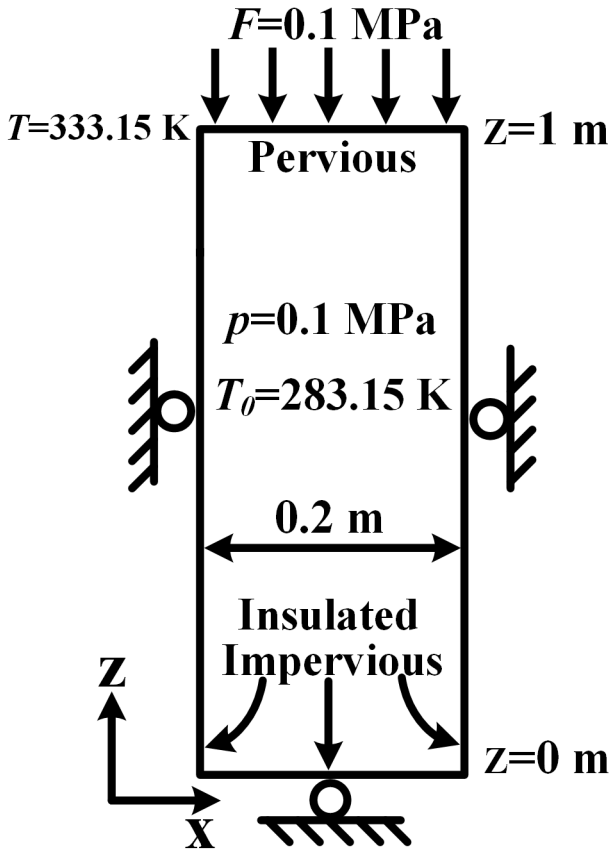


*Figure 2: Schematic of the thermal consolidation problem of a soil column*

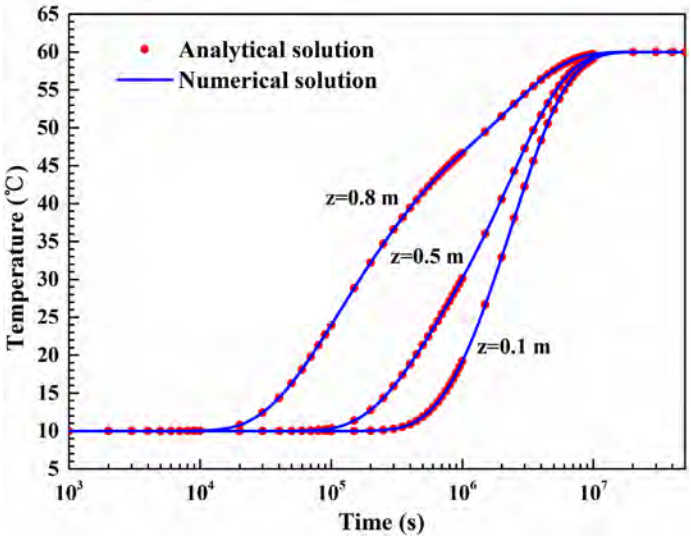


*Figure 3: Displacements along z direction at different positions*

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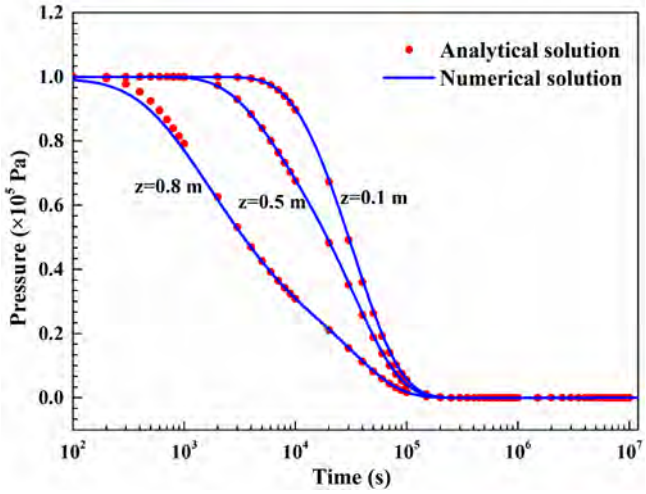


*Figure 4: Pore pressures at different positions in the soil column*

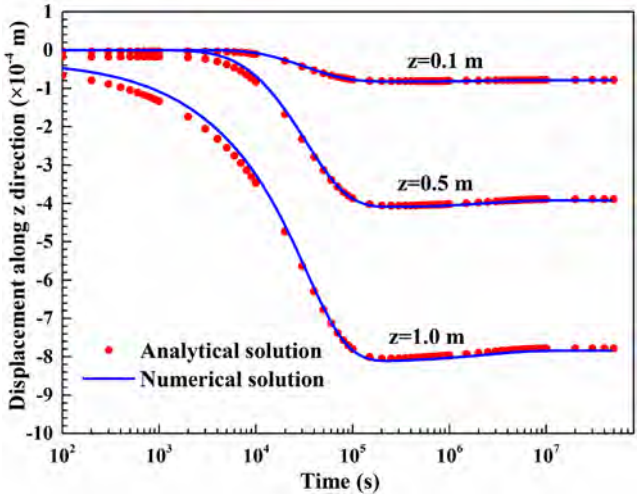


*Figure 5: Temperatures at different positions in the soil column*

**Figures 3-5** illustrate distributions of temperature, pore pressure and displacements obtained by the numerical solution and analytical solution. It can be observed that the numerical results agree well with the analytical solutions though there are slight differences for the displacements between the numerical and analytical solutions at the early time. These differences might result from the numerical errors which is within the reasonable range. Therefore, the THM coupling numerical model is proven to be accurate though there are no fractures involved in this problem.

## 3. A multilateral-well EGS case with discrete fractures

### *3.1 Computational model*

The schematic of the computational model is demonstrated in **Figure 6**, which is modified from our previous model (Song et al. 2018). It consists of an enclosing rock, several upper injection lateral wells, lower production lateral wells and a fractured reservoir instead of the stimulated reservoir volume in the previous model. An example of fractured reservoir implemented in COMSOL is also illustrated in **Figure 6**, which is described by the random discrete fracture network. We assume that there are 90 vertical fractures along three different directions in the model and the angles between fractures and x-axis are 30°, 90° and 150°, respectively. The fracture length follows the normal distribution with a length range of 170-200 m, while the central position of the fracture follows the uniform distribution. The aperture of the fractures is set as 0.5 mm.

The size of the computational model is 1000 m × 1000 m × 1000 m, which is located at a depth from 3000 m to 4000 m. Besides, the fractured reservoir is a 500 m × 500 m × 500 m cube and is located at the center of the computational model. For the base case, there are 6 injection and production lateral wells with the length of 150 m

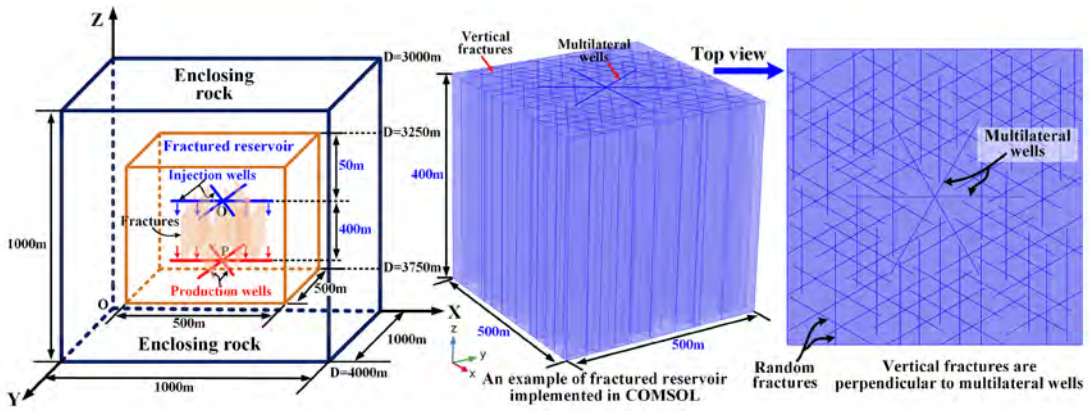


*Figure 6: Schematic of the computational model*

and diameter of 0.10 m. The angle between two adjacent lateral wells is 60° and the vertical spacing between the injection and production wells is 400 m. Besides, the physical properties of reservoir and fractures adopted in this study are listed in Table 2.

**Table 2 The reservoir properties of the computational model**

| Items | Enclosing rock | Fractured reservoir matrix | Fractures |
|---|---|---|---|
| Density (kg/m$^3$) | 2800 | 2700 | 2000 |
| Heat conductivity (W/(m·K)) | 3 | 2.8 | 2.8 |
| Heat capacity (J/(kg·K)) | 1000 | 1000 | 850 |
| Porosity (%) | 1 | 5 | 100 |
| Permeability (m$^3$) | $10^{-18}$ | $10^{-17}$ | $10^{-10}$ ($k_0$) |
| $\alpha_T$ | $5\times10^{-6}$ | $5\times10^{-6}$ | $5\times10^{-6}$ |
| Elastic modulus (Pa) | $2.5\times10^{10}$ | $2.5\times10^{10}$ | $2.5\times10^{10}$ |
| Poisson's ratio | 0.25 | 0.25 | 0.25 |
| $\alpha_B$ | 0.7 | 0.7 | 0.7 |

### *3.2 Initial and boundary conditions*

The initial reservoir temperature and pressure increase linearly from the top to bottom boundary with the geothermal gradient and the pressure gradient of 0.05 K/m and 5000 Pa/m, respectively. The initial temperature and pressure at the top boundary are 473.15 K and 30 MPa, respectively. For the boundary conditions, we assume that there is the cap rock above the reservoir, so the top boundary is considered as insulated. The temperatures at the bottom and side boundaries remain constant at the initial reservoir temperature. We consider that there is no working fluid in the surrounding rock out of the computational domain, so the no-flow condition is exerted at all boundaries. For the displacement field, all boundaries of the computational model are constrained in normal directions. Because we always focus on the stress evolution induced by the temperature drawdown and pore pressure changes during the heat extraction process, the initial geo-stress is not taken into consideration in this model (Sun et al. 2017; Yao et al. 2018). Besides, during the heat extraction process, the injection temperature and mass flow rate of the working fluid are fixed at 333.15 K and 50 kg/s, respectively. Because the geothermal well always produces at a constant downhole pressure, the pressure of the production lateral wells is set as 25 MPa.

### *3.3 Simulation mesh*

The meshing schemes of the computational domain is illustrated in **Figure 7**, where the swept mesh method and free tetrahedral mesh method are utilized. For the fractured reservoir, the triangular elements are produced on the top surface, and then the meshes are swept along the vertical direction ($z$ direction) to the opposite bottom surface to generate triangular prismatic elements. Subsequently, the free tetrahedral mesh method is used to produce tetrahedral meshes for the enclosing rock. The meshes of the fractured reservoir is much finer than those of the enclosing rock, because the fluid flow and heat transfer processes mainly take place in the fractured reservoir. A mesh number of around 120000 is utilized in the following studies to ensure the accuracy of the simulation results. Furthermore, a fully coupled method is used to solve the numerical model in COMSOL. A total heat extraction period of 30 years is studied and the time step is set as 1 day. The absolute tolerance is set as $10^{-6}$ and regarded as the convergence criteria of the numerical solutions.

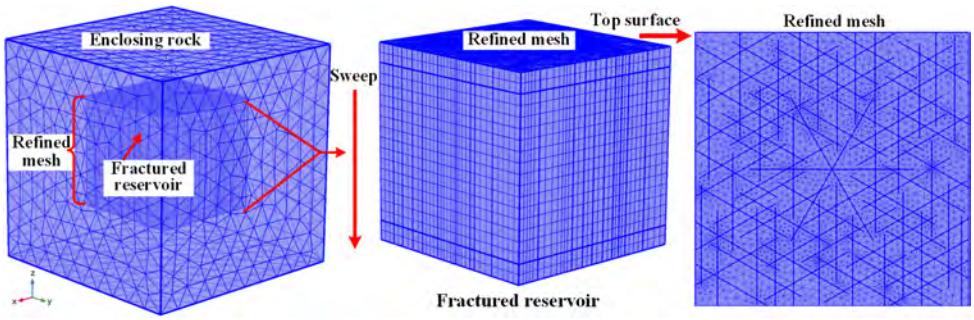


*Figure 7: Numerical meshing schemes*

## 4. Results and discussion

### *4.1 Effects of mechanical behavior*

In this section, the effects of rock effective stress evolution on the heat extraction process are investigated. **Figure 8** shows the temperature contours of TH coupling and THM coupling models on different cross sections of a fractured reservoir after 30 years. It can be observed that the cooling area on the *xy* plane of TH coupling model is larger than that of THM coupling model, which means that the working fluid has access to the larger part of the reservoir in the TH coupling model. Besides, we can see from the temperature contours on the *xz* plane that the cooling area reaches the production lateral wells along some preferential flow channels (fractures) in the THM coupling model, while the cooling area tends to expand along the xy plane and only a little cooling fluid arrives at the production wells in the TH coupling model. This is because that when the mechanical behavior of the reservoir rock is considered, the temperature reduction during the heat extraction induces the contraction of the rock, and then produces tensile thermal stress. The thermal stress would increase the fracture permeability dramatically (see Eq. (10)). Therefore, the flow impedance of fractures keeps decreasing in the THM coupling model and the fractures connected with lateral wells become preferential channels for the cooling working fluid. This also can be concluded from the evolutions of the average production temperature and injection pressure shown in **Figure 9**. It illustrates that the average production temperature in the THM coupling model decreases much earlier and faster than the TH coupling model, while the injection pressure in the THM model is much lower than that of TH model. In a word, the effects of rock mechanical behavior on the heat extraction process of EGS is very significant and should not be ignored in the numerical simulation.

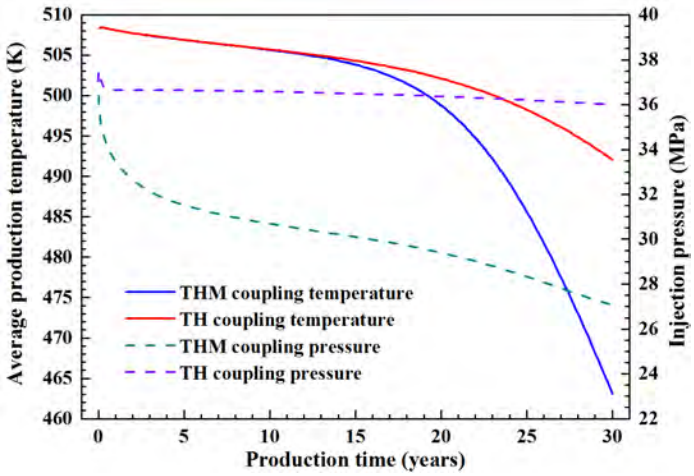


*Figure 9: Comparisons of average production temperatures and injection pressures of THM coupling and TH coupling models*

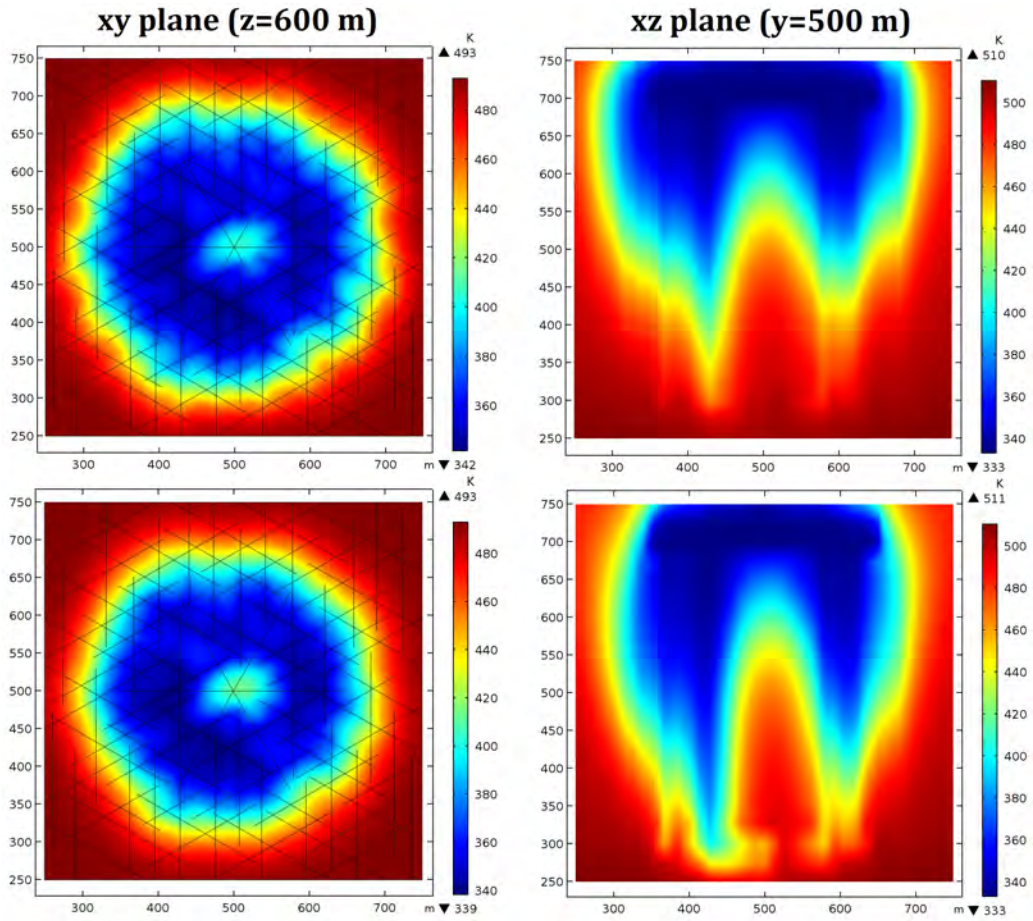


*Figure 8: Temperature contours of TH coupling (first row) and THM coupling (second row) models on different cross sections of fractured reservoir after 30 years*

### *4.2 Effects of lateral-well length*

In this section, the effects of the lateral well length on the heat extraction are studied. The lateral well number, diameter and spacing are set as 6, 0.10 m and 400 m, respectively. The temperature contours of different lateral well lengths on the cross sections of the fractured reservoir after 30 years are illustrated in **Figure 10**. It can be observed that as the well length increases, the cooling area on the *xy* plane becomes larger, while the preferential flow along the fractures on the *xz* plane becomes less obvious. It means that the longer lateral well could connect with more vertical fractures on the xy plane, which makes the cooling area expanding along the horizontal plane more quickly than along the vertical plane. Therefore, the longer lateral well length could postpone the decrease of the average production temperature and extend the lifetime of the EGS. We can also draw this conclusion from **Figures 11 and 12**, in which the characteristic parameters of the EGS are demonstrated. We can see that the production temperature, output thermal power and heat extraction ratio improve with the increases of well length. For example, after 30 years, the production temperature and thermal power increase from 448.05 K and 9.02 MW under the well length of 125 m to 486.58 K and 10.941 MW under the well length of 200 m, respectively. Besides, it also can be concluded that the injection pressure decreases obviously as the well length becomes longer. This is because that more connections between the lateral wells and fractures decrease the overall flow impedance of the working fluid in the reservoir. In a word, the longer lateral well length is beneficial for the improvement of the heat extraction performance of the multilateral-well EGS with a fractured reservoir.

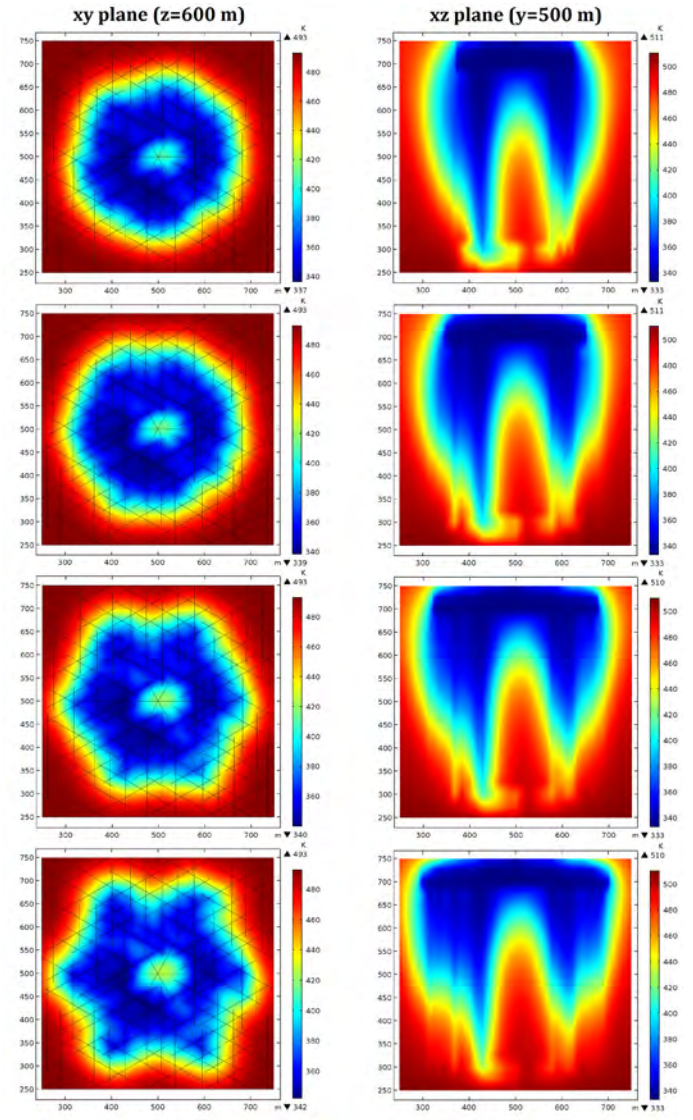


*Figure 10: Temperature contours of various well lengths on different cross sections of fractured reservoir after 30 years (first row: 125 m, second row: 150 m, third row: 175 m, fourth row: 200 m)*

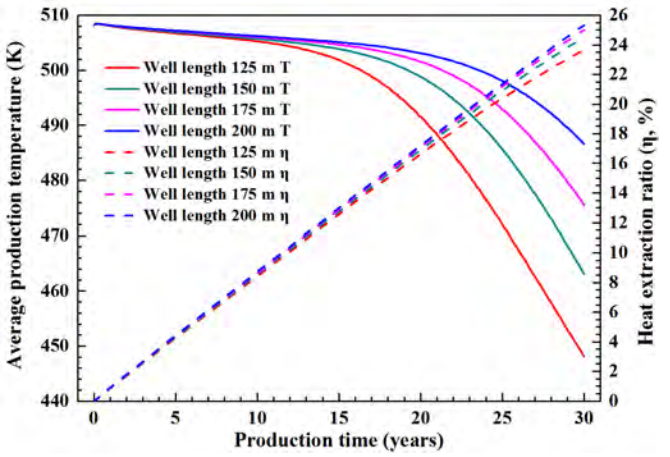


*Figure 11: Production temperatures and heat extraction ratios under various well lengths*

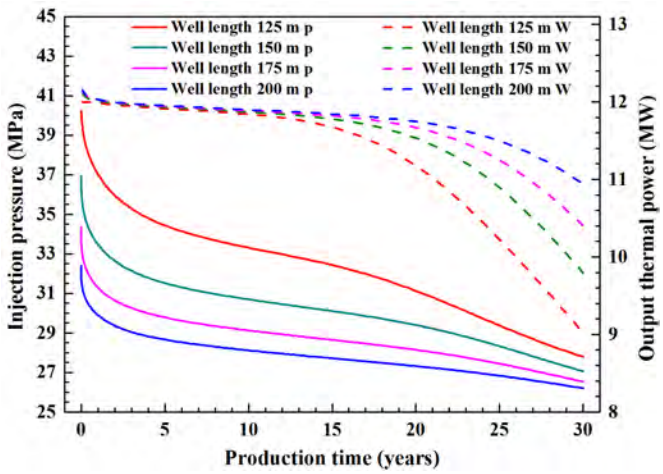


*Figure 12: Injection pressures and output thermal power under various well lengths*

### *4.3 Effects of lateral-well number*

In this section, we study the effects of lateral well numbers on the EGS performance. The well length, spacing and diameter are set as 150 m, 400 m and 0.10 m, respectively. The temperature contours of various well numbers on the *xy* plane at *z*=600 m after 30 years are shown in **Figure 13**. The temperature contour with 6 lateral wells has been illustrated in the second row of **Figure 10**. It can be observed that the cooling area on the *xy* plane increases when the lateral well number increases from 4 to 6, and the cooling areas under the well number of 6, 7 and 8 are similar to each other. Besides, we can see from **Figure 14** that the average production temperature improves when the lateral well number increases from 4 to 6. However, while the well number exceeds 6, the production temperature decreases. This is because that as the lateral well number improves, the connection between lateral wells and fractures increases, which can be found in **Figure 13.** The connections for the well number of 4 to 8 are 15, 17, 17, 27, 31, respectively. Therefore, the working fluid is distributed to more fractures with the increase of lateral well number, which makes the working fluid have access to the larger part of the reservoir rock and improves the production temperature. However, when the lateral well number exceeds 6, there are too many connections providing preferential channels for the working fluid, which promotes the working fluid breakthrough time and thus decreases the production temperature. On the other hand, we can see from Figure 14 that the injection pressure keeps decreasing with the increase of lateral well number. In a word, the well number and connections between lateral wells and fractures have significant effects on the EGS performance. More lateral wells can disperse the working fluid to a larger part of the reservoir, but too many connections would accelerate the working fluid breakthrough. Therefore, a relatively large number of lateral wells with proper connections is beneficial for EGS performance. Under the condition of this paper, the well number of 6 with around 17 connections is the best for the heat extraction performance of multilateral-well EGS.

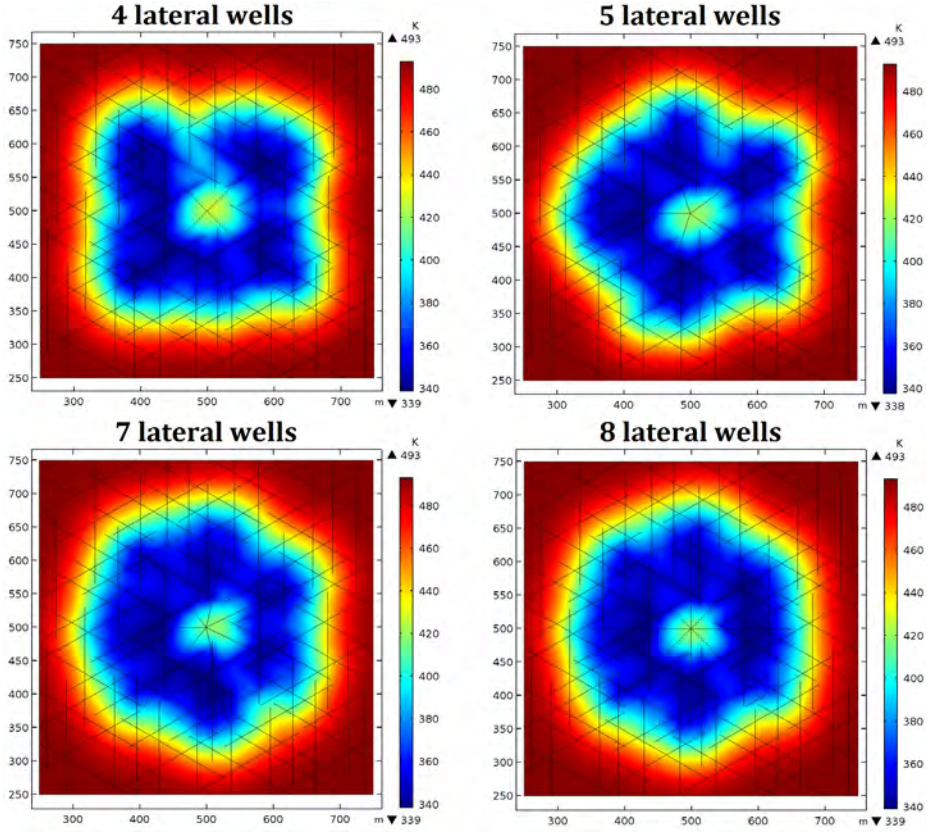


*Figure 13: Temperature contours of various lateral well numbers on the xy plane at z=600 m after 30 years*

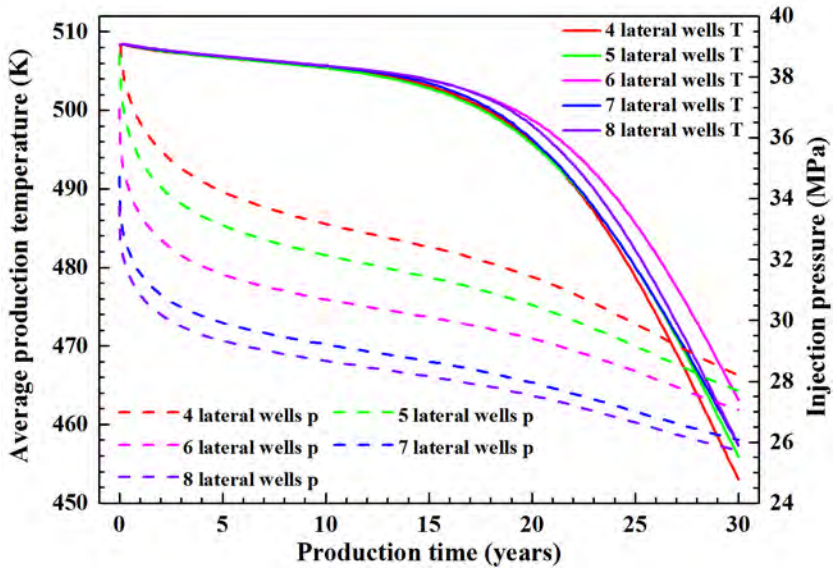


*Figure 14: Average production temperatures and injection pressures under various lateral well numbers*

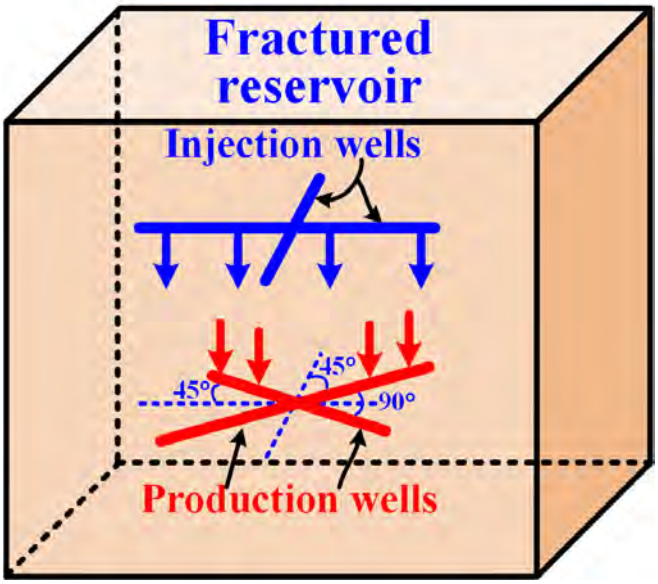


*Figure 15: Schematic of 4 lateral wells with a modified structure*

Based on the above conclusion, we propose a new well arrangement to enhance the heat extraction performance, i.e. rotating production lateral wells to produce a certain angle between production wells and the projections of injection lateral wells. **Figure 15** illustrates the schematic of 4 lateral wells by rotating production wells by 45°. This well arrangement decreases the direct connections between injection and production wells by preferential channels (vertical fractures). The results shown in **Figure 16** reveals that the new well arrangement postpones the thermal breakthrough and increases the average production temperature by 6 K after 30 years.

### *4.4 Effects of well spacing*

In this section, we investigate the effects of well spacings between injection and production wells on the heat extraction performance. The well number, length and diameter are set as 6, 150 m and 0.10 m, respectively. **Figure 17** shows temperature contours of various well spacings on different cross sections of fractured reservoir after 30 years. The white and black lines in **Figure 17** represent the positions of injection and production wells, respectively. We can see that as the well spacing increases, the cooling area on the *xy* plane becomes slightly larger, while the preferential flow along vertical fractures on the *xz* plane is less obvious. This is because that under the same injection rate and production pressure, when the well spacing increases, the velocity of the

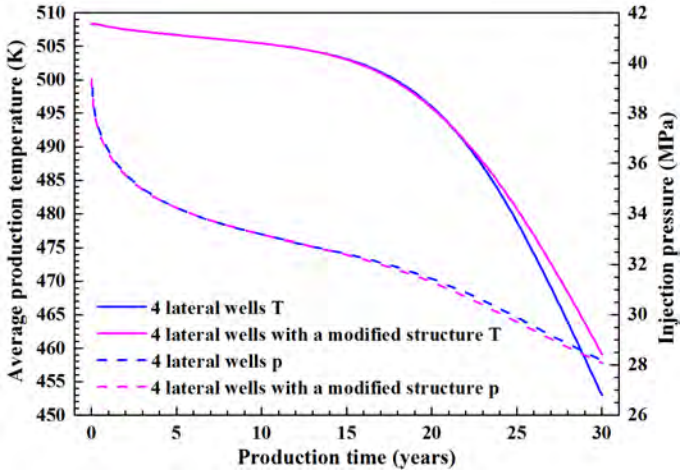


*Figure 16: Average production temperatures and injection pressures of 4 lateral wells with different structures*

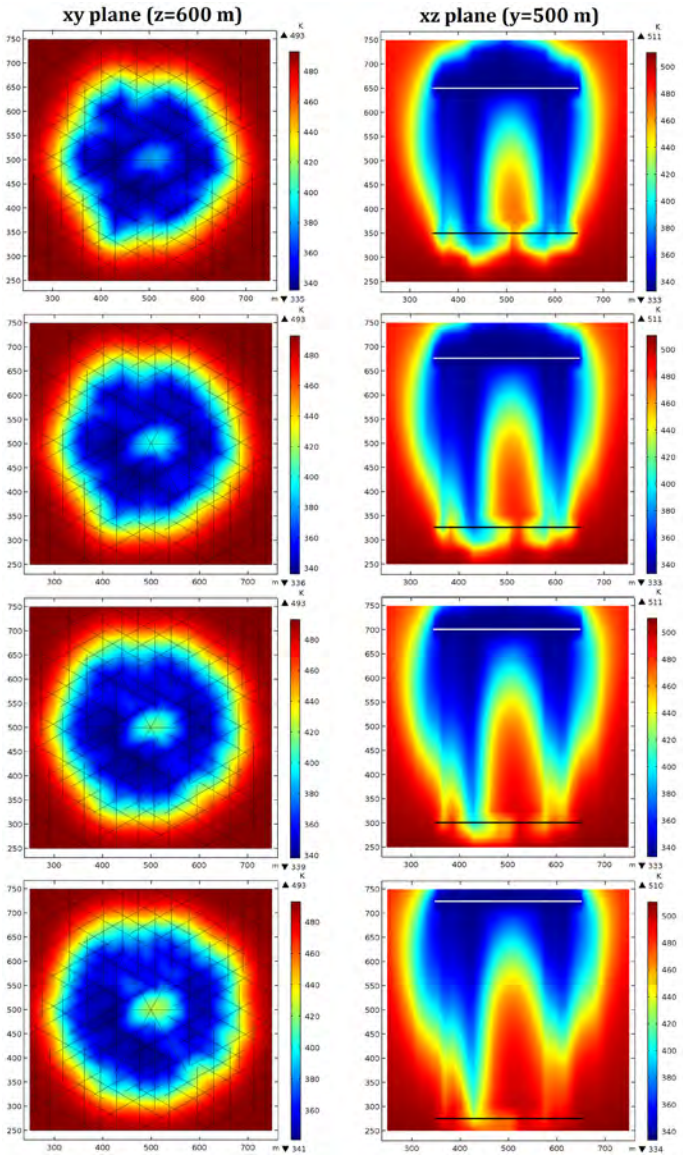


*Figure 17: Temperature contours of various well spacings on different cross sections of fractured reservoir after 30 years (first row: 300 m, second row: 350 m, third row: 400 m, fourth row: 450 m)*

working fluid in the fracture decreases, which extends the cooling working fluid breakthrough time in the vertical direction. **Figure 18** illustrates the average production temperatures and injection pressures evolution with time under various well spacings. It can be concluded that the production temperature and injection pressure both improve with the increase of well spacing. For example, after 30 years, the $T_{out}$ and p increase from 413.18 K and 25.66 MPa under the well spacing of 300 m to 480.24 K and 29.42 MPa under the well spacing of 450 m, respectively. The temperature improves nearly 70 K but the injection pressure only increases around 4 MPa. Therefore, a proper large well spacing is beneficial for enhancing the EGS performance.

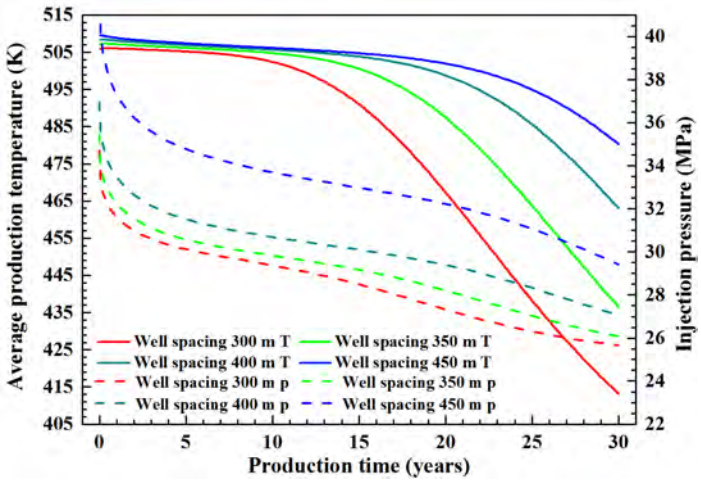


*Figure 18: Average production temperatures and injection pressures under various well spacings*

### *4.5 Effects of lateral-well diameter*

In this section, the effects of lateral well diameter on EGS performance are studied shown in **Figure 19**. The well number, length and spacing are set as 6, 150 m and 400 m, respectively. It is worth noting that multilateral wells are usually sidetracked from the main wellbore by radial jet drilling technology (Nair et al. 2017), and its well diameter is smaller than 10 cm. Therefore, only the well diameter below 10 cm are investigated. We can see from **Figure 19** that the average production temperatures and injection pressure under various well diameters both overlap with each other. It means that the effect of the well diameter on the EGS performance can be ignored.

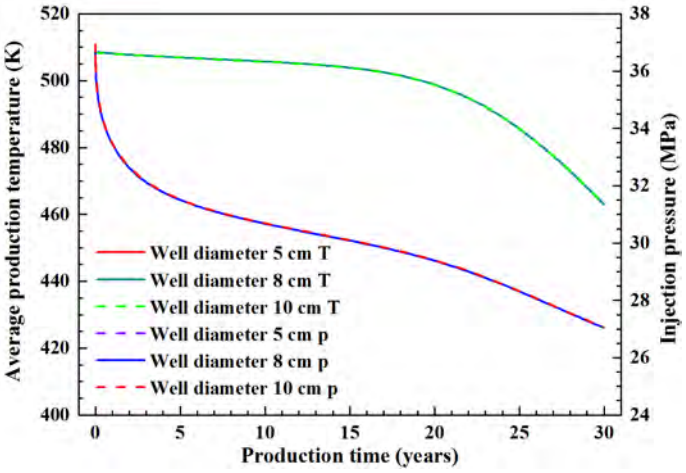


*Figure 19: Average production temperatures and injection pressures under various well spacings*

## 5. Conclusion

In this paper, we present a THM coupling model for the multilateral-well $CO_2$-EGS with a fractured reservoir. The model is verified by an analytical solution of a thermal consolidation problem. Based on the model, the effects of rock mechanical behavior on the heat extraction performance are analyzed. The influences of geometrical parameters of multilateral wells on the EGS performance are studied. The key findings of this study are as follows:

- The rock mechanical behavior has a significant effect on the heat extraction process. The effective stress of rock induced by temperature drawdown and pore pressure changes could increase the fracture permeability and enhance the preferential flow in fractures, which reduces the injection pressure and promotes the thermal breakthrough.
- The longer multilateral wells are beneficial for improving the EGS performance. As the lateral well length increases, more fractures are connected, which makes the working fluid have access to the larger part of the reservoir. Therefore, the longer multilateral wells improve the average production temperature and reduce the injection pressure.
- The well number and connections between lateral wells and fractures have important effects on the EGS performance. More lateral wells can disperse the working fluid to larger part of the reservoir, but under the same well length too many connections would accelerate

the working fluid breakthrough. Therefore, a relatively large number of lateral wells with proper connections is beneficial for EGS performance. Under the condition of this paper, the well number of 6 with around 17 connections is the best for the heat extraction performance of multilateral-well EGS.

- As the well spacing increases, the cooling area tends to expands along the horizontal section and the preferential flow along the vertical fractures becomes less obvious. Therefore, a larger well spacing could improve the production temperature and extends the lifetime of the EGS. Besides, the effect of the lateral well diameter on the EGS performance can be ignored.


## ACKNOWLEDGEMENTS

The authors would like to acknowledge the National Key Research and Development Program of China (Grant No. 2016YFE0124600). Besides, support from the Program of Introducing Talents of Discipline to Chinese Universities (111 Plan) (Grant No. B17045) is appreciated.


## NOMENCLATURE

| | |
|---|---|
| $C_f$ | = fluid compressibility, $Pa^{-1}$ |
| $c_{p,f}$ | = working fluid heat capacity, J/(kg·K) |
| $c_{p,s}$ | = heat capacity of the solid part in the reservoir, J/(kg·K) |
| $e$ | = Volumetric strain |
| $E$ | = elastic modulus, Pa |
| $EGS$ | = enhanced geothermal system |
| $d_f$ | = fracture aperture, m |
| $g$ | = gravitational acceleration, $m/s^2$ |
| $HDR$ | = hot dry rock |
| $k$ | = rock matrix permeability, $m^2$ |
| $k_0$ | = initial permeability of fractures, $m^2$ |
| $k_f$ | = fracture permeability, $m^2$ |
| $K_d$ | = drained bulk modulus of porous matrix, Pa |
| $K_n$ | = stiffness of fractures, Pa/m |
| $K_s$ | = bulk modulus of a homogeneous block, Pa |
| $W$ | = output thermal power, W |
| $p$ | = pressure, Pa |
| $Q_f$ | = mass transfer between the rock matrix and fractures, $kg/(m^3 \cdot s)$ |
| $Q_{f,E}$ | = heat transfer between the rock matrix and fractures, $W/m^3$ |
| $S$ | = Storage coefficient, $Pa^{-1}$ |
| $t$ | = time, s |
| $T$ | = temperature in the porous media, K |
| $T_{out}$ | = average production temperature, K |
| $u$ | = displacement, m |
| $un$ | = normal displacement of fractures, m |

### GREEK SYMBOLS

| | |
|---|---|
| $\rho f$ | = working fluid density, $kg/m^3$ |
| $\rho s$ | = density of the solid part in the reservoir, $kg/m^3$ |
| $\eta f$ | = working fluid viscosity, Pa·s |
| $\mu$ | = Lamé parameter, Pa |
| $\lambda$ | = Lamé parameter, Pa |
| $\lambda f$ | = working fluid heat conductivity, W/(m·K) |
| $\lambda s$ | = heat conductivity of the solid part in the reservoir, W/(m•K) |
| $\phi$ | = reservoir porosity |
| $\sigma' n$ | = Effective normal stress of fractures, Pa |
| $\sigma n$ | = total stress, Pa |
| $\phi f$ | = fracture porosity |
| $\eta$ | = heat extraction ratio |
| $\alpha B$ | = Biot-Willis coefficient |
| $\alpha T$ | = coefficient of thermal expansion, $K^{-1}$ |
| $\nu$ | = Poisson's ratio |

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# Corporate Focus

*The GRC would like to highlight our partners in the industry with a regular series of articles featuring our company colleagues. We thank our friends in the corporate sector for their ongoing support.*

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**Capuano Engineering Company** of Santa Rosa, California, just down the hill from The Geysers geothermal field, was established in January of 2012 as a geothermal services company specializing in geothermal resources around the world.

Louis E. Capuano, Jr., (President & CEO) has worked in the geothermal industry since 1974 and has become a well known figure in the field of geothermal drilling and continues to work on all forms of geothermal development, as well as exploration and development projects. Louis has been a long-term member of the GRC, a volunteer on the Board of Directors and serving twice as President. In 2002, in recognition of his outstanding contributions to the GRC and to the development of geothermal resources, Louis was awarded the Joseph W. Aidlin Award.

Louis Capuano III (Vice President, Drilling/ Project Management) joined his father's firm and has worked in the drilling field since graduating from Louisiana State University with a B.S. in Petroleum Engineering. Along with his father he has provided the geothermal drilling section of The National Geothermal Academy held each year at The University of Nevada, Reno. Louis III is an active member of the GRC Board of Directors.

Capuano Engineering Company excels at providing project management, drilling plan development, drilling procedure development, materials, services, and technologies as well as establishing cost control analysis. The Capuano Engineering Company team has a proven history in performing resource testing and verification.

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*CAPTION: (From left to right) Louis Capuano, Jr., Louis Capuano, III, Anne Marie Clay (Office Manager) and George Scheid (Drilling Superintendent).*
~~~~~~~

A band of wild mustangs gallops along the desert floor, passing by the shrubs of sage and rabbitbrush in Gabbs Valley, Nevada. Here geologists use Play Fairway Analysis, a method for locating "blind geothermal systems". . . ones without any telltale surface features, like hot springs and fumaroles. *Photo by Steve DeOreo, Drilling Program Manager, Nevada Bureau of Mines and Geology. Copyright © 2018 Steve DeOreo*

# Two Secrets, One Desert: Gabbs Valley, Nevada

by Susan Fox Hodgson
cosmos@dcn.org

When you leave your van to wander around the desert in Gabbs Valley, as we did on a recent GRC field trip, the place seems vast and empty but for a huge, pale-blue sky and a few stocky mountain ranges—some brownish, some black, blocking the expanses of tan, flat desert and brushy plants. Recently two secrets from Gabbs Valley have come to light: the influence of William More Gabb, and the blind geothermal systems at work beneath the valley floor. First, *W.M.G.*

**William More Gabb, 1839 – 1878**

Who was the man who lent his name to Gabbs Valley, such a nondescript place—or is it? William More Gabb (*see* photo) was a famed paleontologist with incredible accomplishments (many not mentioned here). He died very early—at age 39. A brilliant student, he graduated from the Central High School of Philadelphia when he was 18, studied under a notable geologist, James Hall, became active in the Philadelphia Academy of Natural Sciences, and joined a group of young scientists studying at the Smithsonian Institution in Washington, D.C.

In 1861, Josiah Whitney, chief of the California State Geological Survey (*see* photo), was looking for a qualified paleontologist when he learned of—and quickly hired—the 22-year-old Gabb, whom he called ". . . young, grassy green, but decidedly smart." Besides undertaking field work for the survey, Gabb's job was to classify the Cretaceous

California State Geological Survey, 1863. Standing from left: William More Gabb, paleontologist; Josiah Dwight Whitney, appointed the first State Geologist for California in 1860; and Clarence King, geologist, who would become the first director of the U.S. Geological Survey in 1879. Seated from left: Chester V. Averill, assistant; William Ashburner, field assistant; Charles F. Hoffmann, cartographer; and William H. Brewer, botanist. Negative on glass. *Reprinted by permission of the California Geological Survey*

and Tertiary fossils, which he sketched himself (*see Selected References*).

In 1867, at the personal request of Professor Whitney, Gabb explored the White Mountain Range on the California - Nevada border. He was asked to carry his work eastward as far as the 116th meridian west of Greenwich and include a large part of the area between 37° and 39° north latitude. This location includes what would become Gabbs Valley, located at latitude 38.77° north and longitude 118.161° west. Gabbs Valley, which includes Gabbs Mountain (Miocene volcanic rocks) and the Gabbs Formation (Upper Triassic limestone and shale), has fossils dating back to the Jurassic-Triassic period, ~250 to 145 million years ago. Thus in 1867, Gabb undertook one of the first scientific, geological explorations of Nevada.

William Gabb was elected to the California Academy of Natural Sciences in 1861. This occurred on the very evening of the day he'd arrived in San Francisco by steamer to undertake his new job at the California State Geological Survey. In 1876 he was elected a member of the National Academy of Sciences—a prestigious organization founded in 1863.

In time, the California survey would publish Gabb's work in two famous volumes. By the end of his career, and long after he had left the survey and spent lengthy stretches working in the Dominican Republic and the Talamanca region of Costa Rica, among other places, Gabb's list of publications covered five and a half pages (I counted).

One more mention about *Gabbs Valley*, the *Gabbs Valley Range*, the *Gabbs Formation*, *Gabbs Mountain*, and the *Town of Gabbs* (once called ***Brucite***—*see* the topo map). All but two of the many documents I've read confirm these all were named after William Gabb.

To add some light-weight confusion, an unnamed person once said an engineer named C.S. Gabbs had worked in Gabbs Valley, and another said the local post office was named after a C.S. Gabbs in 1943. Perhaps this C.S. Gabbs worked at Premier Magnesia, the only magnesium carbonate mine in the United States. It is still operating today in Gabbs Valley, near the Town of Gabbs.

**Gabbs Valley & Play Fairway Analysis (PFA)**

The small human mysteries left on the surface of Gabbs Valley are nothing compared with the knotty geological puzzles embedded beneath. Here is where the blind geothermal systems lie without telltale surface features. How many systems are there and how deep do they go? No one knows. Many of today's geologists use a method called Play Fairway Analysis (PFA) to look for them.

PFA originally was devised to find oil. Geologist Gene Suemnicht says he first heard of PFA during the seventies in the Philippines where he worked in Union Oil's geothermal fields. The company altered the PFA system for geothermal exploration.

No detailed explanations of PFA are included here, only the framework. The 2018 publication by Faulds *et al*., cited at the end, offers a brief, scientific overview. The 2017 publication by Faulds *et al*., also cited, offers much more PFA detail, as a portion of the title indicates: *Integrated Geological, Geochemical, and Geophysical Analyses.*

The PFA study incorporates geological, geochemical, and geophysical parameters indicative of geothermal activity. Typically, writes the author, Dr. Jim Faulds, "PFA will begin with a regional perspective and define broad areas that are more prospective than others. The results are analyzed quantitatively and numerically ranked. PFA will then progress to looking at promising sites in greater detail, so that much smaller areas worthy of detailed study can be defined and individual drilling sites in those areas can be selected. Again the results are analyzed and numerically ranked, and the most promising area, with multiple collocated features indicative of geothermal activity, is selected for temperature-gradient drilling."

PFA costs are not inexpensive, but the process lowers some of the inherent risks of geothermal development. When geologists use the PFA system in geological terrain different from Gabbs Valley, they adjust the geological, geochemical, and geophysical tests accordingly.

**PFA and the DOE**

The U.S. Department of Energy (DOE) has funded multiple PFA studies throughout the United States, going back to 2014. Dr. Susan Hamm is the Director of the DOE's Geothermal Technologies Office and oversees the PFA program. She included the following remarks about the PFA program in her recent address at the Geothermal Resources Council Annual Meeting, in Reno, Nevada.

Dr. Hamm said, "In Phase I, we had 11 project teams doing reconnaissance work covering hundreds of thousands of square kilometers, leading to a ranked list of prospects. In Phase II we moved into field work. More than a dozen field campaigns were conducted to map out prospective areas, acquire new geophysical data, and develop conceptual models with drilling targets.

"Work on the Phase III targets launched this past summer included Gabbs Valley, Nevada. Phase III drilling projects also are near completion at Mount St. Helens in Washington and Camas Prairie in Idaho's Snake River Plain. USGS drill rigs are currently onsite in Nevada at Granite Springs Valley and will head back out next spring to the Cove Fort area in Utah and to Mount Baker in northern Washington. Drilling depths range from 500 feet to over 2,000 feet.

"The Gabbs Valley site, being the first Phase III project, has been completed and the data analyzed. I'll briefly highlight the process and the outcome. The first step was a shallow, push-probe survey, followed by six temperature-gradient holes drilled down to about 500 feet each. Results indicated the bottom-hole temperatures exceed 110°C, with gradients many times higher than the background temperatures in the area. Effectively this means two things. First, the heat model is accurate, and

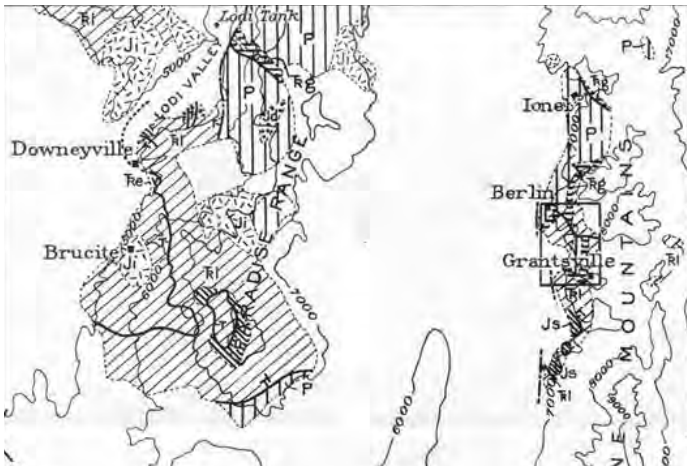
secondly, the thermal features targeted were successfully identified. These results are indicative of resource potential.

"We will look for more data as additional sites are completed and analyzed. In 2019, our PFA team will deliver a comprehensive assessment. PFA will feature active drilling in the first half of the fiscal year, with five of the eight designated sites yet to be drilled. We anticipate at least 11 new thermal holes, for a total of 20 holes at all eight sites. In 2019, we should have a thorough PFA analysis, with data-driven summaries outlining the case for additional research into resource availability at the respective sites."

An afternoon in Gabbs Valley, Nevada. *Watercolor by Susan Fox Hodgson*

**The PFA Field Trip—Who Came and Why?**

A fascinating, one-day field trip to Gabbs Valley, Nevada, was led by Dr. Jim Faulds, aided by several others, including graduate student Jason Craig, working with him on a PFA study of the valley. With funding by the DOE, Jim manages the Nevada PFA project that includes Gabbs Valley. He is also the Nevada State Geologist, with an office housed in the Nevada Bureau of Mines and Geology; and a professor at the University of Nevada, Reno. The field trip was offered by the GRC after the Annual Meeting held in Reno in October 2018. Jason Craig, who is writing his Master's thesis on the Gabbs Valley area, has been the primary synthesizer of all the geologic, geophysical, and geochemical data collected in the area.




Location of the Town of Gabbs, Nevada (labeled ***Brucite***). Gabbs Valley, extending west of Brucite, appears on both the Tonopah and Hawthorne Quadrangles (Muller and Ferguson).

"Work on the Nevada PFA project began in 2014," Jim said, "when southeastern Gabbs Valley was defined as promising place for a blind geothermal system, primarily based on the style of faulting in the area. This PFA project was funded by the DOE. No previous geothermal exploration had been conducted in the area.

"The initial, 2016 reconnaissance of the southeastern Gabbs Valley area found no surface evidence (*e.g.* sinter or travertine) for a geothermal system. However anomalously warm wells (32°C) were identified in the area, which prompted a more detailed reconnaissance, including a shallow (2-m depth) temperature survey. The survey showed a shallow-temperature anomaly (up to 5°C above background) up the hydrologic gradient from the warm wells.

"Based on these favorable attributes, the southeastern portion of Gabbs Valley was chosen for detailed analyses. Detailed geological, geochemical, and geophysical analyses defined a thermal anomaly (potentially with temperatures of 130-140°C) in the southeastern area of Gabbs Valley near an apparently major, subsurface, fault intersection. These favorable factors prompted even more detailed geophysical analyses in 2017, which facilitated selection of sites for temperature-gradient drilling.

"Drilling the temperature-gradient holes began in May 2018, and six holes were completed to a depth of 500 feet (152 m) in a month. Bottom-hole temperatures from two wells in the central part of the most promising area exceeded 114°C. At ~500 feet, the thermal anomaly is at least ~1.2 miles (2 km) long in a north-south extent and probably at least 0.6 miles (1 km) wide from east to west. Potential host rocks for a geothermal reservoir include highly fractured Triassic-Jurassic rocks, such as the *Gabbs Formation.*

"Now that this blind geothermal system has been discovered," Jim said, "it will be up to the geothermal industry to conduct additional drilling for possible development of a geothermal power plant." [The William M. Gabb Geothermal Power Plant? *S.H.*]

At the end of the trip, I asked Jim if he would consider using Artificial Intelligence in a PFA project. He said, perhaps. What would happen, I asked, if a normal PFA score differed from the Artificial Intelligence score? Which one would he choose? He said, "This would be very interesting, and we would compare results to see which seemed to be the best solution."

**The Interviews: Who Could Predict?**

On the way to Gabbs Valley, in the valley, and on the road back to Reno, I interviewed six of the 16 people on the field trip. I asked why they had come and how their own projects related to PFA and to the trip. Their responses follow. It wasn't possible to talk with everybody, but maybe next year…

**********

Greg, who works out of Ontario, Canada, said the field trip to Gabbs Valley helped drive home the significance of this "blind" discovery for future exploration. "There is absolutely no surface indication! Nothing!" he said.

**Gregory Shore, 3D E-SCAN Resistivity Mapping Specialist, Crone Geophysics & Exploration Ltd. (e-scan3d.com)**

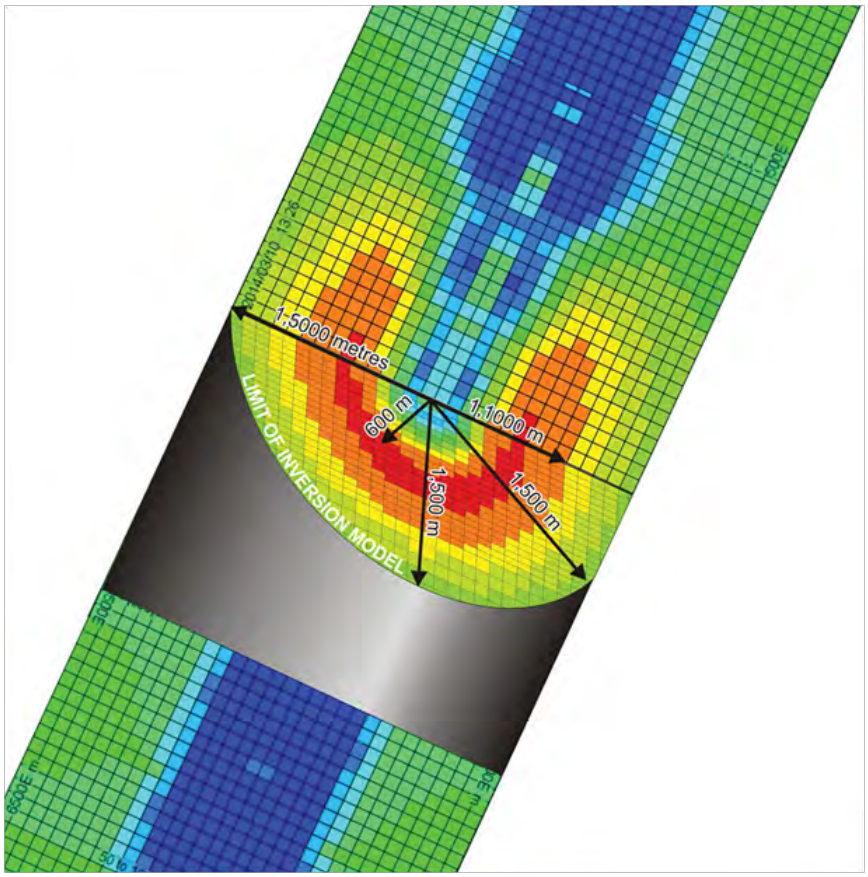
He told me that in a day and a half, you can get an indication of an anomalous conductive area by surveying in-line along a road—where permits might not be needed. This would detect zones of potentially system-indicative conductivity beneath or to either side of the road, which could then be followed up with survey cross lines to locate and constrain the anomaly boundaries in true 3D.

This information can give explorers a quick jump ahead as they look to compile multiple indicators of a possible resource in an otherwise unmarked (blind) setting (one perhaps chosen on the basis of PFA), thus helping to position the more expensive temperature-gradient drill testing.

He showed me the image, seen on the next page, of how an along-road resistivity traverse can sense the presence of a conductive (red) signature, like the one defined by MT soundings here at the blind discovery in Gabbs Valley, at more than a kilometer in any direction from the roadside survey line.

During a field trip stop in Gabbs Valley, the group listens as Jim describes the blind geothermal system beneath the valley floor while referring to an illustrative poster fastened to the side of his van. *Photos by S.F. Hodgson*


Plan view of a capped, temperature-gradient hole drilled by Jim Faulds and his team in Gabbs Valley.




to the identification and, hopefully, the development of additional geothermal systems." Andy enjoys the opportunities for networking at GRC Annual Meetings and learning what others are thinking and doing about geothermal systems."

**Jon Gunnerson, Geothermal Program Coordinator, City of Boise Public Works**

Jon is in charge of the geothermal district heating system in the City of Boise, Idaho, the largest direct-use system in the country.

Recently, the Mayor of Boise asked Jon what more could be done with the geothermal system. Jon came to the GRC meeting with this question in mind and has spent his time networking and looking for new geothermal ideas. Jon says he is surprised by the number of people he's met at the meeting who work with direct heating and cooling projects.

He said the Boise system includes four production wells, with only two in use, and an injection well with a large capacity.

**Andrew Sabin, Ph.D, PG, Navy Geothermal Program Office**

Andy works with the Navy Geothermal Program Office (GPO). Since 2015 when the Play Fairway Analysis (PFA) project was developed by the U.S. Department of Energy, he and his colleagues have been involved with PFA—providing data to some teams and conducting field work for the New Mexico PFA team. Today the GPO continues its decade-long collaboration with Dr. Jim Faulds and his colleagues on select Nevada projects. Andy said that Jim and his colleagues have advanced dramatically our understanding of geothermal systems in the Western U.S.

"A big part of exploration is pattern recognition, he told me. Participating in field trips like this one in Gabbs Valley helps me and others to understand the linkage and the patterns among geological structures, stratigraphy, and other factors leading

**Theron Finley, Geology Graduate Student, University of Alberta**

Theron came to the GRC Annual Meeting and on the field trip to further understand geothermal systems and learn about PFA. He plans to use the information while working in the southeastern part of British Columbia in Canada. According to the *Encyclopedia Britannica,* mountains in this region parallel the Canadian Rockies for about 370 miles and include four distinct ranges: the Cariboo, Monashee, Selkirk, and Purcell, each rising to over 10,000 feet. Theron said that Canada has about 140 hot springs.

**Tiffani Fraser, Project Geologist, Yukon Energy Mines and Resources**

Tiffani works in White Horse, Canada. She told me she works on temperature studies to define geothermal potential in the Yukon. The project is in the early stages, but the Canadian North relies heavily on diesel for space heating and power. Although where she lives, the power is mainly from hydro, she said, "We need alternatives to diesel for space-heating."

Tiffani wants to learn if the area has warm temperatures. She believes several geologic features suggest these temperatures might exist, especially in the Yukon.

**Peter Martin Meier, CEO, Geo-Energie Suisse AG**

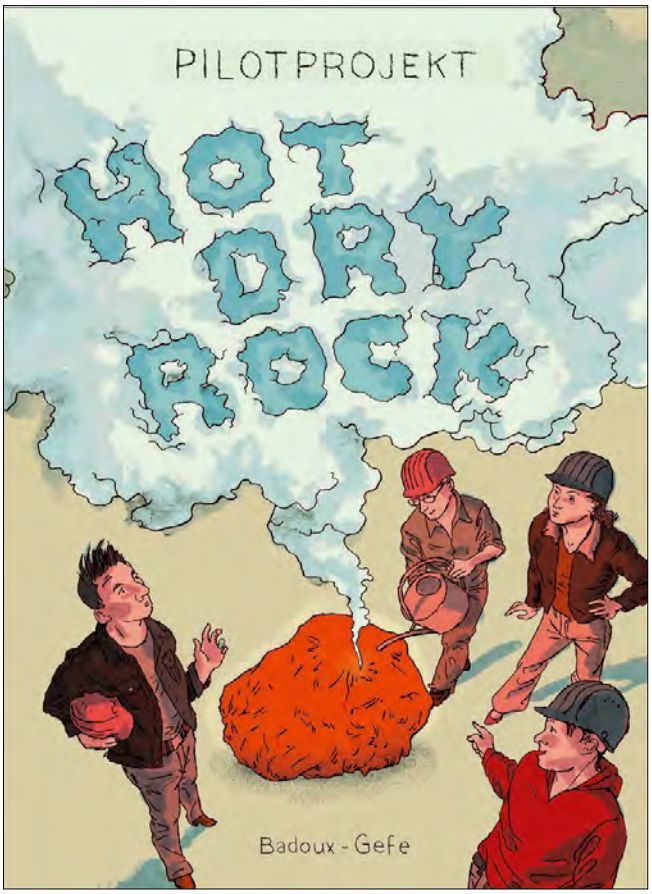
Peter said PFA is a very structured program but one adaptable for studying different types of hydrothermal systems, including the roles of faults. A site may have different geological details but the PFA methodology is easily convertible, although how the PFA elements are weighted will change, depending on the situation.

He noted that in Switzerland, a new energy law went into effect in 2018 that covers up to 60 percent of geothermal exploratory costs: there are government subsidies of up to 60 percent for borehole and well testing activities. "This is amazing but necessary," he said, adding that the country has a good feed-in tariff for power: $.54 Swiss/kWh.

In the last 10 years, immigration has increased the population of Switzerland by several hundred thousand people—and increased the country's need for electricity. Today about 60 percent of the country's electricity comes from hydro and 40 percent from nuclear energy. About 3,000 MW of nuclear power is generated in Switzerland and more is purchased from France.

Switzerland wants to phase out its use of nuclear power and replace it with renewable energy resources. Wind is not a good option for the country and solar generation is limited by the number of sunny days. Geothermal power produces energy around the clock, an important fact that makes it attractive to the Swiss Government.

Peter said a few Swiss spas use geothermal waters, and there are, perhaps, 10 places in the country with natural hot springs.




On the Geo-Energie Suisse website, I found mention of a comic book titled, *Hot Dry Rock*. The comic, available in either German or French, may be ordered at no charge from the website: www.geo-energie.ch/. The attractive cover is reprinted here.

**Selected References & Comments**

Brewer, W.H., 1865, *Up and Down California in 1860 – 1864: The Journal of William H. Brewer.* The 2003 edition (the 4th), edited by Francis P. Faquhar with a *Forward* by William Bright, includes 30 illustrations and four maps and is published by the University of California Press. William H. Brewer

(*see* prior photo) was the botanist hired by Josiah Whitney for the California State Geological Survey. In his journal, Brewer recounts the many journeys he and the others made exploring California and Nevada, including the hot spring areas.

Dall, W.H., *Biographical Memoir of William More Gabb, 1839 – 1878,* published by the National Academy Biographical Memoirs, Vol. VI. (Mr. Dall himself read the biographical memoir to members of the National Academy of Sciences on November 18, 1908. The complete text is available on the Internet.)

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Gabb, W.M., 1864, *Triassic and Cretaceous Fossils,* Palaeontology, Vol. 1, Published under the Authority of the Legislature of California by the Caxton Press of Sherman & Co., Philadelphia.

Many editions are available of *Palaeontology*, both Volumes I and II. Volume I is available online at: http://www.archive.org/details/cu31924003871153. Volume II is available online at: http://www.archive.org/details/cu31924003871161.

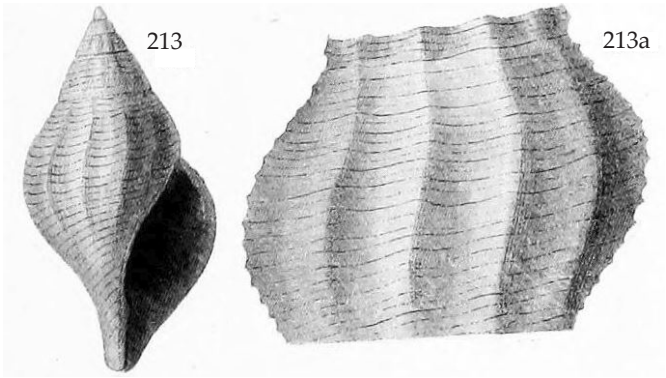



Figure 213: Fasciolaria Sinuata. Figure 213a.: Magnified view of body volution.

The fossil was collected, identified, and sketched by W. M. Gabb.

Muller, S.W.M., and Ferguson, H.G., 1939, *Map Showing Distribution of Pre-Tertiary Formations of the Hawthorne and Tonopah Quadrangles,* Vol. 60, Plate 1, published by the Geological Society of America.

**Acknowledgments**

A large thank you to everyone who talked to me about PFA: what it is, what it means, what it does.

I am grateful for the geological aid and comments of Dr. James Faulds and for the help of Lee Wallinder, California Geological Survey librarian. ■

# Publications, Websites, Videos & Maps

by Ian Crawford

## Renewables 2018 (International Energy Agency)

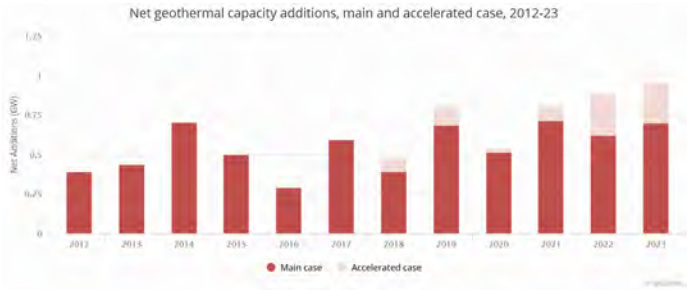
A report by the **International Energy Agency (IEA)** estimates that geothermal capacity is set to **grow 28% to over 17 GW by 2023.**

Renewables will continue their expansion in the next five years, covering 40% of global energy consumption growth, according to IEA's Renewables 2018 market analysis and forecast report. Their use continues to increase most rapidly in the electricity sector, and will account for almost a third of total world electricity generation in 2023. Because of weaker policy support and additional barriers to deployment, renewables use expands far more slowly in the transport and heat sectors.

**Geothermal capacity is set to grow 28%, or 4 GW, to reach just over 17 GW by 2023** as projects in nearly 30 countries come online. 70% of this growth is in developing countries and emerging economies. **The Asia-Pacific region (excluding China) has the largest growth**, at 2 GW, over the forecast period. **Indonesia's expansion is the strongest**, propelled by abundant geothermal resource availability and a strong project pipeline in the construction phase supported by government policies. **Kenya, the Philippines**, and **Turkey** follow, responsible for 30% of additions.

Although pre-development risks are still an important barrier to securing financing for geothermal projects, exploration and **construction of facilities in Latin American and Caribbean countries is expected to take off** because geothermal technology generates stable, $CO_2$ emissions-free baseload power.

Geothermal could grow by an additional 20%, or 900 MW, provided faster commissioning of the projects, mainly in emerging economies. Indonesia could deliver half of the potential growth while Kenya could add an estimated 180 MW as both countries advance in exploitation of their vast geothermal resources. China, Philippines and Turkey each could add around 70 MW of additional geothermal capacity while smaller additions could be seen coming online in Ethiopia and France. More information and download the report.....




*The IEA forecasts that more than 500 MW geothermal capacity will be added worldwide each year in the foreseeable future.*

## GEOCAP Contribution to the Geothermal development of Indonesia (GEOCAP)

The *GEOCAP Handbook for Geothermal Development* describes the GEOCAP bilateral program between Indonesia and the Netherlands that has been running since 2013 as a public-private partnership involving universities, knowledge institutes and companies from both countries.

The prime objective of GEOCAP was to contribute to the development and uptake of geothermal resources in Indonesia particularly in the new to be developed areas outside of Java. Download the handbook.....

## Nunavut Geothermal Feasibility Study (RESPEC)

**Nunavut** is largest and northernmost territory of **Canada** with population of 38,456 spread out over 25 isolated communities. **Qulliq Energy Corporation (QEC)** owns and operates diesel-powered generating stations to supply electricity for Nunavut communities. QEC funded a geothermal feasibility study, which was performed by **RESPEC, Qikiqtaaluk Business Development Corp.** and **Tuya Terra Geo Corp.**

The *Nunavut Geothermal Feasibility Study* is the first phase in identifying potential geothermal resources to help offset the use of diesel for electricity & heat in the isolated communities of Nunavut. The objectives of this study were to gather existing data, identify data gaps, and conduct a geothermal resource assessment based on the existing data. The framework, methodology, and deliverables of the assessment are designed

**GEOTHERMAL PROJECTS IN BIDDING STAGE (785 MW)**
1. Seulawah (2x55 MW)
2. Pusuk Bukit (2x55 MW)
3. Sipoholon (1x20 MW)
4. Bonjol (60 MW)
5. Way Ratai (1x55 MW)
6. Danau Ranau (2x55 MW)
7. G. Endut (1x40 MW)
8. G. Ceremai (2x55 MW)
9. Umbul Telomoyo (1x55 MW)
10. Sembalun (1x20 MW)
11. Mataloko (20 MW)
12. Merana/Masaingi (2x10 MW)
13. Songa Wayaua (1x5 MW)
14. Bora Pulu (40 MW)
15. Oka Ile Ange (10 MW)

**PPA DISCUSSION/ RENEGOTIATION (438 MW)**
1. S. Sekincau (158 MW) COD 2024
2. W. Windu (2x110 MW) COD 2020
3. Hu'u (2x10 MW) COD 2024
4. Jailolo (40 MW) COD 2021/22/23

**PROPOSAL/STUDY (345 MW)**
1. Karaha 2 & 3 (110 MW) COD 2020
2. T. Perahu (60 MW) COD 2020
3. Iyang Argopuro (1x55 MW) COD 2021
4. Sarulla II(110 MW) COD 2024
5. Bedugul (1x10 MW)

**EXPLORATION (745 MW)**
1. Muara Laboh (220 MW) COD 2017 & 2024
2. Rantau Dadap (220 MW) COD 2019 & 2020
3. Sungai Penuh (110 MW) COD 2024
4. Hululais (110 MW) COD 2019 & 2020
5. Ulumbu (5 MW) COD 2019 & 2021
6. Kota Mobagu (80 MW)

**PPA SIGNED/PREPARATION FOR EXPLORATION (1425 MW)**
1. Rajabasa (220 MW) COD 2023 & 2024
2. Ungaran (1x55 MW) COD 2021
3. Ijen (2x55 MW) COD 2020
4. Atadei (1x5 MW) COD 2019
5. Jaboi (2x5 MW) COD 2019 & 2020
6. Sorik Merapi (3x60 MW) COD 2021 & 2022
7. C. Cisukarame (1x50 MW) COD 2020
8. Rawa Dano (1x110 MW) COD 2020
9. T. Perahu I (110 MW) COD 2020
10. Tampomas (1x45 MW) COD 2020
11. Guci (1x55) COD 2021
12. Batu Raden (2x110 MW) COD 2021 & 2023
13. Telaga Ngebel (3x55 MW) COD 2020 & 2021
14. Sokoria (6x5 MW) COD 2020, 2021, 2022, 2013

**READY FOR EXPLOITATION/ Fin. CLOSED (365 MW)**
1. Patuha (110 MW) COD 2019
2. Cibuni (10 MW) COD 2020
3. Lumut Balai 3 & 4 (110 MW) COD 2024
4. Tulehu (20 MW) COD 2018 & 2019
5. Dieng 2 & 3 (115 MW) COD 2019

**CONSTRUCTION STAGE (620 MW)**
1. Sarulla I (330 MW) COD 2017 & 2018
2. Ulubelu 3 & 4 (110 MW) COD 2016 & 2017
3. Lumut Balai 1 & 2 (110 MW) COD 2017 & 2019
4. Karaha Bodas (30 MW) COD 2016
5. Lahendong 5 & 6 (40 MW) COD 2017 & 2018

**PRODUCTION STAGE (1430,5 MW)**
1. Sibayak (12 MW)
2. Kamojang (240 MW)
3. Wayang Windu (220 MW)
4. Gn. Salak (360 MW)
5. Darajat (255 MW)
6. Dieng (60 MW)
7. Ulumbu (10 MW)
8. Mataloko (1,5 MW)
9. Lahendong (80 MW)
10. Ulubelu 1 & 2 (110 MW)
11. Patuha (55 MW)

Figure 21 Geothermal resources in Indonesia

**From the GEOCAP Handbook**

around the reporting guidelines that were set by the **Canadian Geothermal Energy Association (CanGEA)** for the Canadian National Geothermal Database (CNGD) [Canadian Geothermal Code Committee, 2010]. Download the report.....

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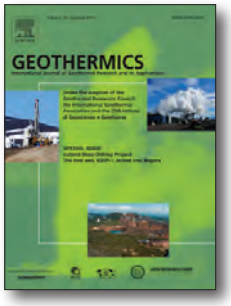
## Geothermics




In affiliation with the **International Geothermal Association (IGA)** the GRC offers a discount to the professional journal *Geothermics*, which publishes articles on the theory, exploration techniques and all aspects of utilizing geothermal resources.

For the year 2018 the subscription rate to a combined print and electronic subscription to the Journal is USD 133 for individual members and USD 305 for corporate/ institutional members. Please note that the member subscription rate does not include any sales or similar taxes required by law, which may be billed by the Elsevier as appropriate.

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# In Memoriam

## Robert E. Tucker
## 1953 - 2018

Bob began working in the geothermal power industry when he joined Stone & Webster (S&W) Engineering in Denver in 1979 and has been a member of the GRC during those 39 years. Bob led the Heat Balance & Studies Group at S&W and went on to become an executive at Westec, then the VP of Power Generation at both Geothermal Resources International, and Caithness Energy, where he led groups in geothermal power engineering, development, financing, and operations for both US and international projects.

Bob co-founded Global Power Solutions in Colorado in 2000, providing management consulting, due diligence reviews, financial advice, and other guidance for geothermal projects. Bob contributed to projects around the world in all of the major resource areas; he thoroughly enjoyed traveling to project sites in the most remote locations

In 2015, Bob was awarded GRC's Ben Holt Award for lifetime achievement and innovation in geothermal power plant and process design. He was known in the industry for his enthusiasm for the geothermal industry and his positive and creative solutions to geothermal problems. Whether the issues were financial or technical, he was excellent at explaining it to others. He combined these qualities to provide excellent high-level observations that cut to the most important issues and enabled him to provide creative solutions for project issues. Many in the geothermal power industry, from plant design to project finance to resource development, can point to Bob as a mentor and a positive influence.

Bob had varied interests. He was an excellent guitarist, collected acoustic guitars and fountain pens, a committed father, grandfather and husband, loved all things purple, and contributed much of his time and energy to Bergen Park Church. He was very active in his church, as an Elder, leader, and musician. He also loved to travel and help others in many ways. He especially enjoyed teaching, which he did in many settings, including several universities. Through his geothermal consulting, teaching, the church, and friendships, Bob shared his enthusiasm for many things in life, while helping many people along the way. The geothermal industry was fortunate that geothermal development was one of his passions.

Bob Tucker passed away surrounded by his family at CU Anshutz Medical Center on November 14, following cardiac complications. He is survived by Terri, his wife of 43 years, and sons Dr. Paul Tucker and Dr. Mark Tucker, both very accomplished in their fields, and three grandchildren. He will be profoundly missed by those who had the opportunity to meet and work with Bob. *(Thanks to Gary McKay with help from Jill Haizlip and Michael Moore).* ■


*Bob Tucker (left) was awarded GRC's Ben Holt Award in 2015. Then GRC President Paul Brophy (right) made the presentation.*

# Calendar of Events

**GeoEnergi 2019 (Norwegian Centre for Geothermal Energy Research)**
**4-5 February 2019, Bergen, Norway**
http://cger.no/index.cfm?id=442606

**GT'2019 - Geothermal Turkey Congress**
**6-7 February 2019, Ankara, Turkey**
https://geothermalturkey.org/

**Stanford Geothermal Workshop**
**11-13 February 2019, Stanford, California, USA**
https://geothermal.stanford.edu/events/workshop

**GeoTHERM - Expo & Congress**
**14-15 February 2019, Offenburg, Germany**
www.geotherm-germany.com/

**10th European Geothermal PhD Day**
**25-27 February 2019, Potsdam, Germany**
www.geothermalresearch.eu/egpd-2019/

**DAP Symposium 2019 (TU Delft)**
**Urban Heating: Risks & Rewards - Integrating cities with geothermal energy**
**12 March 2019, Delft, Netherlands**
www.dapsymposium.nl/

**IGC Invest Geothermal**
**28 March 2019, Frankfurt am Main, Germany**
http://www.investgeothermal.com/

**8th ITB International Geothermal Workshop 2019**
**20-21 March 2019, Institut Teknologi Bandung, Bandung, Indonesia**
http://geothermal.itb.ac.id/

**AAPG 3rd Hydrocarbon – Geothermal Cross Over Technology Workshop**
**9-10 April 2019, Geneva, Switzerland**
www.aapg.org/

**EAGE/DGMK Joint Workshop on Deep Geothermal Energy - Underground Storage of Hydrogen**
**24 April, 2019, Celle, Germany**
https://events.eage.org/en/2019/eage-dgmk-joint-workshop-on-deep-geothermal-energy

**IGC Islands Geothermal Conference**
**15-16 May 2019, Terceira Island, Azores, Portugal**
www.igc-islands.com/

**EAGE Annual Conference & Exhibition 2019**
**3-6 June 2019, London, UK**
https://events.eage.org/2019/eage-annual-2019

**European Geothermal Congress 2019 (EGEC)**
**11-14 June 2019, The Hague, Netherlands**
http://europeangeothermalcongress.eu/

**43rd GRC Annual Meeting & Expo**
**15-18 September 2019, Palm Springs, California, USA**
www.geothermal.org/meet-new.html

**World Geothermal Congress 2020**
**27 April - 1 May 2020, Reykjavik, Iceland**
www.wgc2020.com/

**44th GRC Annual Meeting & Expo**
**18-21 October 2020, Reno, Nevada, USA**
www.geothermal.org/meet-new.html ■

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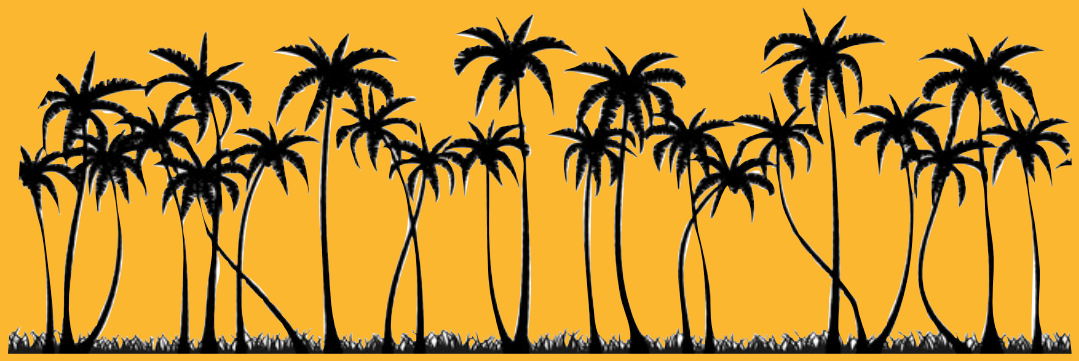

# PALM SPRINGS

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## PALM SPRINGS, CALIFORNIA

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