WATER AND GEOTHERMAL POWER: UNEARTHING THE NEXT WAVE OF ENERGY INNOVATION

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTEENTH CONGRESS

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C O N T E N T S

November 14, 2019

Appendix II: Additional Material for the Record

WATER AND GEOTHERMAL POWER: UNEARTHING THE NEXT WAVE OF ENERGY INNOVATION

THURSDAY, NOVEMBER 14, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 2:14 p.m., in room 2318 of the Rayburn House Office Building, Hon. Conor Lamb [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation
Thursday, November 14, 2019
2:00 PM EST
2318 Rayburn House Office Building, Washington, D.C. 20015

PURPOSE

The primary purpose of this hearing is to examine research and development needs in the geothermal energy and water power industries. The hearing will focus on two draft bills: 1) the Geothermal Energy Research and Development Act of 2019, to support research, development, and demonstration activities in geothermal energy production including enhanced geothermal technologies; and 2) the Water Power Research and Development Act of 2019, which authorizes a research, development, and demonstration program for water power technologies including hydropower, pumped storage, and marine energy technologies.

WITNESSES

- **Dr. David Solan,** Deputy Assistant Secretary for Renewable Power, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy
- **Dr. Bryson Robertson,** Co-Director, Pacific Marine Energy Center, Associate Professor, Civil and Construction Engineering, Oregon State University
- **Dr. Joseph Moore,** Manager, Utah Frontier Observatory for Research in Geothermal Energy (FORGE), Research Professor, University of Utah
- **Ms. Maria Richards,** Director, Geothermal Laboratory, Roy M. Huffington Department of Earth Sciences, Southern Methodist University
- **Mr. Sander Cohan,** Director, Innovation, Enel Green Power North America, Inc.

BACKGROUND

Department of Energy, Geothermal Technologies Office (GTO)

The DOE Geothermal Technologies Office (GTO) supports research to develop new technologies and methods to produce energy from the earth's heat. Geothermal energy production yields far lower greenhouse gas emissions when compared to emissions from conventional fossil fuel use without carbon capture, and its development typically has a relatively small environmental footprint. It is reliable and can be deployed flexibly. Geothermal energy also can be used to meet various heating and cooling demands for buildings. According to the Department of Energy, improvements in geothermal technology could lead to a nearly 26-fold increase in geothermal electric power generation, reaching 60 gigawatts of installed capacity by 2050.[1] Currently, the installed capacity of geothermal energy is around 4 gigawatts.[2]

Research supported by GTO focuses on developing technology and tools to locate and access geothermal resources in the U.S. Research and development activities focus on enhanced geothermal research, hydrothermal resources, low temperature and coproduced resources, and geothermal systems analysis.[3] Enhanced geothermal technologies create permeable pathways enhanced by fluid injected from the surface, which greatly increases the amount of energy generated by allowing the fluid to reach the heat deeper in the Earth's crust. Additionally, developing methods and technologies for locating undiscovered hydrothermal resources could account for up to 30 gigawatts on the grid, according to the U.S. Geological Survey.[4] Once sources for geothermal energy are located, the potential electricity generated from these sources could be brought online quickly with existing technology. Low-temperature geothermal energy is most useful in direct-use applications, such as heating and cooling buildings, and in some cases to generate electricity. The hot geothermal fluid produced as a by-product from oil and gas drilling can be used in these low-temperature applications. The geothermal systems analysis program within GTO focuses on researching environmental issues, policy, regulation, and other data analyses.[5]

In 2014, DOE GTO announced a funding opportunity for an initiative entitled the Frontier Observatory for Research in Geothermal Energy (FORGE), which is envisioned as a dedicated site to demonstrate enhanced geothermal system technologies and techniques. GTO downselected the site to Milford, UT from an initial pool of five potential sites. The FORGE site will be used to demonstrate operational technologies to produce geothermal energy, and to develop and test instrumentation and serve as a data clearinghouse for the industry.

Department of Energy, Water Power Technologies Office (WPTO)

The DOE Water Power Technologies Office (WPTO) supports research on water power technologies, which includes marine energy and next generation hydropower and pumped storage systems. Water power generation also produces relatively few greenhouse gas emissions.

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[1] GeoVision, U.S. Department of Energy, https://www.energy.gov/eere/geothermal/geovision
[2] State of the Geothermal Industry, 2019, Will Pettitt, Geothermal Resources Council, https://geothermal.org/PDFs/Pettitt_GRC_State_of_Geothermal_Industry_2019.pdf
[3] About the Geothermal Technologies Office, U.S. Department of Energy, https://www.energy.gov/eere/geothermal/about
[4] A Roadmap for Strategic Development of Geothermal Exploration Technologies, Benjamin R. Phillips, John Ziagos, Hildigunnur Thorsteinsson, and Eric Hass, https://www1.eere.energy.gov/geothermal/pdfs/exploration_technical_roadmap2013.pdf
[5] Systems Analysis, U.S. Department of Energy, https://www.energy.gov/eere/geothermal/systems-analysis

According to a report produced by DOE, through innovative research and development in hydropower technologies, the U.S. hydropower capacity could increase to 150 gigawatts by 2050. U.S. hydropower capacity is currently a little over 100 GW. [6] Hydropower can also pair with other variable clean energy sources to flexibly deploy electricity by using pumped storage technologies. The Hydropower and Water Innovation for a Resilient Electricity System (HydroWIRES) initiative at the WPTO focuses hydropower and pumped storage research and development on how these resources can best be used as a tool for the U.S.'s future electric grid.[7]

The use of marine energy technologies is growing the electricity market, especially in the Southeast and Northwest. Marine energy is inclusive of power generated from waves, tides, and currents not only in the ocean but in rivers, lakes, and streams, among other sources. The Powering the Blue Economy initiative at the WPTO explores how investment in marine energy technology development can improve other areas of coastal and maritime markets, or the "blue economy": ocean observation, underwater vehicle charging, marine aquaculture, marine algae, seawater mining, seawater desalination, coastal resiliency and disaster recovery, and isolated communities.[8] Much of the research and development in marine energy technologies occurs at the National Marine Energy Centers, which are hosted at institutions of higher education or consortia thereof and funded by both government and private industry. The National Marine Energy Centers are not only used to demonstrate the energy generating technology themselves, but also to develop and test instrumentation and technologies capable of monitoring and mitigating environmental impacts of marine energy technology.

<u>LEGISLATION</u>

Draft Geothermal Energy Research and Development Act of 2019

The Geothermal Energy Research and Development Act of 2019 would reauthorize activities of the DOE's Geothermal Technologies Office. It includes research initiatives on oil and gas technology transfer to geothermal research, secondary use research areas such as minerals recovery, desalination, industrial applications of geothermal energy, grid management and storage, and new areas of enhanced geothermal research.

It would also authorize two FORGE sites, including the existing project in Utah, in addition to authorizing an enhanced geothermal demonstration initiative.

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[6] Hydropower Vision Report, National Hydropower Association, https://www.hydropowervision.org/
[7] HydroWIRES Initiative, U.S. Department of Energy, https://www.energy.gov/eere/water/hydrowires-initiative
[8] Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets, U.S. Department of Energy, https://www.energy.gov/eere/water/powering-blue-economy-exploring-opportunities-marine-renewable-energy-maritime-markets

Draft Water Power Research and Development Act of 2019

The Water Power Research and Development Act of 2019 directs the Secretary of Energy to carry out a research, development, demonstration and commercialization program for water power technologies, which is inclusive of hydropower, pumped storage, and marine energy technologies. The bill outlines activities for a hydropower and pumped storage program and, separately, a marine energy program. The bill also provides for authorization of existing or new National Marine Energy Centers.

The bill requires the Secretary to collaborate with industry, National Laboratories, other relevant Federal agencies, institutions of higher education, and international bodies with relevant scientific expertise. It requires the results of projects supported by the Act to be publicly published to the extent practicable. It also supports education and outreach activities to promote understanding of water power technologies and the water power workforce. The bill encourages the Secretary to conduct technical assistance and workforce development activities.

Finally, the bill instructs the Secretary to create a strategic plan that addresses near and long-term planning for these programs, and also to provide a report to Congress at least every two years on the findings of research conducted and activities carried out under these programs and pursuant to the Strategic Plan.

Chairman LAMB. All right, good afternoon. This hearing will come to order. Without objection, the Chair is authorized to declare a recess at any time. Good afternoon. Welcome to today's hearing entitled, "Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation." Thank you to this distinguished panel of witnesses for joining us. Today we'll be holding another hearing on clean energy technology research and development. I believe this will be our eighth hearing this Subcommittee in the 116th Congress to help us focus our scientific research priorities, create major new job opportunities, and address and mitigate the impacts of climate change. Today's hearing focuses on two draft bills that would support critical research activity to provide cleaner energy by using geothermal energy and water power technologies.

The Earth contains vast amounts of heat just under its surface, which can be tapped and turned into electricity. Today, just 0.4 percent of total U.S. utility scale electricity generation is produced by geothermal power plants. The Department of Energy (DOE) Geothermal Technologies Office (GTO) has programs focused on conventional geothermal energy production, from hydrothermal resources, such as geysers, as well as research focused on enhanced geothermal systems (EGS) research, which could help us access the higher temperatures deeper underground. This has the potential to increase geothermal electric power generation to 60 gigawatts of installed capacity by 2050, up by about four gigawatts today. This potential is why it's important for us to focus on R&D (research and development) in this promising area.

The draft *Geothermal Energy Research and Development Act of 2019* would reauthorize the activities of the DOE Geothermal Technologies Office. In addition to laying out focus areas for both conventional and enhanced geothermal systems, this legislation would instruct the Secretary to establish a demonstration initiative for advanced geothermal energy systems. And we have heard from many witnesses in many areas all year about the importance of doing not only the fundamental research, but also the demonstration-scale research for these technologies, and we'll be looking to hear from you all about that today as well.

At least one of the demonstration projects in this initiative must be located in the eastern United States, which currently has no such facility, and, finally, the bill would authorize two frontier observatories for research and geothermal energy, or FORGE, sites, including the site DOE selected in Milford, Utah. Today we will hear from Dr. Joseph Moore, who is the project manager at that site.

Another clean energy technology we will be discussing today is water power, which includes conventional hydro, pumped storage, and marine energy technologies. Around 7 percent of total U.S. utility-scale electricity generation is produced by conventional hydropower. Pairing this technology with pumped storage systems allows energy produced by hydropower plants to be deployed to the grid flexibly.

Marine energy, which includes wave, tidal, and current power, is another water power technology that has great potential. DOE's Powering the Blue Economy initiative highlights the importance of each maritime industry to the success of other such industries. Investing in this technology can help improve other areas of coastal and maritime markets, such as underwater vehicle charging and aquaculture. Given the overlap and independence between these industries, it makes sense to address the blue economy as a whole.

The Water Power Technologies Office (WPTO) at DOE can do just that, and support research across a wide range of technologies, so the draft *Water Power Research and Development Act of 2019* emphasizes key R&D focus areas and supports, again, important technology demonstration activities. It also authorizes existing and new national marine energy centers, which are testing sites for marine energy technologies hosted by academic institutions, and funded by both government and private industry. We are lucky today to have Dr. Bryson Robertson, Co-Director of the Pacific Marine Energy Center, to tell us about the important research done at these centers.

I want to thank our panel of witnesses for coming all the way here today, and I look forward to hearing your input and feedback on these important topics, and especially on our draft pieces of legislation.

[The prepared statement of Chairman Lamb follows:]

Good afternoon and thank you to this distinguished panel of witnesses for joining us today. This afternoon we'll be holding another hearing on clean energy technology research and development. I believe this will be our eighth hearing this Subcommittee has held this Congress to help us focus our scientific research priorities, create major new job opportunities, and address and mitigate the growing impacts of climate change. Today's hearing focuses on two draft bills that would support critical research activities to provide cleaner electricity by utilizing geothermal energy and water power technologies.

The Earth contains vast amounts of heat just under its surface, which can be tapped and turned into electricity. Today, just 0.4% of total U.S. utility-scale electricity generation is produced by geothermal power plants. The Department of Energy Geothermal Technologies Office has programs focused on conventional geothermal energy production from hydrothermal resources, such as geysers, as well as research focused on enhanced geothermal systems research, which could help us access the higher temperatures deeper underground. This has the potential to increase geothermal electric power generation to 60 gigawatts of installed capacity by 2050, up from about 4 gigawatts today. This growth potential is why it is important for us to focus research and development on this promising clean energy technology.

The draft *Geothermal Energy Research and Development Act of 2019* would reauthorize the activities of the DOE Geothermal Technologies Office. In addition to laying out focus areas for both conventional and enhanced geothermal energy systems, this legislation also instructs the Secretary to establish a demonstration initiative for enhanced geothermal energy systems. At least one of the demonstration projects in this initiative must be located in the Eastern U.S., which currently has no such facility. Finally, the bill would authorize two Frontier Observatory for Research in Geothermal Energy, or FORGE sites, including the site DOE selected in Milford, Utah. Today we will hear from Dr. Joseph Moore, who is the project manager at this site. The FORGE initiative is crucial for demonstrating and testing geothermal technologies.

Another clean energy technology we will be discussing today is water power technologies, which include conventional hydropower, pumped storage, and marine energy technologies. Around 7% of total U.S. utility-scale electricity generation is produced by conventional hydropower. Pairing this technology with pumped storage systems allows energy produced by hydropower plants to be deployed to the grid flexibly.

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The Water Power Technologies Office at DOE supports research across a wide range of technologies. The draft *Water Power Research and Development Act of 2019* emphasizes key R&D focus areas and supports important technology demonstration activities. It also authorizes existing and new National Marine Energy Centers, which are testing sites for marine energy technologies hosted by academic institutions and funded by both government and private industry. Today we are lucky to have Dr. Bryson Robertson, co-director of the Pacific Marine Energy Center, testify about the important research done at these Centers.

I thank our panel of witnesses again for being here today and I look forward to their input and feedback on these important topics and this draft legislation.

Chairman LAMB. The Chair now recognizes the Ranking Member, Mr. Weber, for an opening statement.

Mr. WEBER. Thank you, Chairman Lamb, for holding today's Subcommittee hearing. Looking forward also to hearing from our witnesses about the state of water and geothermal power technologies in the U.S., and about the Department of Energy's innovative clean energy R&D activities in these areas.

Water and geothermal power R&D is funded through the Department's Office of Energy Efficiency and Renewable Energy, or EERE, and as we discuss yet another applied energy program this afternoon, it is important to remind ourselves that EERE is, by far, the Department of Energy's largest applied research program. At almost $2.4 billion, with a B, in annual funding, EERE receives more funding than the R&D budgets for research in fossil energy, in nuclear energy, electricity, and cybersecurity combined.

Since DOE's Water Power Technologies Office, WPTO, and Geothermal Technologies Office, GTO, are both housed under this very well-funded program, I'm kind of again surprised to see my colleagues on the other side of this aisle propose legislation to grow these offices even more without proposing the funding offsets. As written, the *Water Power Research and Development Act* would increase spending on EERE's water power technologies activities by nearly 60, that's 6–0, percent by Fiscal Year 2024. Similarly, the *Geothermal Energy Research and Development Act* would increase annual spending on EERE's geothermal technology activities to 150 million, with an M, dollars, which is nearly 70 percent higher than the House passed 2020 appropriations level. It would also provide $150 million for this program each year through 2024.

Once again, I do want to be clear, I'm supportive of DOE funding for innovative research in advanced renewable energy sources, and I believe that these technologies play a vital role in our country's path forward to a clean energy future. This is why I'm also supportive of basic research, the kind that the energy industry cannot conduct, like research in advanced computing, machine learning, and the development of new materials. This discovery science lays the foundation for the next technology breakthrough, and can only be supported by the Federal Government. This will require sustained Federal investment in the construction of critical research facilities, and infrastructure across the country, particularly in our world-leading National laboratories, and in our universities. By providing American researchers with the tools to perform that cutting-edge research, we can accelerate the development of a diversity of advanced energy technologies. These are the kind of investments we see prioritized in my friend Ranking Member Lucas' bill, the *Advanced Geothermal Research and Technology Act of 2019*.

I'm also particularly pleased to see investments in a geothermal advanced computing and data science program, and critical support for GTO's innovative experimental user facility included in this legislation. Best of all, it prioritizes these areas responsibly, without significant increases in new spending.

So I'm looking forward to considering this bill, Mr. Chairman, and hearing about the research it would prioritize today. So, in closing, let me say—I feel like I keep repeating myself. I hope that moving forward we can focus on prioritizing investments in fundamental research that we all agree are necessary to develop new energy technologies. And, with that, Mr. Chairman, thank you again for holding the hearing. I yield back.

[The prepared statement of Mr. Weber follows:]

Thank you, Chairman Lamb for holding today's subcommittee hearing. I'm looking forward to hearing from our witnesses about the state of water and geothermal power technologies in the U.S., and about the Department of Energy's innovative clean energy R&D activities in these areas.

Water and geothermal power R&D is funded through the Department's Office of Energy Efficiency and Renewable Energy (EERE).

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As written, the *Water Power Research and Development Act* would increase spending on EERE's Water Power Technologies activities by nearly 60 percent by fiscal year 2024.

Similarly, the *Geothermal Energy Research and Development Act* would increase annual spending on EERE's Geothermal Technologies activities to $150 million - nearly 70 percent higher than the House-passed 2020 Appropriations level. It would also provide $150 million for this program each year through 2024.

Once again, I want to be clear - I'm supportive of DOE funding for innovative research in advanced renewable energy sources.

And I believe that these technologies play a vital role in our country's path forward to a clean energy future.

This is why I'm also supportive of basic research - the kind that the energy industry cannot conduct - like research in advanced computing, machine learning and the development of new materials. This discovery science lays the foundation for the next technology breakthrough and it can only be supported by the Federal government.

This requires sustained Federal investment in the construction of critical research facilities and infrastructure across the country, particularly at our world-leading National laboratories and universities.

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So in closing - and I feel like I keep repeating myself - I hope that moving forward, we can focus on prioritizing investments in fundamental research that we all agree are necessary to develop new energy technologies.

Chairman LAMB. If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Good afternoon and thank you, Chairman Lamb, for holding this timely hearing on two very important renewable energy resources, water and geothermal power.

Water and geothermal power are some of this country's and the world's oldest forms of energy. The United States has harnessed hydropower for decades and Americans have used various forms of geothermal energy since the 1800s.

Despite this long history, many water and geothermal energy technologies have struggled to become or remain competitive in modern energy markets, yet both still possess huge potential for further advancement and commercialization.

The Department of Energy's recent GeoVision report found that with technology improvements, geothermal electricity generation could increase 26-fold by 2050. The same study found that my home state of Texas, as well as most other states, have significant opportunities to expand their use of one or more geothermal energy technologies. New approaches could also apply geothermal energy to industrial activities, such as through heat production for manufacturing processes or critical mineral extraction, including the production of lithium, which is often needed for advanced batteries.

As for water power, pumped hydropower systems are considered a leading candidate to provide the large-scale, long-term energy storage that our electric grid will need as more renewables enter the electricity mix. Further, marine energy, which includes energy generated from waves, tides, and currents, has significant potential to power remote operations, and the U.S. Navy and others are already testing specific projects.

With these opportunities for energy innovation comes a need for strong, well-guided federal investments in research, development, and demonstration activities. Federal R&D can continue to lower water and geothermal power costs and validate their emerging applications. We have only begun to touch the surface of what these technologies can do, and the DOE and our National labs, universities, and industry partners possess the expertise to explore them to their fullest potential. I look forward to using today's hearing to inform forward-looking legislation that will enable DOE to propel these technologies into the future.

With that, I yield back.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairman Lamb, for hosting this hearing, which is especially relevant to the geothermal industry in my home state of Oklahoma.Geothermal energy systems draw from the constant and naturally occurring heat that radiates beneath the surface of the earth. This heat is a source of clean and renewable energy that is always ″on.″ Our country has significant hydrothermal and geothermal energy resources, and if harnessed correctly, these resources have the capability to provide secure baseload power and energy storage for Americans across the country.

Yet although the United States leads the world in installed geothermal capacity, geothermal energy contributes less than one percent to the total utility-scale U.S. electricity generation.

In 2018, while wind energy generation accounted for 21 percent of the growing U.S. renewable energy portfolio, geothermal energy generation accounted for just 2 percent.

This is because today's geothermal energy technologies are often too expensive, time consuming, or risky for industry to take to scale. While I've seen the potential of geothermal energy in my district of Oklahoma with our thriving geothermal heat pumps industry, more work needs to be done to allow the rest of the country to access the full power of this resource.

In order to effectively leverage these vast untapped energy resources, the next generation of geothermal technologies and techniques must become more efficient and less expensive for American consumers. Fortunately, we are uniquely positioned to prioritize the basic and early stage research that leads to groundbreaking technology.

Federally funded research programs at the Department of Energy (DOE) have a history of paving the way for industry innovation. So I am pleased to see DOE and its Geothermal Technologies Office taking the lead in this valuable science, and to see them here today. It is critically important to our clean energy future that they have the support they need to pursue research that industry cannot undertake.

This is an issue that my draft bill, the *Advanced Geothermal Research and Development Act of 2019*, will address. This legislation will provide the DOE's Geothermal Technologies Office with critical funding and program direction to enable innovative research in advanced geothermal technologies, strengthen the U.S. geothermal workforce, and encourage international collaboration. More specifically, it will authorize and expand the Department of Energy's early-stage research in enhanced geothermal systems and the major facilities needed to support this work.

Today we will hear about one of these facilities from Dr. Joseph Moore, the manager of the Department's first Frontier Observatory for Research in Geothermal Energy (FORGE) field site in Utah. This facility will provide U.S. researchers with large-scale experimental capability to develop and test cutting edge geothermal technologies and validate experimental models. Using these tools, industry partners will be able to adapt techniques developed in the field for commercial use across the country. Dr. Moore, thank you for joining us today.

My bill will also authorize a new program in advanced geothermal computing and data science research and development. This will leverage DOE's best-in-the-world computational capabilities to provide geothermal researchers with modeling and simulation tools that will allow them to more accurately model complex subsurface systems.

With these tools, industry can improve the next generation of geothermal energy systems, using advanced designs to save time and money in planning, and producing power more efficiently with less impact on the environment. I believe this bill is an excellent opportunity for bipartisan cooperation, and I look forward to working with my friends across the aisle moving forward.

We know that American industry has the resources to successfully commercialize new technology - we've already seen it happen with wind and solar. What they often lack is the infrastructure to conduct early stage research and test new technologies. This is where DOE, the National labs, and academia can help, providing experimental facilities and computational tools that will drive costs down and innovation forward.

If we want to ensure a diverse portfolio of clean energy technologies now and in the future, we in Congress should prioritize this important fundamental research.

I want to thank you Chairman Lamb for holding this hearing, and I look forward to hearing from our witnesses today about the path forward for next generation clean energy technologies.

Chairman LAMB. OK. At this time I'd like to introduce our witnesses. Dr. David Solan is the Deputy Assistant Secretary for Renewable Power in the Office of Energy Efficiency and Renewable Energy (EERE) at the U.S. Department of Energy. He directs renewable energy applied research, development, and demonstration activities for the Geothermal, Solar Energy, Wind, and Water Power Technology Offices at EERE. He also oversees EERE's energy system integration efforts. Previously he was the Acting Executive Director and Principal Deputy Director of the Office of Policy, as well as the Senior Advisor in the Office of Science. Welcome, Doctor.

Dr. Bryson Robertson is the Co-Director of the Pacific Marine Energy Center, and Associate Professor in Civil Engineering at Oregon State University. He has a bachelor of mechanical engineering from the University of Victoria, and a Ph.D. in environmental engineering from the University of Guelph. He has spent the better portion of the past 20 years actively involved within the North American marine energy market, energy systems, and coastal engineering sectors.

Dr. Joseph Moore is the Manager of the Utah Frontier Observatory for Research in Geothermal Energy, or FORGE. He also holds appointments at the University of Utah as a Research Professor in the Department of Civil and Environmental Engineering, and as an Adjunct Professor in the Department of Geology and Geophysics. His expertise is in the geology, hydrothermal alteration, and geochemistry of geothermal systems, and his current research is focused on expanding geothermal development through the creation of enhanced geothermal systems.

Ms. Maria Richards is the Director of the Geothermal Laboratory in the Roy M. Huffington Department of Earth Sciences at Southern Methodist University. She was the President of the Geothermal Resources Council in 2018. Her current research focuses on the use of temperature well logs for understanding climate change, the transition of oil fields into geothermal production, and low-temperature geothermal applications, such as district heating for commercial buildings.

Mr. Sander Cohan directs North American Innovation for Enel Green Power North America, Inc. He has over 15 years of experience in the energy sector, specializing in innovation and emerging and alternative energy technologies. He has served as chief project director and manager for technology projects in diverse areas, such as energy storage, microgrids, and smart grid technology, predictive analytics, geothermal energy, hybrid renewables, and marine energy.

Again, I know many of you came from far away today to be with us, so we really appreciate that. As you know, you will have 5 minutes for your spoken testimony. Your written testimony will be included in the record. When you've all completed your spoken testimony, we will begin with questions. Each Member will have 5 minutes to question the panel. We will start with Dr. David Solan.

TESTIMONY OF DR. DAVID SOLAN, DEPUTY ASSISTANT SECRETARY FOR RENEWABLE POWER, OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY

Dr. SOLAN. Thank you. Chairman Lamb, Ranking Member Weber, and Members of the Energy Subcommittee, thank you for inviting me to testify today on the opportunities and challenges of geothermal and water power technologies, and the activities that the U.S. Department of Energy is undertaking to help secure America's future through energy independence and scientific innovation. My name is David Solan, and I am the Deputy Assistant Secretary for Renewable Power in the Office of Energy Efficiency and Renewable Energy, or EERE. I direct renewable energy applied research, development, and demonstration activities there. Today I will be discussing the valuable work underway in two of our technology offices: The Geothermal Technologies Office, or GTO, and the Water Power Technologies Office, WPTO. I will also highlight several announced and upcoming activities at the Department.

GTO conducts R&D to reduce cost and risks associated with geothermal development by supporting innovative technologies that address key exploration and deployment barriers. The U.S. is the world leader in installed geothermal capacity. As an always-on energy source that harnesses the Earth's natural heat, geothermal energy provides base load power with the flexibility to ramp on and off. Geothermal power plants can also provide essential grid services, and operate in a load-following mode, helping to support reliability and flexibility in the U.S. grid, and ultimately facilitating a diverse, secure, and resilient energy mix. Geothermal energy can be used in three technology areas: The first generating electricity; the second providing residential and commercial heating and cooling using geothermal heat pumps; and the third direct use applications that can provide district scale heating solutions, as well as a wide array of commercial and industrial applications where process heat is required.

In May 2019 the Department released its GeoVision Analysis, a multi-year collaboration among DOE and its stakeholders to evaluate the potential for different geothermal resources. It assessed opportunities to expand U.S. geothermal energy deployment through 2050 by improving technologies, reducing costs, and addressing project development barriers, such as long permitting timelines. GTO's flagship initiative, the Frontier Observatory for Research and Geothermal Energy, known as FORGE, heads the list of activities called out in the GeoVision roadmap. FORGE is a dedicated site to develop, test, and accelerate breakthroughs in enhanced geothermal systems, technologies, and techniques. It is now finishing the second of three phases, with the third slated to start later this fall.

Turning to WPTO, it works with National laboratories, industry, universities, and other Federal agencies to conduct R&D activities through competitively selected projects. It is pioneering efforts in both marine energy and hydropower technologies to improve performance, lower cost, and, ultimately, support our ability to meet evolving energy demands.

Hydroelectric power is the leading renewable energy source in the U.S., accounting for 7 percent of utility-scale electric generation in 2018. Conventional and pump storage hydropower are stable power sources that are also flexible enough to smooth out fluctuations between electric generation and demand, as they have large reservoirs of fuel, that is water, to fill any gaps in generation at a moment's notice. This stability and flexibility supports the deployment and integration of more variable renewable resources, such as wind and solar.

Hydropower and pump storage fit in extremely well with the Department's activities in the Grid Modernization Initiative, or the GMI. Just last week we announced $80 million for new laboratory call projects. This is the latest solicitation released by the GMI, a cross-cutting DOE effort to develop new tools and technologies that measure, analyze, predict, protect, and control the grid of the future.

In addition to critical R&D efforts in hydroelectric power, WPTO leads the way in evaluating new sources of marine and hydrokinetic energy, such as predictable waves, currents, tides, and ocean thermal resources. WPTO is investing in this new and innovative industry, a nascent technology sector that can contribute to our Nation's energy independence, and which is highlighted in WPTO's report: *Powering the Blue Economy*, published earlier this year.

In addition, as we speak, EERE's Assistant Secretary, Daniel Simmons, is participating at the White House summit on partnerships in ocean science and technology. Later this afternoon, or as we speak, he will announce exciting developments in two new water technology prizes.

Thank you for the opportunity to testify before the Subcommittee today. DOE appreciates the ongoing bipartisan efforts to address our Nation's energy challenges, and looks forward to working with the Committee on the bills in the future. I would be happy to answer your questions.

[The prepared statement of Dr. Solan follows:]

Testimony of Deputy Assistant Secretary David Solan

Office of Renewable Power

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Before the

Committee on Science, Space, and Technology

Subcommittee on Energy

United States House of Representatives

November 14, 2019

INTRODUCTION

Chairman Lamb, Ranking Member Weber, and Members of the Energy Subcommittee of the Committee on Science, Space, and Technology, thank you for the opportunity to testify today on the opportunities and challenges of geothermal and water power technologies and the activities that the U.S. Department of Energy is undertaking to secure America's future through energy independence, scientific innovation, and national security.

My name is David Solan, and I am the Deputy Assistant Secretary of the Office of Renewable Power in the Office of Energy Efficiency and Renewable Energy (EERE). As the Deputy Assistant Secretary, I direct renewable energy applied research, development, and demonstration activities for the geothermal, solar energy, wind, and water power technology offices in EERE. Today, I will be discussing the valuable work underway in two of our technology offices, the Geothermal Technologies Office (GTO) and the Water Power Technologies Office (WPTO).

As the U.S. electric grid incorporates an increasing amount of renewable energy, challenges arise to incorporate variable sources of energy while also addressing systems integration needs and grid resiliency. Both geothermal and water power technologies have the capacity to supply valuable baseload power and provide additional grid services such as storage. Hydropower in particular can provide flexibility and scheduled dispatch to address grid integration of variable technologies.

GEOTHERMAL TECHNOLOGIES OFFICE (GTO)

The Geothermal Technologies Office (GTO) conducts research and development (R&D) to reduce costs and risks associated with geothermal development by supporting innovative technologies that address key exploration and deployment barriers.

The United States is the world leader in installed geothermal capacity (3.8 gigawatt-electric (GW) nameplate capacity; 2.5 GW net summer capacity). As an always-on energy source that harnesses the earth's natural heat, geothermal energy provides baseload power with the flexibility to ramp on and off. Geothermal power plants can also provide essential grid services and operate in a load-following mode, helping to support reliability and flexibility in the U.S. grid and ultimately facilitate a diverse, secure energy mix.

Geothermal energy can be used in three technology areas: (1) generating electricity, (2) providing residential and commercial heating and cooling using geothermal heat pumps, and (3) direct-use applications that can provide district scale heating solutions as well as a wide array of commercial and industrial applications where process heating is required.

In May 2019, the Department released its *GeoVision* analysis, a multiyear collaboration among industry, academia, the National Laboratories, and federal agencies to evaluate the potential for different geothermal resources. The effort assessed opportunities to expand nationwide geothermal energy deployment through 2050 by improving technologies, reducing costs, and addressing project development barriers such as long permitting timelines, ultimately identifying the potential of 60GW of generating capacity, a 26-fold increase from today's geothermal capacity, representing 8.5% of expected national electricity capacity in 2050.

Our flagship initiative, the Frontier Observatory for Research in Geothermal Energy, FORGE, heads the list of activities to address the technology improvement needs called out in the *GeoVision* roadmap. FORGE is a dedicated site where scientists and engineers will be able to develop, test, and accelerate breakthroughs in enhanced geothermal system (EGS) technologies and techniques.

The FORGE initiative is now finishing the second of three phases. GTO selected the final site at Milford, Utah, with the University of Utah-led team, during Phase 2. The University of Utah-led FORGE team is fully instrumenting the site for surface and subsurface investigation, and bringing FORGE to full readiness for R&D technology testing and evaluation in preparation for one final stage gate. During the five-year Phase 3 – Technology Testing and Evaluation, slated to start later this fall, FORGE funding will support tasks necessary for management and oversight of FORGE operations and annual competitive R&D solicitations open to the entire stakeholder community.

GTO is also pursuing innovative technologies in the non-electric sector. Deep Direct Use (DDU) utilizes low temperature (<150°C) geothermal resources, and has the potential to lower the cost of heating and cooling for university campuses, industrial parks, and military installations across the entire U.S., as well as address more global energy storage and resilient grid needs. GTO is funding six DDU studies to determine the economic feasibility of these technologies in various regions around the country.

Two additional challenges to bringing geothermal energy on line are exploration risk and drilling cost. GTO has major sustained investments to address these challenges, including our Play Fairway Analysis program for finding hidden geothermal systems, finishing up validation drilling this fall; Efficient Drilling for Geothermal Energy, with 10 R&D awards to reduce drilling costs; and a recent funding opportunity for R&D in Lost Circulation and State of Stress.

WATER POWER TECHNOLOGIES OFFICE (WPTO)

The Water Power Technologies Office (WPTO) works with national laboratories, industry, universities, and other federal agencies to conduct R&D activities through competitively selected, directly funded, and cost-shared projects. They are pioneering R&D efforts in both marine energy and hydropower technologies to improve performance, lower cost, and ultimately support the United States' ability to sustainably meet its evolving energy demands.

Hydroelectric power is the leading renewable energy source in the United States, accounting for seven percent of total U.S. utility-scale electricity generation in 2018[1]. Conventional and pumped-storage hydropower are stable power sources that are also flexible enough to smooth out

[1] https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

fluctuations presented by variable renewable energy sources, such as wind and solar, as they have large reservoirs of "fuel" (i.e. water) to fill any gaps in generation at a moment's notice. This stability and flexibility supports the deployment and integration of more variable renewable resources.

In addition to critical research and development efforts in hydroelectric power, WPTO leads the way in evaluating new sources of marine and hydrokinetic energy, such as highly predictable waves, currents, tides, and ocean thermal resources. With more than 50 percent of the American population living within 50 miles of the coast, a cost-effective marine and hydrokinetic industry could provide a substantial amount of electricity for the nation. WPTO is investing heavily in this new and innovative industry, a nascent technology sector that is an example of American ingenuity at its best, producing cutting-edge technologies that can contribute to our nation's energy independence. In addition to supporting the early-stage R&D that will enable long-term cost reductions and performance improvements, WPTO has also recently undertaken new efforts to explore nearer-term opportunities for marine energy to reduce power constraints for other ocean industries.

In FY 2019, WPTO launched its Powering the Blue Economy Initiative (PBE), which supports marine energy R&D targeting maritime markets that could benefit from the early adoption of wave or current technologies. Successfully leveraging marine energy technologies to solve existing power problems for other ocean industries also offers the potential to meaningfully accelerate cost reductions for marine energy systems, by both providing greater opportunities for in-water experience and attracting additional private capital.

In FY 2020, WPTO will expand the PBE portfolio, creating new funding initiatives and lab-focused work that builds on the analysis from FY 2019 and launch new partnerships with federal partners. An example of those partnerships is WPTO's recently announced joint Ocean Observing Prize with the National Oceanic and Atmospheric Administration (NOAA) to generate innovation in marine energy-powered ocean observing platforms.

On the hydropower side, WPTO launched a new grid research initiative in FY19—Hydropower and Water Innovation for a Resilient Electricity System (HydroWIRES)—to understand, enable, and improve hydropower and pumped storage hydropower contributions to reliability, resilience, and integration in a rapidly evolving electricity system. The initiative leverages expertise from industry and DOE National Laboratories to understand the value drivers for hydropower, to quantify its unique capabilities and constraints, to improve operations and planning for hydropower alongside other resources, and to invest in technology innovation to improve hydropower capabilities. Key efforts in FY19 included industry support for quantifying hydropower flexibility, and National Lab work to improve hydropower modeling capabilities.

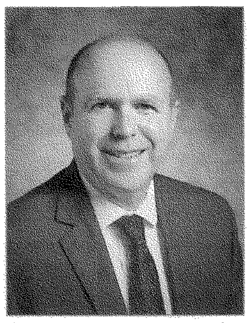
In FY20, the HydroWIRES initiative will apply modeling tools developed in FY19 to investigate the highest-value technology innovations needed to improve hydropower flexibility. This will include the launch of a cross-cutting technical assistance program for external decision-makers so that National Lab research results can be implemented for the benefit of the broader hydropower and power system communities.

CONCLUSION

Thank you again for the opportunity to testify before the Subcommittee today. The Department appreciates the ongoing bipartisan efforts to address our Nation's energy challenges, and looks forward to working with the Committee on future legislation and activities. I would be happy to answer your questions.

David Solan

Deputy Assistant Secretary for Renewable Power



David Solan directs renewable energy applied research, development, and demonstration activities for the geothermal, solar energy, wind, and water power technology offices in the Office of Energy Efficiency and Renewable Energy (EERE). In addition, he oversees EERE's energy system integration efforts.

Previously at the U.S. Department of Energy (DOE), he was the Acting Executive Director and Principal Deputy Director of the Office of Policy, as well as a Senior Advisor in the Office of Science.

Before that, Solan was an executive at a multi-institutional research consortium and directed a research institute at Boise State University. He was the Principal Investigator or Co-PI for energy research awards from the National Science Foundation, the International Atomic Energy Agency, DOE, state governments, non-profits, and industry.

He has also been a member of the board for the manager and operator of the Idaho National Laboratory, the energy and advisory council to the Idaho state government, Idaho Power's Integrated Resource Plan advisory council, and the advisory board for The Electricity Journal. He has published across the energy technology spectrum on solar, wind, renewables integration, bioenergy, electric transmission planning, energy efficiency, nuclear power, energy security, and natural gas and natural gas liquids.

He has long-time experience in Federal government service outside of DOE. At the House of Representatives, he was a staffer for the Government Reform Subcommittee on Energy and Resources, and a Legislative Director for a Member of Congress. He also served at the Environmental Protection Agency as a Senior Policy Advisor to the Deputy Administrator and to the Office of Research and Development on energy issues.

Solan received his Ph.D. and M.A. from the University of Delaware and his bachelor's degree from Drew University.

Chairman LAMB. Thank you. Dr. Robertson?

TESTIMONY OF DR. BRYSON ROBERTSON, CO-DIRECTOR, PACIFIC MARINE ENERGY CENTER, ASSOCIATE PROFESSOR, CIVIL AND CONSTRUCTION ENGINEERING, OREGON STATE UNIVERSITY

Dr. ROBERTSON. Chairman Lamb and Ranking Member Weber, thank you for the opportunity to testify today. In my testimony I'll address three things: First, the domestic marine energy opportunity; second, the strategic important of—importance of investment in innovation to spur the domestic marine energy technology sector; and finally, the importance of the *Water Power Research and Development Act of 2019* for realizing the marine sector's potential.

First, what is the marine energy opportunity? It encompasses energy in waves, tides, currents, rivers, salinity, and temperature differentials. Recent resource assessments quantify the U.S. wave resource at approximately 3,500 terawatt hours, the tidal resource at 450 terawatt hours, the ocean current at an additional 200, and the river at an additional 150, providing a cumulative total of 4,300 terawatt hours. To provide perspective, the current U.S. electricity demand is 41 terawatt hours, so less than the total resource. As such, marine energy has the as yet untapped potential to provide significant and needed renewable electricity resources for the U.S. grid. These resources would enhance a suite of renewable resources currently helping drive the U.S. transition from fossil fuels to renewable electricity generation.

Of further economic interest to the U.S., marine energy offers a number of competitive advantages, and opportunities within the emerging blue economy. According to the OECD's (Organisation for Economic Co-operation and Development's) 26th report, blue economy related industries and activities contribute more than $1.5 trillion in value added to the economy each year, and that value is expected to double by 2030. Marine energy is both part of this new economy and plays a linchpin role in providing the necessary power for innovation in the remaining spaces. To this end, the U.S. Department of Energy's Water Power Technologies Office recently released its Powering the Blue Economy initiative, which details specific near-term opportunities for marine energy. These include powering oceanographic measurement devices, recharging underwater autonomous vehicles, renewably powering offshore aquaculture facilities, desalinating water, and powering remote isolated communities.

It is important to understand and underscore that a principle challenge in achieving the marine energy resource potential is the inconvenient fact that the technology commercialization pathway takes longer and costs more than terrestrial counterparts. That said, for the U.S. to capture the benefits of the marine energy resources, the level of Federal investment in early-stage marine energy technology and innovation must at least increase in line with comparative technology investments in our other renewable resources. Water power investment, including marine energy and hydropower, has consistently been 3- to 4-times lower than solar. This is despite the early stage of marine energy technologies, and the widely acknowledged importance of Federal investment at this stage of innovation to spur economic development.

Thanks to the efforts of Congress over the past several years, the U.S. is starting to make significant and strategic investments in the Department of Energy's Water Power Technology Office to support research, development, and the commercial viability of a domestic marine energy sector. Looking forward, the *Water Power Research and Development Act of 2019* is essential to providing a strategic direction, and authorizing the sustained funding necessary to accelerate the development of a domestic marine energy industry. Unlike wind and solar, marine energy technology developers do not currently benefit from any tech support mechanisms, such as the investment tax credit or the production tax credit. Funding from the DOE WPTO is the key, and only, mechanism to support U.S. technology developers competing against overseas companies that receive sweeter subsidies.

Finally, as a faculty member at an institution of higher education, I wish to close with a focus on the urgent need to educate and train the next generation of energy leaders and maritime innovators. As the world becomes increasingly interconnected and resource stressed, it is the important role of universities, colleges, and training programs to develop the talentbase and workforce who understand the technological, environmental, and social codependencies needed for true innovation. This workforce is required now. It is my hope that the *Water Power Research and Development Act of 2019* will provide the fundamental building blocks to ensure that we are able to create this next generation workforce.

I thank the Subcommittee for your efforts to consider the opportunity to associate with the thriving marine energy industry in the U.S., and with that, I'm happy to answer questions.

[The prepared statement of Dr. Robertson follows:]

Written Statement of

Bryson Robertson, Ph. D.
Co-Director, Pacific Marine Energy Center at Oregon State University
Associate Professor, Civil and Construction Engineering

Before the Subcommittee of Energy
Of the Committee on Science, Space and Technology
U.S. House of Representatives

"Marine Energy: The opportunity and benefits of U.S. leadership"

November 14th, 2019

Chairman Lamb and Ranking Member Weber, thank you for the opportunity to testify today on the untapped potential of our U.S. marine energy resource, the value propositions for marine energy, the opportunity for U.S. leadership, and how the *Water Power Research and Development Act of 2019* is of utmost importance for domestic capture of this emerging, multibillion-dollar sector.

I am a co-Director of the Pacific Marine Energy Center (PMEC) and an Associate Professor in Civil Engineering at Oregon State University. I have spent the better portion of the past 20 years actively involved within the North American marine energy market, energy systems and coastal engineering sectors. From helping design the hybrid renewable energy system for the Race Rocks, the first tidal energy turbine deployed in North America (2004), to my current role in PMEC, my involvement has included conducting fundamental research within universities, developing commercial products within industry, and helping government organizations develop implementation roadmaps for marine energy commercialization. My research and professional portfolio covers the full development cycle for marine energy systems with expertise that includes resource assessments, to technology development, to market opportunity evaluations. I have worked with large multinational corporations, small technology developers, private NGO's, tribes, large electrical utilities, and international information technology companies to better understand their roles and opportunities in this emerging sector. Additionally, my research efforts also include long-term electricity system transition analyses. As our electricity systems rapidly evolve, it is imperative that we understand the opportunities and challenges at the nexus of global economic growth, climate change, renewable technology development, policy ambitions, and human social structures.

Overview

This testimony provides an overview of the marine energy opportunity, the strategic advantages associated with the U.S. effort, the renewable energy funding landscape, and a clear vision of the value proposition for the *Water Power Research and Development Act of 2019*.

The Pacific Marine Energy Center (PMEC) is a competitively designated U.S. Department of Energy (DOE) Center focused on the responsible advancement of marine energy by expanding scientific understanding, engaging stakeholders, and educating students. Within PMEC, researchers from Oregon State University, the University of Washington, and the University of Alaska Fairbanks work closely with marine energy technology developers, academic and National Laboratory researchers, coastal community members, ocean users, federal and state regulators, and other government officials, to address key challenges in the sector and accelerate its emergence. Our mission is to serve as an objective voice regarding the opportunities, capabilities, and effects of marine energy, including wave, tidal, riverine, and offshore wind resources.

Marine Energy Resources and Opportunities

Marine energy is one of the last significant untapped renewable resources.

Marine energy encompasses energy in waves, tides, currents, rivers, salinity and temperature differentials. As shown in Figure 1, recent resource assessments quantify the U.S. wave resource as upwards of 3500 TWh, the tidal resource as 450 TWh, the ocean current as approximately 200TWh, and the river resource as 130TWh. To provide some context, the current U.S. electricity demand is approximately 4100 TWh. As such, marine energy has the potential to provide significant and needed renewable electricity resources to the U.S. grid – resources which will compliment the suite of other renewable energy resources currently helping drive our transition from fossil fuels to renewable electricity generation.

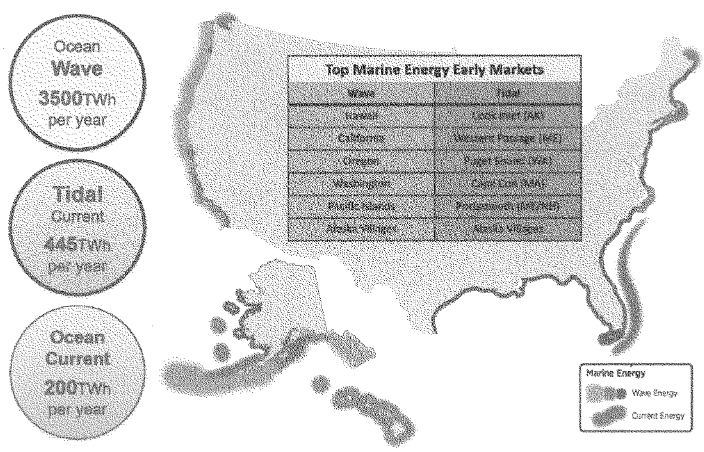


Figure 1: U.S. Marine Energy Resources (U.S. DOE National Renewable Energy Laboratory)

In addition to its potential as an immense raw resource, marine energy offers a suite of additional ancillary benefits to the utility electricity markets. These include location, forecastability and availability, to name just a few. Coastal counties of the U.S. are home to over 126 million people, or 40 percent of the nation's total population. If these counties aggregated their GDP, it would rank third in the world – behind only the U.S. and China. As such, the electricity demands of our coastal region is massive and rapidly increasing. The ability to transmit electricity vast distances from remote electricity generation facilities is becoming increasingly expensive, socially unacceptable, and susceptible to climate-related changes (e.g., California wildfires and the relationship with the electricity system). Marine energy resources are the most proximate renewable resources to these growing coastal electricity demands and will play an important role helping reduce electricity-related emissions while improving the electrical system resilience. In terms of forecastablity, the fundamental physics behind the ebb and flow of marine energy resources is well understood, allowing for system operators and project developers to accurately forecast the future power generation – a high value benefit when trying to manage a dynamic and increasingly variable electricity system. Finally, for many locations, the seasonal availability of marine energy resources correlates with the demand for electricity – thus minimizing the need to back-up fossil fueled generation or large-scale energy storage systems.

Last year alone, the renewable energy market saw investments of $280B – far exceeding fossil fuel investments. As global markets and electricity utility policies drive towards increasing penetrations of renewable electricity, the need for new renewable electricity generating resources (beyond wind and solar) is creating significant economic opportunities for supportive countries, marine energy technology development companies, and research enterprises.

The U.S. Competitive Strategy and Advantage

The development of marine energy technologies is a challenge. The commercialization pathway takes longer and costs more than terrestrial renewable energy technology development – this is an inconvenient fact. As such, the commercial progress of marine energy companies has been slower than our wind and solar counterparts. However, the technology performance improvements and cost reductions clearly illustrate that marine energy is following the same dramatic cost reduction trajectory as both of these complimentary renewable resources.

In addition, and contrary to our wind and solar counterparts, marine energy inherently includes a number of competitive advantages and opportunities within the emerging 'Blue Economy'. According to the *Organization for Economic Co-operation and Development's* 2016 report, 'Blue Economy'-related industries and activities contribute more than $1.5 trillion in value added to the economy each year, and that value is expected to double by 2030. Marine energy is part of this economy, but also plays a linchpin role in providing the necessary power for much of the innovation space in the Blue Economy. Marine energy has the potential to enable entirely new sectors of offshore economic activity that are impossible today due to lack of reliable electricity in the open ocean.

Through extensive consultation within the U.S. marine energy and maritime sectors, the U.S. Department of Energy's Water Power Technologies Office (WPTO) recently released its '*Powering the Blue Economy*' initiative; which details specific, near-term market opportunities for marine energy. These include powering oceanographic measurement devices, recharging Underwater Autonomous Vehicles (UAV), renewably powering offshore aquaculture facilities, desalinating water, and powering remote isolated communities, amongst others (see Figure 2).

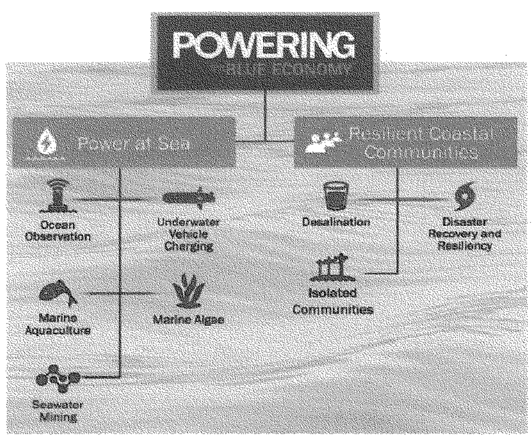


Figure 2: Powering the Blue Economy Sectors (WPTO)

By widening the aperture for marine-energy commercialization markets, the WPTO has shown international leadership – leadership which many of our international peers are now following. The *Powering the Blue Economy* initiative will allow U.S.-based technology developers to develop smaller marine energy devices, at lower per-unit-costs, and find commercial success faster; while concurrently building new capacities for remote observation and surveillance, providing clean drinking water, and mitigating energy poverty in isolated communities.

The '*Powering the Blue Economy*' initiative clearly illustrates the wide spectrum of commercial opportunities available for marine energy clean tech development – many of which are along the development trajectory to utility-scale power generation. The leadership shown by our colleagues within the WPTO has provided the U.S. with a clear opportunity to maintain global leadership, and a pathway to better utilizing our marine energy resources.

Federal Renewable Energy Investment

Thanks to the efforts of Congress over the past several years, the U.S. is beginning to make significant investments in marine energy technology development through the DOE WPTO. However, there is stiff international competition and other nations are actively seeking to capture this projected $61.8B per annum market (2050). The EU and Canada invest approximately $300M per year in marine energy, China invests approximately $150M per year, and Australia recently announced a $330M investment in marine energy and associated Blue Economy initiatives. Sustained and increased U.S. investment to optimize the domestic innovation and development potential for marine energy technology is critical to support U.S. leadership and market capture in this space.

The global marine energy industry is still widely dispersed around the world. Unlike our wind and solar peers, the U.S. still has the opportunity to ensure that technology development and associated economic benefits occur here rather than the U.S. simply being a user of other nations' technology. However, in order to achieve this objective and capture the benefits, the level of federal investment in early stage marine energy technology innovation must increase in-line with comparative early stage investment in renewable energy sector peers that effectively contributed to commercial viability. As shown in Figure 3, water power (marine energy & hydropower) funding has consistently been 3 to 4 times lower than wind and solar – despite marine energy representing early stage technologies where federal investment has the greatest opportunity to spur innovation and associated economic growth.

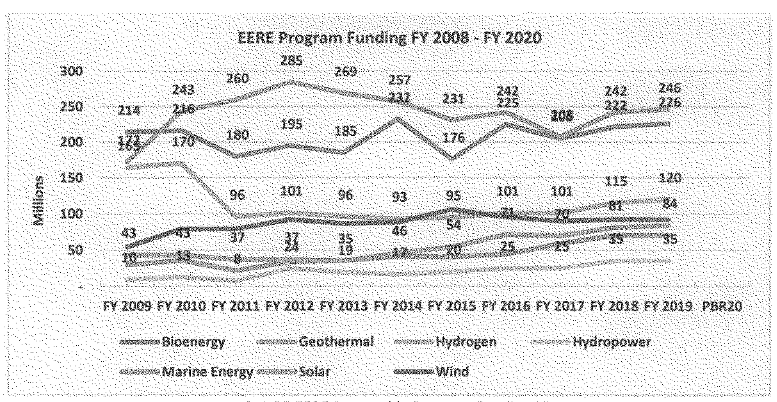


Figure 3: DOE EERE Renewable Program Funding History

The Pacific Marine Energy Center and Building an Industry

PMEC is globally recognized for our holistic view of the development pathway for marine energy. This pathway includes playing an integral role in the development of innovative technologies, but also developing a fundamental understanding of the environmental and social opportunities and challenges.

Through our Industry Partner Network (IPN), industry is able to work closely with PMEC affiliated faculty and students to leverage the wealth of knowledge and expertise within the academic institutions to accelerate development. As an example of PMEC-Industry collaboration, the Ocean Energy buoy currently on route for deployment in Hawaii was initially tested at small scale in the PMEC-Affiliated O.H. Hinsdale Wave Research Laboratory at OSU, numerical modelling by OSU Faculty, and will host the next generation of the PMEC Adaptable Monitoring Package (AMP) from the University of Washington during its' testing at the U.S. Navy's Wave Energy Test Site at Marine Corps Hawaii.

Additionally, PMEC-affiliated faculty and students understand the development of projects and industry require more than just technologies. We have active projects completing the most comprehensive environmental baseline analyses possible; which includes benthic species, transitory ocean mammals, sediment samples, and high-value fisheries. These efforts are paramount to ensure regulatory and permitting agents have all the necessary data to make evidence-based decisions for future projects. Additionally, PMEC at Oregon State University conducts rigorous outreach and engagement activities to identify the human dimensions and social constructs which would impact or accelerate future development.

The Water Power Research and Development Act of 2019

The *Water Power Research and Development Act of 2019* is essential to providing the sustained funding necessary to accelerate the development of this industry, ensure the U.S. leadership position, and support the wider spectrum of opportunities to allow marine energy technologies to provide disruptive solutions to the multibillion-dollar Blue Economy. Unlike wind and solar, marine energy technology developers do not currently benefit from any tax support mechanisms such as the Investment Tax Credit (ITC) or the Production Tax Credit (PTC). Funding from the DOE WPTO is the key (and only) mechanism to support U.S. technology developers competing against overseas companies that receive a suite of subsidies.

By investing in a marine energy focused program at DOE, comparable especially to our solar peers, we can grow a marine energy industry that will provide new economic opportunities, high wage jobs, a clean energy source to coastal communities, and a new understanding of our oceans.

The Next Generation

As a faculty member at an institution of higher education, I would be remiss if I did not close by focusing on the urgent need to educate and train the next generation of energy leaders and maritime innovators. As the world becomes increasingly interconnected and resource stressed, it is increasingly important for universities, colleges and training programs to develop the talent base and workforce who understand the technological, environmental and social co-dependencies needed for true innovation. Innovation that will help the U.S. reduce our impacts on the global climate, innovation that will reduce energy poverty in rural communities, and innovation that will allow us to sustainably explore and harness our ocean resources.

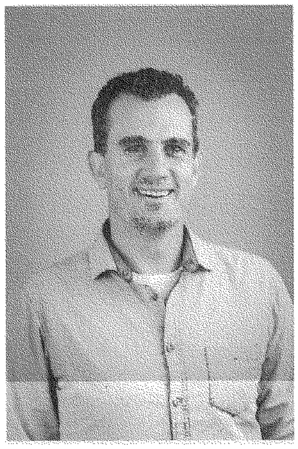
This workforce is required now. The students that graduate from programs and centers, like PMEC, are in increasing demand at private companies, national laboratories, and within the broader academic community. We need to ensure that the financial support is available to ensure that PMEC and other similar centers can continue to provide this workforce – a very real concern that is frequently noted by our industrial and national laboratory partners. It is my sincere hope that the *Water Power Research and Development Act of 2019* will provide one of the fundamental building blocks to ensure we are able to create this next generation workforce.

In closing, I thank the Subcommittee for your efforts to consider the opportunities associated with the development of a thriving marine energy industry in the U.S. With the right support, the U.S. marine energy industry can capture a significant share of a massive emerging market, assist in our transition to carbon-free electricity generation, and develop the next generation of renewable energy leaders. I would be pleased to answer any questions about this testimony, the Pacific Marine Energy Center, or the marine energy industry writ large.

Sincerely,

Bryson Robertson
Co-Director, Pacific Marine Energy Center
Associate Professor, Civil and Construction Engineering
Oregon State University

Bryson Robertson
Associate Professor, Department of Civil and Construction Engineering
Co-Director, Pacific Marine Energy Center
Oregon State University



Dr. Robertson is the co-Director of the Pacific Marine Energy Center (PMEC) and an Associate Professor in Civil Engineering at Oregon State University. He has a Bachelor of Mechanical Engineering from the University of Victoria, and a PhD in Environmental Engineering from the University of Guelph. He has spent the better portion of the past 20 years actively involved within the North American marine energy market, energy systems and coastal engineering sectors. From helping design the hybrid renewable energy system for the Race Rocks, the first tidal energy turbine deployed in North America (2004), to his current role with PMEC, his involvement has included conducting fundamental research within universities, developing commercial products within industry, and helping government organizations develop implementation roadmaps for marine energy commercialization. His research and professional portfolio covers the full development cycle for marine energy systems with expertise that includes resource assessments, to technology development, to market opportunity evaluations. Dr. Robertson have worked with large multinational corporations, small technology developers, private NGO's, tribes, large electrical utilities, and international information technology companies to better understand their roles and opportunities in this emerging sector. Additionally, his research efforts also include long-term electricity system transition analyses. As North American electricity systems rapidly evolve, it is imperative that we understand the opportunities and challenges at the nexus of global economic growth, climate change, renewable technology development, policy ambitions, and human social structures.

Chairman LAMB. Thank you. Dr. Moore?

TESTIMONY OF DR. JOSEPH MOORE, MANAGER, UTAH FRONTIER OBSERVATORY FOR RESEARCH IN GEOTHERMAL ENERGY (FORGE), RESEARCH PROFESSOR, UNIVERSITY OF UTAH

Dr. MOORE. Good afternoon, Chairman Lamb, Ranking Member Weber, and distinguished Members of the Subcommittee. My name is Joseph Moore. I represent the University of Utah's Energy and Geoscience Institute. I'm honored to appear before you today to discuss Project FORGE, an innovative geothermal energy research project funded by the Department of Energy in the State of Utah.

The thermal energy beneath our feet is enormous. Some of this energy reaches the surface naturally through hot springs, like those found in Virginia, Arkansas, and Wyoming, but this is only a tiny fraction of the available energy. If we could capture even 2 percent of the thermal energy at depths between 2 and 6 miles, we would have more than 2,000 times the yearly amount of energy used in the U.S.

Natural geothermal systems require a source of heat, water to transfer the heat, and permeability to allow the water to carry the heat upward. Although we can drill deep enough to reach temperatures suitable for electric generation anywhere in the world, and inject water to transfer the heat, most areas don't have sufficient natural permeability to circulate water at the depths we require.

Attempts to create enhanced, or engineered, geothermal systems were initiated by the Los Alamos National Laboratory in the late 1970s. More than a dozen attempts to create reservoirs by hydraulic stimulation followed worldwide, but none created commercial-scale reservoirs capable of producing more than a couple of megawatts of electricity. The Frontier Observatory for Research in Geothermal Energy, or FORGE, was envisioned to be an underground field laboratory where new technologies for enhanced geothermal system reservoir creation and operation could be developed. The Utah FORGE site was one of five locations in Utah, Idaho, Nevada, Oregon, and California originally considered for the laboratory.

The granite rocks at the Utah site are representative of the geologic environments at many locations across the U.S., thus reservoir creation in Utah can provide a template for enhanced geothermal system development elsewhere. The site is located on State land near three conventional geothermal plants: A wind farm, a solar field, and a biogas facility. Can you think of a better place to create an enhanced geothermal system? I can't.

DOE has obligated nearly $125 million to Utah FORGE for FY 2020 to 2024. Fifty percent of the funds will be utilized for research. The remainder will be used for field operations and drilling. The technologies that will be developed are not limited to enhanced geothermal systems. New stimulation and drilling technologies will also improve the productivity in conventional geothermal systems and high temperature oil and gas plays by reducing the number of wells that must be drilled.

In 2020 we will begin full deployment of the Utah FORGE laboratory. The centerpiece of the laboratory will be a pair of deep wells into rock with temperatures of 400 to 450° F. One of the wells will be for injection, the other for production. The second well will be completed in FY 2023. Testing and demonstrated commerciality of enhanced geothermal systems will occur in the following 18 months. At the end of 2024, Utah FORGE will decommission the site, plug and abandon the wells, and bring the drill pads back to their original grade.

The Utah FORGE site is a unique publicly owned and operated laboratory, and an essential stepping stone to commercial enhanced geothermal system development. Maintenance of the site beyond 2024 will provide a facility where new technologies can be tested at low cost in an ideal enhanced geothermal system environment. No alternative facilities currently exist in the U.S., and none are envisioned at this time. We strongly urge the Committee Members to continue their support of Utah FORGE and enhance geothermal system development in the U.S.

Thank you for the opportunity to testify on Project FORGE. I am happy to answer any questions you may have.

[The prepared statement of Dr. Moore follows:]

Written Testimony before the U.S. House of Representatives, Science, Space and Technology Committee, Subcommittee on Energy

Hearing Entitled
"Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation"

Dr. Joseph Moore
Research Professor—Energy and Geoscience Institute
University of Utah
Thursday, November 14

Good Afternoon--Chairman Lamb, Ranking Member Weber and distinguished Members of the Subcommittee, my name is Joseph Moore from the University of Utah's Energy and Geoscience Institute. I am honored to appear before you today to discuss Project FORGE, an innovative geothermal energy research project funded by the Department of Energy in the state of Utah.

The thermal energy beneath our feet is enormous. Some of this energy reaches the surface naturally through hot springs like those found in Virginia, Arkansas, and Wyoming. But this is only a tiny fraction of the available energy. If we could capture even 2% of the thermal energy at depths between about 2 and 6 miles, we would have more than 2000 times the yearly amount of energy used in the US.

Natural geothermal systems require a source of heat, water to transfer the heat, and permeability to allow the water to carry the heat upward. These natural systems are found primarily in the western US. Hot water produced at temperatures of 250°F or above can be used to produce electricity. Although we can drill deep enough to reach temperatures of 250°F anywhere in the world, and inject water to transfer the heat, most areas don't have sufficient natural permeability to circulate water at the depths we require. The oil and gas industries have demonstrated that permeability can be created or enhanced through hydraulic stimulation, but these techniques require modification because of the higher temperatures required to generate electricity and lower thermal value of geothermal fluids.

Attempts to create Enhanced Geothermal Systems (EGS) were initiated by the Los Alamos National Laboratory in the late 1970s at Fenton Hill, New Mexico. More than a dozen attempts followed worldwide. These projects utilized pressurized water to stimulate existing fractures and create new ones. While important lessons were learned, none of these attempts created commercial scale reservoirs capable of producing more than a couple of megawatts of electricity.

Rather than repeat the previous experiments, the DOE issued a Funding Opportunity Announcement (FOA) for building and operating an underground laboratory where new technologies for EGS reservoir creation and operation could be developed. Some of these technologies were successfully tested in April 2019 during the stimulation of well 58-32, a 7536 foot well drilled at the Utah Frontier Observatory for Research in Geothermal Energy (FORGE) site.

The Utah FORGE site was one of five locations in Utah, Idaho, Nevada, Oregon and California originally considered for the laboratory. The first phase of the project consisted of desktop studies. Based on these studies, the Fallon, Nevada and Milford, Utah sites were selected for further evaluation. A deep well was drilled at each of the two sites to demonstrate the reservoir met the required temperature, rock type, permeability, and stress criteria established by the DOE. In 2018, the site in south-central Utah was selected.

The granite reservoir rocks at the Utah site are representative of the geologic environment at many locations across the US. Thus, reservoir creation in Utah can provide a template for EGS development elsewhere. The site is located on state land in Utah's renewable energy corridor. This corridor contains three conventional geothermal plants, a windfarm, a solar field, and a biogas facility. There are no environmental or cultural constraints that would impact Utah FORGE activities. Water for testing is available at the site. The local groundwater cannot be used for agriculture or human consumption and the Utah FORGE project has secured sufficient water rights for testing and drilling. The local infrastructure is well developed and the site can be accessed year-round on public roads near, Milford, a community of 1400 located 10 miles away. The residents of Milford, the Beaver County commissioners, local landowners, and state and federal agencies have all enthusiastically supported the project. The Governor's Office of Energy Development, the Office of Economic Development, and the University of Utah have contributed significant funds to the project.

In FY2020, we will begin full deployment of the Utah FORGE laboratory. The centerpiece of the laboratory will be a pair of deep wells, one for injection and one for production. Additional infrastructure will consist of wells to monitor microseismic activity and produce groundwater, and facilities to support the research activities. The deep wells have an estimated cost of $15 million each. The first deep well will be drilled in FY2020-2021; the second in 2022-2023. Once the two wells are drilled, water will be circulated between them to extract heat from the hot rocks. Currently, the project is scheduled to continue through 2024.

DOE has obligated nearly $125 million to Utah FORGE for FY2020 to 2024. Fifty percent of the funds will be utilized for research; the remainder will be used for field operations and drilling. Definition of the research and development topics is the responsibility of an independent group of experts that includes members of the Fallon, Nevada FORGE team. The first set of competitive solicitations will be released in FY2020. Solicitations will then be released yearly throughout the project's life.

EGS reservoirs have the potential to provide low cost, secure, green electrical energy across the US. Research conducted under the Utah FORGE program will allow the scientific and engineering community opportunities to develop and test technologies outside of those used by commercial geothermal developers and the oil and gas industry. New stimulation and drilling technologies will, in turn, improve the productivity of conventional geothermal systems and high-temperature oil and gas plays. The cost of geothermal wells typically accounts for 50% of the total cost of a geothermal project. Stimulating existing wells and increasing production and injection rates can significantly reduce the overall cost of a geothermal project by reducing the number of wells that must be drilled.

The development of new technologies requires a fundamental understanding of the reservoir characteristics. These include temperature, rock type, principal stress orientations and magnitudes, the mechanical properties of the reservoir rock (e.g. rock strength), fracture orientations and distributions, sustainable heat extraction, the potential to induce microseismic events, and the level of seismic risk.

The importance of microseismic monitoring and seismic risk mitigation cannot be overemphasized. Because reservoir creation results in a release of energy, microseismic events are a natural consequence of stimulation. Events with magnitudes greater than 2-3 can be felt and have led to public outcries in Europe.

A unique feature of the Utah FORGE site is the opportunity to work on microseismic monitoring and hazard mitigation while simultaneously developing the permeability required for commercial EGS development. To mitigate issues related to microseismicity, a network of surface and downhole seismometers is being deployed at the Utah FORGE site and a Seismic Hazard Mitigation Plan has been developed.

Operational funds for the project will total approximately $62.5 million for the remainder of the project. Close to two-thirds of these funds will be used for infrastructure development. This includes drilling, reservoir creation, and deployment of the microseismic monitoring network. Once the two deep wells are drilled, long term circulation testing will be required to confirm the universal application of the newly developed EGS technologies and to demonstrate the commercial viability of EGS resources.

We anticipate completing the second well in Q1 FY2023, as noted above, and decommissioning the site by Q4 FY2024. The completion of the second well will mark the full realization of the Utah FORGE laboratory and initiation of full-scale reservoir development. Significant testing, and demonstrating commerciality of EGS, will occur in the following 18 months. At end of these 18 months, Utah FORGE is required to plug and abandon the wells and bring the drill pads back to their original grade.

The Utah FORGE site is a unique publicly owned and operated laboratory and an essential stepping stone to commercial EGS development. Maintenance of the site beyond FY2024 will provide a facility where new technologies can be tested at low cost in an ideal EGS environment. No alternative facilities currently exist in the US. We strongly urge the Committee members to continue their support of the Utah FORGE project and EGS development in the US.

Thank you again for the opportunity to testify on Project FORGE. I am happy to answer any questions you may have.

Dr. Joseph N. Moore
Research Professor
Energy & Geoscience Institute
University of Utah

Dr. Joseph Moore holds appointments at the University of Utah as a Research Professor in the Department of Civil and Environmental Engineering and as an Adjunct Professor in the Department of Geology and Geophysics. His expertise is in the geology, hydrothermal alteration and geochemistry of geothermal systems. Since the mid-1970s, Dr. Moore has conducted studies of many of the world's major geothermal fields for the U.S. Department of Energy, geothermal exploration and development companies, the U.N., and US AID. He is a past Associate Editor for the Americas of the journal Geothermics and former member of the Geothermal Resources Council Board of Directors.

Dr. Moore's current research is focused on expanding geothermal development through the creation of Enhanced Geothermal Systems (EGS). He was the Principal Investigator of the successful DOE funded Raft River, Idaho EGS Demonstration project and the Project Manager of the Utah FORGE (Frontier Observatory for Research in Geothermal Energy) project. FORGE is an innovative program designed to develop new technologies for the characterization, creation, and sustainability of EGS reservoirs.

Chairman LAMB. Thank you. Ms. Richards?

TESTIMONY OF MS. MARIA RICHARDS, DIRECTOR, GEOTHERMAL LABORATORY, ROY M. HUFFINGTON DEPARTMENT OF EARTH SCIENCES, SOUTHERN METHODIST UNIVERSITY

Ms. RICHARDS. Chairman Lamb, Ranking Member Weber, and Members of the Committee and staff, it is an honor for me to be here today, speaking with you. My name is Maria Richards, and I am the SMU (Southern Methodist University) Geothermal Lab Director. As a geothermal researcher, university program coordinator, and past president of the Geothermal Resources Council, I'll share with you ways to grow our country's ability to find innovative methods which use this Nation's geothermal base for a more resilient and diversified electric grid, plus a cleaner environment for generations to come.

The House bill is similar to the Senate bill, the *Advanced Geothermal Innovation Leadership Act*, the *AGIL Act*, so I'll be referencing that today in my talk. It tells you what is helpful, but does not tell you why it's important. Using my 25 years of geothermal experience, I will provide background on increasing our usage of geothermal resources, building projects connecting industries, and the significance of university research and outreach.

The National Renewable Energy Lab's GeoVision Study provides a road map from today's western U.S. geothermal power production of 3.6 gigawatts to a deployment across our country of 60 gigawatts by 2050. It also estimates two million homes are heated and cooled by geothermal heat pumps today, with this number increasing to 28 million homes by 2050. That's 30 years away, yet now is the time to act because geothermal power plants, they take 7 to 10 years from conception to production, and even having enough installers for the geothermal heat pumps and their growth require time for local companies to grow and train employees. And to help create momentum for geothermal heat pumps, please support House Bill 3961, the *Renewable Energy Extensions Act of 2019*.

Surprisingly, it is the oil and gas industry who comprehends the volume of untapped heat and fluid sitting idle, just waiting to be extracted. Oil and gas colleagues share how geothermal energy is considered their safety net because of how giant it is as a resource. We've learned the two industries are definitely different, yet complementary. The SMU Geothermal Lab is known for our outreach and bridge building conferences. These conferences bridge the geothermal industry with oil and gas, waste heat to power, desalinization, heat storage, and district energy systems, plus we've examined ways to cool and inlet temperatures of natural gas plants, and how to transition a coal plant to geothermal power.

Currently there are no technologies able to use the 150 to 185° low-temperature produced fluids from our productive shale plays. The Southwest Research Institute is working with a small company to get to market a technology that could generate electricity from these produced fluids, and it could assist many States. Yet it may not come to fruition. Over the past 15 years it has been exciting for me to participate as new technologies enter the market, only to learn the company is out of funds before a proper demonstration.

The funding of small tech companies in small-scale, low-temperature demonstrations in our sedimentary basins, is a strong next step. These are plug and play, easy to adapt technologies to include if the United States is going to achieve widely sourced geothermal power from sedimentary basins.

The House Bill and the *AGIL Act* are funding—arriving at a critical juncture for universities. It is a resource assessment allocation for the USGS (United States Geological Survey), yet, as Dr. Robertson mentioned, universities are important components of this. We have been the lead in collecting and assessing these data for decades. A broader initiative will provide essential funding for keeping faculty and researchers in geothermal exploration, while training students. Founding researchers in heat flow and geothermal resources are either already retired, or in retirement age. A geothermal fellowship program is another step, as part of training the next generation. Funding universities now is of utmost importance to preserve the greater technology transfer and knowledge in keeping us a world leader in the geothermal energy.

The DOE's ability to fund universities, National labs, and companies allows all of us to work together in finding innovation, which shifts from the United States as a fossil fuel-dependent country to partnerships between industries, and a win-win-win for the fossil fuel industry, the geothermal and other renewable industries, and the public. Through Congress' consistent yearly funding, the geothermal industry can reach its full potential. Thank you for this opportunity to testify today.

[The prepared statement of Ms. Richards follows:]

SMU | GEOTHERMAL LABORATORY

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Testimony for the Record by
Maria Christine Richards
Director of SMU Geothermal Laboratory
Roy M. Huffington Department of Earth Sciences
Southern Methodist University
Dallas, Texas 75275-0395

Hearing on: Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation
Before the United States House Subcommittee on Energy
Rayburn House Office Building

November 14, 2019 at 2 pm

Chairman Lamb, Ranking Member Weber, and members of the committee, it is an honor for me to testify before you today. As a geothermal resources researcher, university program coordinator, past president of the Geothermal Resources Council, and as a taxpayer, your willingness to expand your knowledge of geothermal resources is appreciated. Today I'll share with you mechanisms for growing our country's ability to find new innovative methods to use this nation's resource base for improved energy independence. By expanding the use of geothermal resources across the United States, we build a more resilient, diversified electric grid, and cleaner environment for generations to come.

Senate Bill S.2657, The Advanced Geothermal Innovation Leadership Act (The AGILE Act) with hearings on June 20, 2019, proposed specific ways to increase geothermal development. The bill tells you *What* is helpful, yet does not tell you *Why* these items are important. Using my 25 years of experience in the geothermal community, I will provide background and examples on Why it is important to 1) increase our usage of the geothermal resources, 2) build projects connecting industries, and 3) the importance of university research and outreach.

Google.org, Siemens, Anadarko Petroleum, and Conoco Phillips, all came to the SMU Geothermal Laboratory for geothermal project involvement. Behind each large recognizable company are 1000s of other companies, plus individuals wanting to use the available geothermal resources. Through consistent long-term funding such as the AGILE Act initiates, the geothermal community can reach its full potential. It is important to realize the geothermal value for the entire country. When one examines the main geothermal applications: electrical power generation, direct-use of the fluid, and shallow heat pumps for heating and cooling, it makes sense for all 50 states' representatives to be interested in exploring options for increased geothermal development, from the cold north to the hot south and from New York City to Los Angeles.

Geothermal by 2050– GeoVison Study

"Earth is a gigantic heat engine. A tremendous amount of heat is constantly transported from its center to the surface by thermal convection and conduction".[1] Geothermal resources sit invisibly below us, *everywhere*! Earth will produce heat from its core 24/7 for billions of years. It is the oil and gas industry who comprehends the volume of untapped heat and fluids sitting idle waiting to be extracted, as they invest considerable effort understanding heat production in the earth and its association with hydrocarbon formation as well as avoidance of overheated subsurface zones when drilling. Petroleum researchers are the main users of our SMU heat flow maps to determine formation maturity. Oil and gas colleagues share that geothermal energy is

[1] Nagihara, S., Brooks, J.M., Bernard, B.B., Summer, N., Cole, G., and Lewis, T., 2002, Application of marine heat flow data important in oil, gas exploration. *Oil and Gas Journal*, 100(27), 43-50.

considered their 'retirement fund' because of how giant it is as a resource.[2] The more we drill, the more we understand how significant our resource is. Today's consumption for U.S. energy is approximately 100 EJ and geothermal stored energy is over 14 x 10^6 EJ.[3] It's also considered an emerging green energy, because it produces no direct carbon dioxide. As our society moves away from a carbon-based market, extracting geothermal resources incorporates similar oil and gas industry knowledge and skills. Still, the two industries are different.

The National Renewable Energy Laboratory completed the GeoVision Study for the Department of Energy, providing a roadmap that starts from today's Western US geothermal power production of 3.6 gigawatts to a deployment across our country of 60 gigawatts by 2050. And in parallel, expanding the current 2 million homes heated and cooled already by geothermal heat pumps, with this number increasing to 28 million homes, or ¼ of all homes by 2050. That's 30 years away, yet now is the time to act because geothermal power plants usually take 7 to 10 years from conception to production, and even having enough installers for the geothermal heat pumps requires time for local companies to grow and train employees.

For a comparison of what can be accomplished in 30 years, we can use the success story of today's shale play in the oil and gas industry.[4] Experimenting how to drill horizontal wells began in the 1970s. 20 years later it reaches production capability in the Barnett Shale. By early 2000s horizontal drilling reaches economic viability, and by 2010 it became widespread throughout all U.S. shale plays.[5]

[2] Cutright, B.L., 2012, The Transformation of Hydrofracked Reservoirs to Thermal Energy Production. AAPG Annual Convention presentation, Search and Discovery Article #80223.
[3] Blackwell, D.D. and Richards, M.C., 2006, Chapter 2. In Tester et al., *Future of Geothermal Energy*, MIT.
[4] Davids Hinton, D., 2018, *Shale Boom: The Barnett Shale Play and Fort Worth*. TCU Press. ISBN-10: 0875656854
[5] https://www.enverus.com/blog/unconventional-play-development-in-one-map/

Thus the DOE's focus on reservoir research for FORGE and Enhanced Geothermal Energy (EGS) are key to keeping us on the trajectory necessary for the United States to achieve the GeoVision roadmap to 60 gigawatts of electrical energy by 2050.

Build Projects through Connecting Industries

The SMU Geothermal Laboratory is known for its research on geothermal resource assessments and for our outreach program where we convene bridge-building conferences[6] between geothermal and other industries. The SMU conferences found collaborations between geothermal and the oil and gas industries, geothermal and waste-heat to power technologies, geothermal brines and desalination, geothermal deep direct-use of fluids and inlet cooling of natural gas plants, geothermal planning and district energy systems, geothermal power and transitioning of coal plants, and geothermal pumps for heating and cooling homes and buildings as part of off-grid projects. I see geothermal energy as the friendly and flexible energy option.

Energy Development in Rural America

We drive across the country pointing out to each other the wind turbines and solar arrays. The oil and gas well pads show-up from airplanes with their grid patterns. Yet the geothermal energy constantly being released by the Earth is invisible. Invisible because we can't normally feel or see it rising from the ground. Plus geothermal power plants are clean and have a small surface footprint.[7]

Rural America is where there is high economic growth creating undue pressure on cooperative electric utilities. As our coal plants age out of production, we see investments in

[6] SMU Geothermal Lab conference website and past papers available at http://www.smu.edu/geothermal
[7] https://www.energy.gov/eere/geothermal/geothermal-basics

natural gas plants and non-baseload renewable energy. Incorporating geothermal development into the mix will provide long-term security through increased diversification. Here are examples of possible projects:

Geothermal heat pumps for heat *and* cooling, are being incorporated into a microgrid for 7,500 net-zero homes in Austin, Texas in the Whisper Valley neighborhood.[8] New smaller binary turbines (less than 500 kW) can plug and play with watered out oil and gas wells as shown by the Denbury Resources demonstration in central Mississippi[9]. Using deep direct-use resources can reduce hot inlet temperatures to improve efficiency of a natural gas plant as shown at the Eastman Chemical power plant, Longview Texas.[10] Models show how retrofitting an aging coal plant to incorporate geothermal generation could keep plant workers employed while simultaneously transitioning to a cleaner environment.[11]

The shale plays produce high volumes of fluids along with the oil and gas production. Finding ways to generate electricity from the low-temperature produced fluid, in the range of 150 – 185 °F, could off-set the need for burning on-site fuels. The Southwest Research Institute in San Antonio, is working with a small company to get to market a technology that could generate electricity from produced water in many states (Figure 1).

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[8] Whisper Valley, Texas 78653

[9] ElectraTherm Report, 2012, Mississippi Oilfield Generates Low-Temperature, Emission Free Geothermal Energy at the Wellhead. Denbury White Paper, *SMU Geothermal Lab website*: http://www.smu.edu/geothermal

[10] Turchi, C., McTigue, J., Akar, S. Beckers, K., Tillman, T. 2018, Deep Direct-Use for Industrial Applications: Producing Chilled Water for Gas-Turbine Inlet Cooling, *Geothermal Resources Council Transactions.*

[11] 2018 SMU workshop on Coal and Geothermal: A Path Forward; Petty, 2016, Transitioning Coal to Geothermal, *Proceedings of 41st Workshop on Geothermal Reservoir Engineering.*

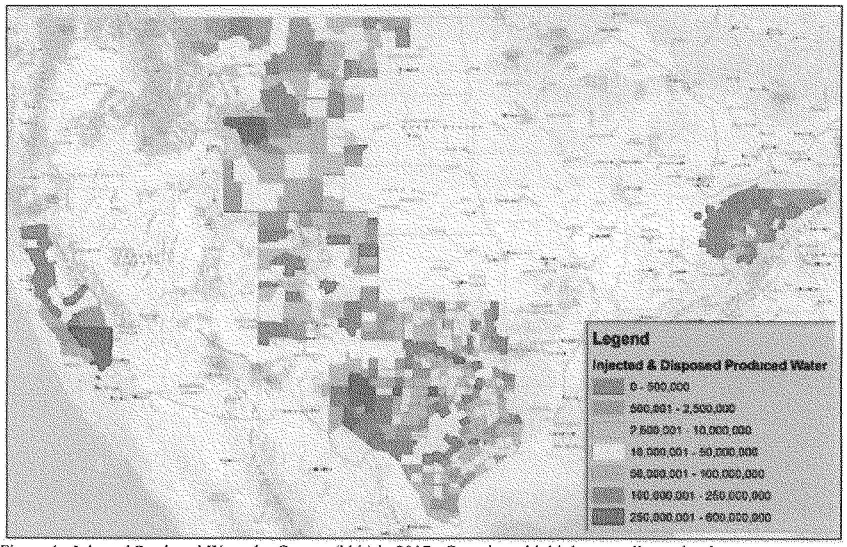


Figure 1. Injected Produced Water by County (bbl.) in 2017. Counties with high water disposal volumes, a proxy for high water production, are highlighted in red, orange, and yellow and are mostly concentrated in Texas and Oklahoma. This figure shows the estimated volume of injected produced water in barrels (42 gallons per barrel) generated at a county level in 2017, where available. These volumes are a proxy for water production, but do not account for reuse or water crossing county lines.[12]

Over the past 15 years it has been exciting for me to participate as new geothermal technologies enter the market, only then to become disappointed as I learn the company is out out of funds before a proper demonstration occurs. Technology breakthroughs for geothermal energy typically request funding in the range of less than $10 M, rather than the finance firms' preference of $100 M+. Technology companies need funding for small-scale low-temperature demonstrations in our sedimentary basins to prove both their technology and the resource long-term availability. An example: Dr. Will Gosnold of the University of North Dakota worked

[12] Produced Water Report: Regulations, Current Practices, and Research Needs, Module 2. http://www.gwpc.org/sites/default/files/files/Module%202.pdf

with a start-up technology firm to install two 125 kW binary-turbine using Continental Resources wells and pad in a Southern North Dakota oil field. Today the system is sitting idle because of repairs needed to successfully demonstrate the technology and field. The technology company does not have financing, nor does the University, and it's outside of Continental Resources' expertise/focus.

Oil and gas companies may be excellent at drilling their resources, yet they are *not* in geothermal resource plays nor in the electrical power industry and vice versa. The new AGILE initiative for DOE Offices of Fossil Energy and Geothermal Energy to transfer and adapt key technologies is an important next step. Funding is still necessary for both sides to work together on demonstration projects and to find synergies between industries for extraction and finances if the United States is going to achieve low-temperature (and high temperature) geothermal power from sedimentary sources.

University Importance in Training the Next Generation

The AGILE Act highlights a 5-yr consistent $150 M budget for competitive R&D, and $20 M for a mineral extraction competition. These funds are arriving at a critical juncture for universities. The AGILE Act also includes a specific resource assessment allocation for solely U.S.G.S., yet universities are the lead component in collecting and assessing these data for decades. Thus a broader initiative will provide critical funding for keeping faculty and researchers in geothermal exploration and training students, rather than changing to other fields. As an example, the SMU Geothermal Lab as a leader has received no upcoming funding for research in developing geothermal resource assessment techniques (details in section below). Therefore, we switched to researching methane hydrates and climate studies as a way to maintain our expertise in heat flow research, directing students to these new fields. Whether it is SMU, Cornell University, University of North Dakota, University of Utah, or University of Michigan, those founding researchers in heat flow and geothermal resources are either already retired or at retirement age. A geothermal fellowship program, similar to the Department of Energy Computational Science Graduate Fellowship, is another next step as part of training the next generation. Funding universities now is of most importance to preserve the greater knowledge transfer and keeping us as a world leader in geothermal energy.

The funding for resource assessments is also significant in growing the geothermal industry. SMU Geothermal Laboratory is just one example, yet look at the impact possible. Each new SMU geothermal map (1992, 2004, 2011, 2016)[13] developed new techniques from computer programing to inclusion of new data, e.g., oil and gas data, which highlighted the available resources of the midcontinent sediments from North Dakota to the Gulf Coast. Working with Google.org we developed nation-wide temperature-at depth maps to 10 km (2011) that led to working in Alaska (Figure 2) and with Cornell University and University of West Virginia to improve site-specific methods of temperature calculations and incorporate mapping of risk levels.[14] More recently our re-evaluation of the Oregon Cascades,[15] East Texas,[16] and the Snake River Plain, Idaho[17] examined geothermal potential on a 1 km x 1 km x 1 km resolution.

[13] Blackwell, D.D., and Steele, J.L., 1992, Geothermal Map of North America, *Geological Society of America* DNAG Map No. 006, scale 1:5,000,000.
Blackwell D.D., and Richards, M.C., 2004, Geothermal Map of North America, *AAPG* Map, scale 1:6,500,000.
Blackwell, D., Richards, M., Frone, Z., Batir, J., Ruzo, A., Dingwall, R., and Williams, M., 2011, Temperature-at-depth maps for the conterminous US & geothermal resource estimates, *Geothermal Resources Council Transactions*.
Batir, J.F., Blackwell, D.D., and Richards, M.C., 2016, Heat flow and temperature-depth curves throughout Alaska: finding regions for future geothermal exploration *Journal of Geophysics and Engineering*.

[14] Jordan, T., et al., 2016, Low Temperature Geothermal Play Fairway Analysis For the Appalachian Basin: Phase 1 Revised Report. Principal Investigator Teresa E. Jordan. Technical report DEE0006726.

[15] Frone Z., Richards, M., Blackwell, D. and Augustine, C., 2015, Shallow EGS Resource Potential Maps of the Cascades, *Stanford Geothermal Workshop*, Stanford University.

[16] Richards, M., Batir, J., Schumann, H., 2018, Resource Analysis for Deep Direct-Use Feasibility Study in East Texas, Geothermal Data Repository, https://gdr.openei.org/submissions/1073.

[17] SMU Geothermal Laboratory and Nat Renewable Energy Lab Subcontract No. XEJ-9-92239-01 under Prime Contract DE-AC36-08G028308. Shallow EGS Regional Resource Potential Map – Snake River Plain, 2019-2020.

At this level of detail, SMU determines total land surface area and location for future project development based on the different types of geothermal resource. Each of these projects involves students and successfully trains the next generation of professionals, which then positively impacted programs in other universities and organizations such as the Geothermal Resources Council.

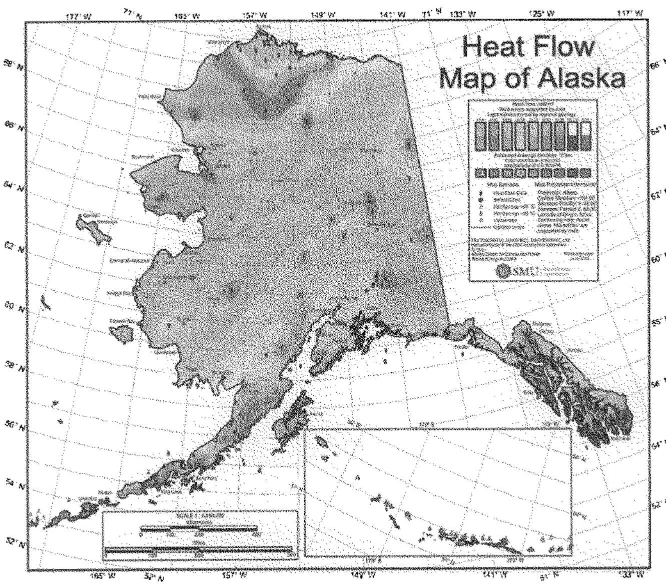


Figure 4. Subset of U.S Geothermal Map 2011 updated for the Geothermal Resources of Alaska, Batir et al., 2016.

Universities and their faculty are America's powerhouses for training the next generation of science, technology, and engineering workers. Their research drives the ability for the national labs to achieve excellence, and entrepreneurs' ability to drive technological innovation.

Your support for DOE's funding for universities, national labs, and companies will allow us to work together to find the innovations that will shift the United States from a fossil fuel dependent country to one with partnerships between industries; this is a win-win-win for the geothermal and other renewable industries, fossil fuel industries, and the public -one that will allow us to achieve the GeoVision roadmap to 2050, with more diverse, efficient, safe, secure, and sustainable energy solutions.

Today I've highlighted 1) why we need to increase our usage of the geothermal resources: it will provide a diversified and thus more secure, power grid, 2) why we need to build projects connecting industries: it leverages our strengths and provides a path forward, and 3) why it is important to fund university research and outreach: it preserves our current knowledge base while preparing the next generation of innovators.

Thank you for the opportunity to testify today. I welcome any questions you may have for me.

Brief Biography

Maria Richards is a researcher, project coordinator, and fundraiser for the SMU Geothermal Laboratory. She works directly with faculty and students overseeing related research as an Investigator on grants/contracts from initial application, management of budget, to final report with primary funding from companies, State Agencies (e.g., TXSECO), and Federal Agencies (e.g., Dept. of Energy; National Laboratories). She coordinates outreach programs on geothermal energy, speaks locally to internationally, developed and oversees the lab website, facilitates operations and training of oil/gas software, and develops learning activities between SMU and community programs. Research projects vary from temperature-depth maps for Google.org to on-site geothermal exploration in the Northern Mariana Islands, Peru, and Montana. Current concentration is on use of temperature well logs for understanding climate change, the transition of oil fields into geothermal production, and low temperature geothermal applications such as district heating for commercial buildings. She coordinated ten conferences focused on developing geothermal energy in oil and gas fields, building a network of individuals, companies, and government agencies from all aspects of development with cross-over between many related industries. Sponsorships from the conference help fund the lab outreach and student projects. Through the SMU Geothermal Lab outreach efforts Maria assists numerous companies and students world-wide to disseminate information on geothermal energy and resources. With colleagues, she coordinated the design, population, and ongoing dissemination of data for the SMU Node of the National Geothermal Database System. Highlights of research with Dr. David Blackwell include the Geothermal Map of North America, Dixie Valley Synthesis, Eastern Texas Geothermal Assessment, and the Report on the Future of Geothermal Energy; with Dr. Matthew Hornbach the Climate Impact of Northern Rocky Mountains. Maria holds a Master of Science degree in Physical Geography from the University of Tennessee, Knoxville and a B.S. in Environmental Geography from Michigan State University.

Chairman LAMB. Thank you. And Mr. Cohan?

TESTIMONY OF MR. SANDER COHAN, DIRECTOR, INNOVATION, ENEL GREEN POWER NORTH AMERICA, INC.

Mr. COHAN. Chairman Lamb, Ranking Member Weber, and all distinguished Members of the Subcommittee, I appreciate and thank you for the opportunity to appear before you today. My name is Sander Cohan. I lead innovation efforts for Enel Green Power North America. I am part of a team within the Enel group to lead the deployment and commercialization of new energy technologies.

I'm pleased to provide testimony in support of continued U.S. programs to foster geothermal and water technology R&D. As a longtime advocate for these technologies, Enel's innovation group focuses on issues of market deployment helping new ideas cross the so-called commercialization valley of death. As a company, we are interested in both incremental innovations that can improve existing technologies, and disruptive innovations that create entirely new opportunities. What is important to realize, that, instead of delivering on corporate venture capital, our mission is to serve as a catalyst and driver of energy innovation as an invention's first large industrial partner. The reason why I'm here today is that the programs described in the proposed legislation create the necessary preconditions to realize this mission. Without support from government, National laboratories, and inspiring startups, the full economic and social benefit and impact of geothermal and marine technology would remain out of reach.

To give more context, the Enel Group is a multinational energy company, and one of the largest integrated electricity and gas operators. Enel Green Power North America, based in Massachusetts, is one of the largest and fastest growing renewable energy companies in the United States. To date we manage over 100 renewable energy plants in 24 U.S. States, with a capacity of just over 5 gigawatts, leveraging wind, solar, hydroelectric, and, of course, geothermal and marine. The company is currently the largest wind operator in Kansas, and the second largest in Oklahoma.

With regard to geothermal and water power, Enel has a history of innovation in both. Italy is a birthplace of geothermal energy, with the development of the first commercial geothermal facility in Larderello, Italy more than 100 years ago. Today, in the U.S., we own and operate three binary cycle geothermal plants, distilled water and salt wells facilities in Nevada, and the Cove Fort plant in Utah, part of a global geothermal fleet that spans four continents. Enel's experience in water power, specifically ocean energy, is more recent. In the same way Enel manages a competency in geothermal, we also maintain a similar competency in marine energy research and development on both wave and tidal streams. Marine energy is a younger technology than geothermal, and the projects we have are largely in the development phase. Enel Green Power is focused on supporting companies to create and deploy foundational technologies to capture the energy produced by ocean waves. For example, we were one of the lead industrial partners in the Marine Energy Innovation and Research Center in Santiago, Chile.

Looking forward, Enel's current innovation slate for geothermal through 2021 contains budget for roughly 15 new projects. This pipeline contains a broad range of technologies, from ways to streamline and improve plant operations, to data, analytics, and methods to evaluate and process seismic data, to hardware intensive activities, such as new drilling methods, and investment in, and support of, enhanced geothermal systems, such as those being tested at FORGE. In the United States, Enel continues to leverage its presence as a geothermal operator to improve the state of technology and increase its economic value. Three projects highlight our ongoing and future commitment: Our Stillwater Triple Hybrid Plant that contains geothermal, photovoltaic, and solar thermal technologies; our Cove Fort Plant that contains hydroelectric and geothermal; and our recent commitment to the University of Utah's Earth and Geosciences Institute.

This is a way of saying that continued Federal funding in support of research, development, and deployment efforts is important. As Enel and other developers work to expand the footprint of geothermal energy, fundamental investment in scientific capital is essential to overcome substantial challenges. In order to remain competitive with other renewable energy sources, and serve as a viable resources, the programs being discussed today in today's hearing are essential. As a developer of technology, Enel's focus would be to expand and deploy these inventions, enhance geothermal systems, minerals recovery, and hybrid systems fostered under the investment made through this policy. Marine energy also deserves attention. Though my colleagues and I agree that more work is required, especially in the establishment of open ocean marine. These are key to bridging the gap between smaller scale university and naval sites and the commercial market.

In conclusion, successful energy innovations are difficult to realize, especially ones like geothermal and water power technologies, they rely on require the development of new infrastructure, and the construction of capital-intensive hard assets. They require intense cooperation throughout the entire value chain, originating in fundamental research and development programs like the ones today to initiate the process of technology transfer, and continuing through the process of technology deployment and commercialization. My team, and the rest of Enel Green Power, look forward to cooperating with this network of government programs, National laboratories, and industry and related fields, especially oil and gas, to lower the cost of deployment, and realize geothermal and marine's full potential.

Thank you again for allowing me this opportunity. My comments today and submitted testimony just begin to address this topic, and I look forward to fielding your questions.

[The prepared statement of Mr. Cohan follows:]

Sander Cohan
Enel Green Power North America, Inc.
November 14, 2019

Testimony to the House Subcommittee on Science, Space and Technology in Support of Geothermal and Water Technology R&D: "Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation"

I. Introduction

Chairman Lamb, Ranking Member Weber, and distinguished members of the Subcommittee, I appreciate and thank you for the opportunity to appear before you today. My name is Sander Cohan, I lead innovation efforts for Enel Green Power North America, Inc. My team and I are part of a global organization within the Enel Group to lead the deployment and commercialization of new energy technologies. Within this group, I focus on developments in the United States and Canada, serving as the project lead for proof of concept projects domestically and a conduit to communicate local best practices to our worldwide organization.

I am pleased to provide testimony in support of continued U.S. programs to foster geothermal and water technology research and development. Enel Green Power North America, Inc., in conjunction with its affiliated entities, has a long history of building and supporting geothermal and water power. As a longtime advocate for this technology, we focus on the commercialization and deployment of innovative inventions that lower overall cost of the technology, to achieve Enel's long term corporate and environmental sustainability goals.

The programs described in the draft legislation create the necessary groundwork and first step to enable broad scaling and market development of challenging and fundamental energy technologies. Without cooperation and collaboration from government, national laboratories, and inspiring startup technologies, the economic and social benefits of geothermal and marine technology would remain theoretical.

II. About Enel and Enel Green Power North America, Inc.

The Enel Group is a multinational energy company and one of the world's leading integrated electricity and gas operators. The Group works in 34 countries across five continents, generates electricity with a managed capacity of more than 90 gigawatts (GW) and distributes electricity, across a network spanning over 2.2 million km to more than 73 million end-users.

Enel Green Power North America, Inc. is one of the largest and fastest growing renewable energy companies in the United States, based in Andover (Massachusetts) with offices in Washington DC, San Diego (California), Oklahoma City (Oklahoma) Reno (Nevada), and Lenexa (Kansas). From 2015 to 2019 the company more than doubled its managed capacity, expanding from 2 GW to over 5 GW.

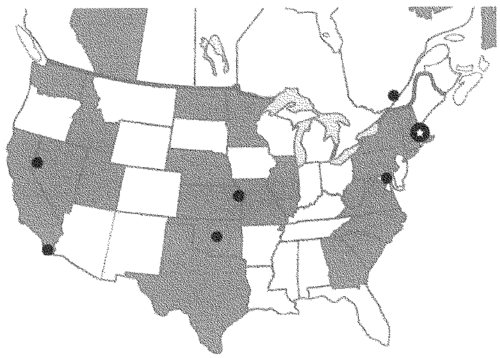


Figure 1: Enel Green Power North America, Inc. Footprint

To date, Enel Green Power manages over 100 renewable energy plants in 24 U.S. states with a diversified technology portfolio (wind, solar, geothermal and hydroelectric). The company is currently the largest wind farm operator in Kansas and second-largest in Oklahoma.

Enel Green Power is also a leader in the direct supply of renewable energy to corporate customers through long-term supply agreements. In total the company has 11 contracts, representing over 1 GW of Enel's capacity in the U.S., serving customers such as Anheuser-Busch, T-Mobile, Facebook, Adobe, General Motors, Bloomberg and Kohler.

III. Enel Green Power Innovation – Open Innovation Network Approach

Enel's approach to innovation is based on the creation of an Innovation ecosystem – a network of startups, national laboratories, industry consortia, and other formal and informal networks to push new clean energy technologies and business models into the marketplace.

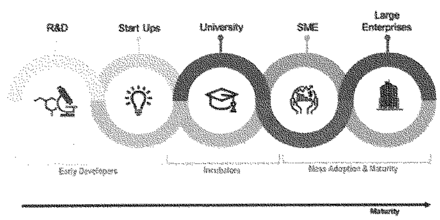


Figure 2: Innovation Network Ecosystem

With reference to geothermal energy, as detailed in a later section of this document, new ideas and potential partners come from a variety of sources. The majority of projects originate in academic and startup circles from researchers devoted to developing solution for the geothermal energy space. We also work with industrial partners from adjacent industries, such as oil and gas development, to take lessons learned and new ideas from their world into ours.

In the innovation ecosystem, Enel works as the strategic partner. We provide the capital, manpower, and industry expertise to take an invention from the late pilot stage to commercial deployment. This enables inventions to cross what is commonly referred to in emerging technology as the "commercialization valley of death". In this latter stage of research and development, the core technology has proven to have the potential to make a substantial impact in the market place but lacks the infrastructure and capital to scale from a single iteration. Crossing this valley is especially difficult for "hard" technology like geothermal and water power, which require the development of physical infrastructure and devices that have substantial technical risks and cost requirements. Our approach gives them the opportunity to scale up their solutions on our operations at global level so that we can use the innovation in place to make our traditional activities more efficient or to uncap new growth opportunities.

Enel typically does not make investments in startups. Instead, with its focus on providing equitable access to electricity it serves as the catalyst and the driver of energy innovation into the marketplace as an invention's first large industrial partner.

IV. Enel Green Power Geothermal Innovation

In our interest to support the global growth of renewable energy and the economic and social benefits this energy resource provides, we share the priority from the proposed legislation that increasing the use and reducing the cost of geothermal energy in the United States is essential.

Enel has a long history of geothermal innovation, starting with the development of the first commercial geothermal facility in Larderello, Italy outside of Pisa in the early 20th century. Today, Enel Green Power manages more than 880 MW of geothermal capacity globally, enough to power nearly 880,000 homes every year.

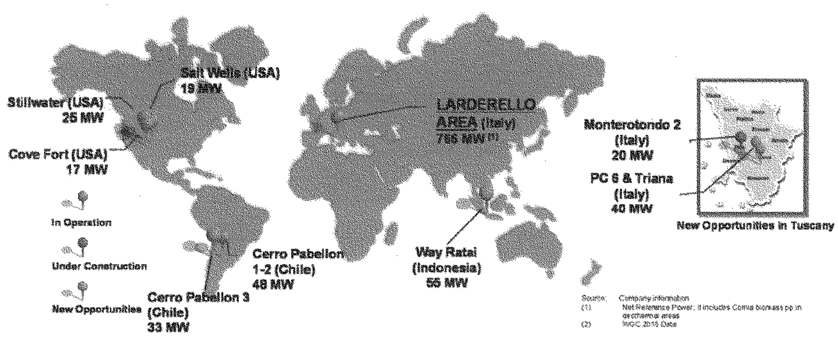


Figure 3: Enel Green Power geothermal footprint

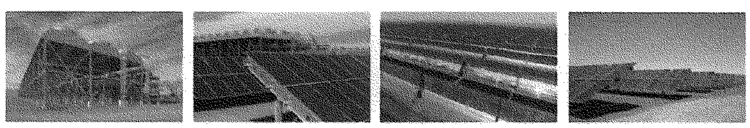
Geothermal energy is an important cornerstone of Enel Green Power's technology agnostic approach. In order to reach its decarbonization goals, the company understands the importance of relying on portfolio approach to project development. To that end, we seek to continuously grow our geothermal generation as a component of our portfolio spanning the spectrum of renewable energy generation technologies.

Enel's current innovation pipeline for geothermal through 2021 contains budget for roughly 15 new projects. This pipeline includes a broad range of technologies, from ways to streamline and improve plant operations, to data analytics and methods to evaluate and process seismic data, to hardware intensive activities such as new drilling methods and investment in and support of Enhanced Geothermal Systems (EGS).

In the United States, Enel continues to leverage its presence as a geothermal operator to drive the state of innovation in the industry forward. Three projects highlight our ongoing and future commitment to advancing the state of this technology.

Stillwater Triple-Hybrid Plant and CRADA with National Renewable Energy Lab and Idaho National Laboratory Teams: By adding a photovoltaic solar plant to an existing geothermal binary power plant and by subsequently enhancing that hybrid system with the further addition of solar thermal (concentrating solar power), Stillwater, located in Churchill County, Nevada, is the first plant in the world to incorporate all three renewable energy technologies at the same site on an industrial scale.

Stillwater's first-of-its-kind hybrid technology inspired a Cooperative Research and Development Agreement (CRADA) between Enel Green Power North America, Inc. (EGP), the National Renewable Energy Laboratory and the Idaho National Laboratory under the oversight of the U.S. Department of Energy Geothermal Technologies Office, to study the integration of these three technologies at the same site. This resulted in an award winning power plant and revolutionary research that confirms this hybrid theoretical model, paving the way for the possible deployment of hybrid solutions at other sites around the globe. In 2017, EGP began construction of a fourth project at the Stillwater site, the Stillwater PV II Solar Plant. The project, located adjacent to the existing site, supplies the project's corporate off taker, Wynn Las Vegas, with enough energy to meet up to 75% of the resort's current peak-power requirements.



Stillwater Geothermal Plant

- Start of Operations: 1H 2009
- Capacity: 33.1 MW
- Annual Generation: 150,000 MWh
- State-of-the-art medium enthalpy geothermal binary power plant. One of the only sites in the world to operate large-scale electrical submersible pumps for the extraction of geothermal fluid.

Stillwater Solar Photovoltaic Plant

- Start of Operations: 1H 2012
- Capacity: 26.4 MW
- Annual Generation: 44,000 MWh
- Over 89,000 polycrystalline silicon PV panels built on 110 acres.
  The PV plant compliments the geothermal plant's efficiency and production creating a better whole.

Stillwater Solar Thermal Plant

- Start of Operations: 1H 2015
- Capacity: 2 MW
- Annual Generation: 3,000 MWh
- 22-row parabolic trough system that concentrates the sun's energy by 75 times and adds energy to increase the temperature of geothermal fluid entering the plant, and allowing for a substantial increase in the amount of energy the plant can produce.

Wynn Solar at Stillwater

- Start of Operations: 1H 2018
- Capacity: 27 MW
- Annual Generation: 44,000 MWh
- The energy produced by the 160-acre solar PV facility will be sold to Wynn Las Vegas, marking an industry first partnership for a gaming operator in Nevada.

Cove Fort Downhole Generator Project – Adding Hydroelectric to Geothermal and Collaboration with Oilfield Operator Baker Hughes: Continuing the pattern of hybridizing our geothermal facilities is the ongoing effort to add hydroelectric power to binary geothermal energy. Enel's Cove Fort facility, located in Beaver County in Southwest Utah, was commissioned in 2013 and has an installed capacity of approximately 25 MW, enough to power more than 13,000 U.S. households.

The unique geologic conditions at the Cove Fort site created a situation where it was possible to integrate hydroelectric technology on the downstream side of the facility as geothermal brine was reinjected into the aquifer. The innovative generator technology captures the energy of the water flowing back into the earth to generate additional electricity while also better controlling the flow of brine back into the ground. This has the additional effect of mitigating conditions that that had potential to cause damage to the wellhead. The result is a new technology that can reduce operational and maintenance expenses, while also having the potential to generate additional revenues.

A partnership with oilfield services company Baker Hughes catalyzed the innovation. Baker Hughes manufactured the type of electric submersible pumps that the Cove Fort plant uses to pump geothermal brine out of the ground on the upstream side of the facility, and they collaborated with Enel to modify this technology to use it as a generator.

The first version of this technology was used throughout 2016 and produced noticeable results and improvements in efficiency. Findings from the initial testing phase held between July and September 2016 reveal that the addition of the hydro generator to the geothermal injection well resulted in an overall increase in output of 1,008 MWh over this time, improving the plant's operational efficiency. Enel continues to collaborate with Baker Hughes on this project to iterate and improve the generator design.

Collaboration with University of Utah Energy and Geosciences Institute (EGI): In early 2019, Enel expanded its commitment to geothermal innovation in the United States by joining the Energy and Geosciences Institute at University of Utah. The goal of this partnership will be to leverage the strengths of institutions on both sides of the Atlantic to address persistent challenges facing the development of geothermal energy. The collaboration will be focused on both conventional geothermal technologies as well as enhanced geothermal systems.

V. Support for U.S. RD&D to Advance Geothermal Technology

Enel voices its support for continued federal funding and support of geothermal research, development and deployment efforts. As Enel and other developers work to expand the footprint of geothermal energy, fundamental investment in scientific capital is essential to overcome the substantial challenges geothermal energy faces. In order to remain competitive with other renewable technologies and serve as a viable resource, the programs being discussed at today's hearings are essential.

As a developer of technology, Enel's focus would be to expand and deploy the inventions fostered under the investment made through this policy. As described above, our innovation program focuses on ameliorating the challenges that emerging technologies and business models face in the commercialization and deployment phases, dealing with the ability of an idea to scale from basic proof of concept pilot to fully realized, market ready product.

Enel's effort to help bridge the second, commercialization valley of death are only effective if there is investment and focus from U.S. institutions to bridge the first fundamental challenge of new ideas, the technology valley of death, concerned with growing ideas from core academic theory to initial proof-of-concept and minimum viable product stages.

The program areas described in the draft bill are, in general, congruent with Enel's geothermal innovation priorities. As technology development in these areas progress, the company would find itself a logical first customer, helping to scale and develop the technology and allow it to achieve a scale that would benefit U.S. jobs, economic growth and environmental goals.

Within the draft bill text, several specific goals align with Enel's innovation priorities

- **Support for Enhanced Geothermal Systems (EGS):** This is an area of active exploration. While in the past we have worked predominantly with European partners in this topic looking at the fundamental technologies required to make Enhanced Geothermal Systems possible, the foundation and creation of the Frontier Observatory for Research in Geothermal Energy (FORGE) project is a positive development. Enel looks forward to exploring opportunities to work in the U.S. to develop EGS technologies.

- **Geothermal energy as a grid management resource or seasonal energy storage:** As a way of improving the overall performance of geothermal electricity production, Enel is actively exploring ways to integrate new hardware and software technology to better manage the geothermal heat resource and overall plant output, both to deliver more baseload power and to increase the flexibility and reactivity of the geothermal resource to grid conditions.

- **Geothermal minerals recovery:** This remains an area of interest for Enel and could be an area for which our sites in the United States can serve as potential test sites as technologies leave the research area or are successful in a proposed prize competition.

The topics above, notably EGS and geothermal minerals recovery, have substantial overlap with priorities seen in the oil and gas industry. Oil and gas expertise in drilling, subsurface monitoring are also applicable to the geothermal world, and Enel looks to opportunities to gain from expertise in that sector. Other areas of Enel innovation focus that have connections to oil and gas include:

- **Artificial Lift Technologies:** Enel works with oil and gas industry partners to develop high temperature, high horsepower artificial lift systems (Electrical Submersible Pumps) and we have actively contributed to this cause through our involvement in the Society of Petroleum Engineers. Enel has even provided no cost training in Midland Texas to oil field ESP operators on ESP equipment reliability and operations, as the improvement of ESP technologies industry wide is well aligned to our mission in Geothermal power and district heating technologies.

- **Breakthrough drilling technologies:** Drilling costs are one of the major components of the entire geothermal project. Technologies that can reduce this cost have a formidable impact on savings for future projects.

- **Geothermal exploration and monitoring technologies:** Reducing drilling risk through better surface exploration techniques, applying modern models to seismic, gravity and magnetotelluric data.

- **New approaches to reservoir stimulation:** Utilization of alternative chemicals for well stimulation, utilization of hydraulic/thermal stimulation, including radial jetting.

- **Corrosion Scaling Monitoring and Control:** Corrosion is a major issue for steam systems, while scaling is more critical for water systems. Both the phenomena can create severe damage in wells, piping and turbine inlet.

In addition to these areas above, R&D priorities for Enel Innovation include, but are not limited to:

- **Zero (or near zero) emission geothermal**: We are currently studying closed loop plant designs, with total reinjection of all non-condensable gases to be ready for new European regulation limiting the CO_2 dispersion in the atmosphere by geothermal plants

- **CO_2 reuse, either from biological or chemical transformation, from geothermal emissions:** Testing different techniques for removing CO_2 from the emission stream, using chemical and biological components.

- **District heating, process heat uses from geothermal electricity production:** We are providing several district heating systems with geothermal heat from our power plant systems. An optimization of this cascade utilization can improve energy efficiency factor and can have an important impact on the local community energy balance.

- **Technologies to reduce chemical consumption in geothermal emissions control systems**: Developing a downstream gas treatments (H_2S and CO_2 removal) aimed at limiting chemical consumption. Developing an upstream treatment (i.e. chlorine removal) aimed at limiting chemical consumption.

- **Utilization of supercritical fluids:** It will be the new frontier of geothermal development: using supercritical fluid at very high conversion efficiency can create a very powerful generation system and savings on overall cost and land occupation.

- **New technologies for geothermal plant management:** Better data handling for power plant management, integration of all different systems into a single data lake, for better plant management and advanced diagnostic.

- **New technologies for geothermal resource exploitation:** New unconventional ways to exploit geothermal energy for power generation can be evaluated

VI. Enel Green Power Marine Energy Innovation

In addition to our support for geothermal R&D, the points proposed under the proposed water power innovation R&D also resonate with Enel's innovation mission.

In the same way Enel manages an innovation competency in geothermal energy, we also maintain a similar competency in U.S. marine energy research and development on both wave and tidal streams, with stronger emphasis on wave power.

Marine energy is in an earlier stage than geothermal, and as such Enel Green Power is focused on supporting companies to develop and deploy the foundational technologies to allow project developers to capture the energy produced by ocean waves.

Currently the bulk of Enel's project activity in this sector is focused outside of the United States in Europe and Latin America, but it does not mean that the United States has not a good resource potential. That noted the substantial technology development taking place in domestic innovation clusters has created a scenario where while project development is not taking place domestically, there is substantial technology scouting taking place, with U.S. companies and organizations making meaningful contributions to Enel innovation programs.

VII. Enel Green Power Marine Energy Innovation Focus Areas

Enel Green Power Innovation has current operations supporting the development of marine technology.

Device Testing and Deployment: Enel Green Power Innovation has an active scouting activity looking for opportunities to test and deploy utility-scale wave energy conversion devices both in the United States and abroad. These are all in relatively pre-commercial stages. Recently, however, Enel Green Power signed a purchase agreement with New Jersey-based Ocean Power Technologies (OPT) to deploy their PowerBuoy devices at the Marine Energy Research and Innovation Center (MERIC) in Chile.

Marine Energy Research and Development Centers: In collaboration with the Chilean Government, French firm Naval Energies and University stakeholders, Enel is participating the development of a marine energy research and development center called the Marine Energy Research and Innovation Center (MERIC). Within this area, Enel Green Power has specifically taken leadership of establishing the Open Sea Lab, a facility devoted to providing a "test bench" for research to test technology solutions for marine energy in an open-ocean environment.

VIII. Support for U.S. RD&D to Advance Marine Energy Innovation

Enel Green Power supports the programs highlighted under the proposed legislation. It agrees that the establishment of open-ocean marine energy test centers are key to bridging the gap between university and military marine test areas and the commercial market. The company remains excited to support their development.

Other specific interests from Enel Green Power include, but are not limited to:

- **Grid Connection Cost Reduction:** One of the most significant components of marine energy project capital expense is represented by the grid connection. Enel would like to identify best practices for interconnection of marine energy production. This involves not only best an easiest solutions from a technical and economic point of view but also identifying potential partners to for collaboration.

- **Low environmental impact moorings and foundations:** A main issue for marine energy converters is the development of low impact moorings and foundations, ones that can secure advice in place in the ocean environment but minimizes the impact on wildlife and geography.

- **Power Take Off systems of Marine Energy Converters:** A best mechanism for power offtake for wave or tidal energy has yet to be found. Enel is looking for disruptive solutions to support. The solutions have to be robust, minimizing the mechanical parts in contact with water and full sustainable.

IX. Final Remarks

Thank you again for allowing me this opportunity. Energy innovation, especially ones that rely on the development of new infrastructure and hard assets to succeed, like geothermal and water technologies, are especially difficult to realize. They require intense cooperation through the entire value chain, originating in fundamental research development programs like the ones described in this legislation to initiate the process of technology transfer, and continuing through the process of technology deployment and commercialization. Contrary to how we think of it process is not a series of discrete steps, but rather an integrated ecosystem and a series of cooperative efforts. My team and the rest of Enel Green Power look to cooperate in this network with government programs, national laboratories, and industry in related fields, notably oil and gas, to lower the cost of deployment and realize geothermal and marine energy's full potential. The policy discussed in this hearing is an essential first step.

Speaker Biography

Mr. Cohan directs North American Innovation for Enel Green Power North America, Inc. He has over 15 years of experience in the energy sector, specializing in innovation and emerging and alternative energy technologies. He has served as chief project director and manager for technology projects in diverse areas such as energy storage, microgrids/smartgrid technology, predictive analytics/big data, geothermal energy, hybrid renewables, and marine energy. His expertise is in the implementation of aspirational policy goals, both responsive to and anticipatory of government stimulation of private markets in innovative technology.

Prior to joining Enel, Sander worked in a variety of roles focusing on the commercialization of clean energy technologies, most recently as a Principal at ESAI Energy as the founder of that firm's practice in Renewable Energy, Climate, Transportation Fuels and Electric Vehicles. He has a M.A. in Energy Policy and International Finance from the Johns Hopkins University School of Advanced International Studies and a B.A. from Columbia University.

Chairman LAMB. Thank you very much. We'll begin with our first round of questions, and I recognize myself for 5 minutes.

Dr. Solan, there's been increasing discussion on our Committee all year, and back in Western Pennsylvania, where I represent, about emissions from the industrial and heavy manufacturing sectors, you know, sort of apart from the grid itself, and how we start to tackle some of those problems. So I was curious, is DOE's Geothermal Office looking at this problem at all, and how you could provide heat for sort of very serious heavy manufacturing, whether it's steel or other similar processes?

Dr. SOLAN. We are. The Geothermals Office has actually started a program for looking at feasibility of deep direct use for industrial heat processes. So we have a number of studies that represent a number of use cases in a diversity of regions around the U.S. I believe that there's six or so, and I think two are in the Appalachian Basin. So they're looking at various processes, and trying to take a look at innovation in these areas. So whether it's agriculture, or a little bit higher temperature processes, but still low temperature for industrial processes in east Texas. We are just finishing those up, and the Appropriations Committees have taken an interest in doing an eventual demonstration, but we're not quite at demonstration stage yet, so we are also looking at opportunities in more design engineering as a possible next step.

Chairman LAMB. Is there any particular industry, or sector, or type of manufacturing, that would be the most promising from the early studies?

Dr. SOLAN. That I would have to get back to you on, but I know agriculture, paper drying, these are the types of activities that a number have looked at, especially with the low temperature at this point.

Chairman LAMB. OK. Are you coordinating with the Advanced Manufacturing Office on any of that, or do you know if they're engaged in this same line of activity.

Dr. SOLAN. In these activities, I don't believe so. I'd have to get back to you. But we are engaged with the Advanced Manufacturing Office (AMO) with geothermal on a number of activities, one of which is with AMO and the Critical Materials Institute with opportunities to harvest lithium from geothermal brines. That's an area. And we are also in discussions with them on taking a look at advanced manufacturing for specific geothermal mechanisms and parts, et cetera. So we're taking a look at that as well.

Chairman LAMB. OK. Thanks. Ms. Richards, you highlighted the possibility of retrofitting aging coal plants for geothermal. Has that been tried anywhere, or is it more sort of in the idea phase? Could you just kind of elaborate on that a little bit?

Ms. RICHARDS. Yes. The idea of transitioning a coal plant to geothermal is the ability to do it over a long period of time, so it'd be 5 to 10 years, most likely, and the best cases have started to be looked at. Primarily Susan Petty is the person who's spearheading this, and she has looked at, and her team, at ones in Oregon and Washington, and then also in Texas, because of our aging Texas coal plants. And what we have focused on in Texas was the idea that we could overlap with the oil and gas industry, and their wells. And the idea is that you would use the same—they already have water, they have infrastructure, they have the turbines, they have a workforce. And so the goal would be—is to use that same workforce, re-train them, and use the same grids, and things like that, and slowly transition from electric power from coal to geothermal being the power source.

Chairman LAMB. Do you know sort of where on the spectrum they are toward a demonstration-type activity, or——

Ms. RICHARDS. Susan has talked with people in Montana as well, so there's a coal plant in Oregon that has been—specifically been in discussion with her. So those are the two States that have been closest to discussing it. So in terms of the blueprints that would be getting to that point, I would need to go back to her and give you more information.

Chairman LAMB. Great, thanks. And just wanted to ask one question for the group. I don't know if Dr. Solan would be the one, or anyone, but I'm curious about hydropower as it gets built onto existing infrastructure. I think a lot of us, given the difficulty of getting infrastructure legislation through, are skeptical about truly large-scale dams in a lot of parts of the country. But in Pittsburgh, for example, on the Allegheny River, the University of Pittsburgh has helped develop adding hydropower capacity to an existing lock and dam that we have on the river. And it's small, but it's going to supply about a quarter of the electricity for the University. Are you aware of other efforts underway to do similar things like this on our existing infrastructure?

Dr. SOLAN. Yes. There's actually about 80,000 unpowered dams that provide a great opportunity. Even if we could do just a small number of those, or a small percentage, it would actually provide a lot, in terms of reliability and resiliency. So we are doing activities in these areas. WPTO actually looks at, in a couple areas, low head hydro, standard modular hydro. So these are the type of the areas where, if you put in smaller, modular, cheaper turbines, and—it would make a lot of sense because in the past—hydro's an interesting industry, because when dams were built a very long time ago, if it was for power, folks just optimized it to deliver as much energy as possible, and then they thought about the environment after that. Now that we're looking at in stream reaches and low head, we're actually trying to design it as an integrative function across all the needs that you need to meet. Instead of making it unique to one situation and one spot, as we did many years ago, to get that last kilowatt hour out of every project.

For the most part, a standard modular design would work many different places, and it would actually bring the cost down a lot, so we expend a lot of activities in that particular area.

Chairman LAMB. Great. Thank you, and I'm out of time. I'll recognize Mr. Weber for 5 minutes.

Mr. WEBER. Well, where do we start? Thank you. I'm going to go back to you, Deputy Assistant Secretary Solan, for a minute. As you mentioned in your prepared remarks, the future of the electric power grid may look very different than it does today. Do I recall correctly there are nine grids in this country, electric grids? Do you know that number?

Dr. SOLAN. I don't. It depends on how you define the—whether it's reliability, or organization area, or interconnections, but there's a lot of different market structures, and—whether it's regional, transmissional, or——

Mr. WEBER. I'm thinking there's nine grids, and, of course, Texas——

Dr. SOLAN. Um-hum.

Mr. WEBER [continuing]. Has ERCOT, Electric Reliability Council of Texas——

Dr. SOLAN. Right.

Mr. WEBER [continuing]. Which is about 85 percent of the State's in its own grid. So you say that it's going to look very different, however, no matter how those grids evolve, we understand that many of today's challenges will still be there in the future, meaning we will still need to address grid flexibility. You said connectability, how you define a grid, and I would add variability, while we want to ensure the reliability and the affordability of energy resources. So, as we seek to decarbonize the electric power sector, we will need to advance a diversity of clean energy resources in order to encourage the development of innovative energy technology, while ensuring at the same time minimal cost increases for American consumers, you follow me? OK. I'm getting to my question.

As the Deputy Assistant Secretary for the Office of Renewable Power, how do you propose to balance all of these? First we have to define those grids. How do you balance those, affordability, reliability, all at the same time?

Dr. SOLAN. So the—for—Assistant Secretary Simmons has made one of his three core pillars on affordability, so everything that we do is trying to bring the cost down, and the efficiency. I mentioned the GMI before. This is one of the efforts that we're doing to make sure that the grid is both reliable and resilient, and that we're bringing costs down to make it more affordable as we move forward. But the grid is definitely transitioning over time, and how we use electricity, the system's becoming—the need for flexibility and speed is a lot greater than——

Mr. WEBER. Is absolutely increasing. How often do you coordinate with the Advanced Research Projects Agency Energy, ARPA-E, in your work with the Geothermal Technologies Office and the Water Power Technologies Office? Do you get to coordinate with them?

Dr. SOLAN. Yes, we do. Actually, for each area, the ARPA-E has actually had some calls related to enhanced geothermal systems, with the input of the Geothermal Office, to make sure that the space that they were in was complementary to the work that we were doing, and all of our applied research offices in renewable power actually worked directly with ARPA-E on those, and in many cases we actually sit on each other's panels.

Mr. WEBER. And the Office of Science as well?

Dr. SOLAN. The Office of Science—we do a lot on the storage area, which does include hydro. We do a lot in EERE generally to do with battery chemistries, so that's not only in renewable power, but that's also in the Vehicle Technologies Office as well. But we also work on that with grid storage. So that's Assistant Secretary Simmons' second pillar, is on storage.

Mr. WEBER. OK. I'm going to jump over to you, Dr. Moore. In your prepared testimony you highlight the various conditions of your research site that make it an ideal location for DOE's first FORGE field laboratory. So how unique are these conditions, number one, and the second question, in your opinion, how important is it for this kind of experimental geothermal facility to represent general geologic conditions across the entire country?

Dr. MOORE. The DOE established five criteria for an ideal enhanced geothermal system. One was temperatures of 175 to 225 Celsius degrees at 1-1/2 to 4 kilometers. The second was the rock type should be granite. Third was no environmental issues. Fourth was low seismicity, and fifth was no connection to an existing system, so a Greenfield system. We looked at sites across the country, and Utah is not unique. Granite is the country rock. Here's an example of one, what it might look like, and the permeable fracture in it. Granite is found across the country. In fact, I would suggest that we could drill here, beneath our feet, to find conditions that are similar. Probably drill a little deeper, but we would find very similar conditions here.

Mr. WEBER. Mr. Chairman, I have about 17 more questions, but I guess I'd better yield back. Thank you.

Chairman LAMB. And only 15 more seconds, which is a shame.

Mr. WEBER. I know.

Chairman LAMB. Now recognize Mr. McNerney for 5 minutes.

Mr. MCNERNEY. I thank the Chairman. I thank the witnesses. I really liked your testimony. It's encouraging, it's positive. Thank you for that. Dr. Robertson, you mentioned a capacity potential for 4,300 terawatt hours. That's per year, right?

Dr. ROBERTSON. Yes, that's correct.

Mr. MCNERNEY. And how much of that is marine power?

Dr. ROBERTSON. All of those would sit within the sort of broader space of marine power. Wave would account for about 80 percent of that. The numbers were, if I can bring them back up——

Mr. MCNERNEY. Well, I was kind of driving at a question. How much impact would that have on the coast, if you took that much energy out of the waves and the——

Dr. ROBERTSON. Goodness, this is, like, a bulk resource. It's not feasible to block the whole coastline to generate that much electricity, so it's really about finding locations where you understand the implications of the other economic activities that are happening in that location. In the State of Oregon, and the test facility we are building there with Oregon State University, we've had extensive engagement with the crab fishery, the Dungeness crab fishery. So you have to account for all these. It's a large marine special planning exercise to try and identify high priority locations, and use those as your first deployment sites.

Mr. MCNERNEY. Thank you. Dr. Moore, talking about injection and production of geothermal, how about the wastewater? How does the wastewater production from geothermal compare with the wastewater production from fracking, for example?

Dr. MOORE. These are completely two different processes. In a fracking environment, water is produced, along with oil and gas, and that water has to be removed, it can't be reinjected. So, in the oil and gas industry, that water is taken somewhere else and injected into rocks that are already saturated with water. And occasionally some of those fractures in the basement will slip, and we have earthquakes. Geothermal doesn't have wastewater. We inject, and we produce. So, in a natural geothermal system, the water is already present in fractures like these. That water is produced, and then it is re-injected back into the reservoir. In fact, by law it's——

Mr. MCNERNEY. So you re-use the wastewater.

Dr. MOORE. Yes. It's renewable in that——

Mr. MCNERNEY. All right. Thank you. Ms. Richards, what about some of the extra benefits of this wastewater? For example, in Southern California, there's efforts to couple geothermal with critical mineral production.

Ms. RICHARDS. Yes. In fact, the lithium industry, there's a company from Australia who is working on the largest geothermal power plant that will exist in the United States just to extract lithium. So there's a lot of production there. The wastewater, though, also in our sedimentary basins, has a huge opportunity for us to gather heat, and create small distributed energy systems, as well as larger EGS systems. So even in the central United States, this wastewater has opportunity to be productive.

Mr. MCNERNEY. OK. Thank you. What about the role geothermal plays in base load, and providing additional grid storage? What are some of the benefits of that part of geothermal energy?

Ms. RICHARDS. So, with storage—and solar makes a lot of heat, and so—but if it's at night, it gets cool, so the goal is to take that hot solar fluid that—solar can heat fluid. That fluid is then put into wells, such as abandoned oil and gas wells. Those wells then become a storage which contains that heat, that then is brought back to the surface, and then is used during the day for needs—for the grid, or to offset the solar.

Mr. MCNERNEY. OK. Dr. Robertson, you highlighted in your testimony the need to educate and train the next generation of energy technicians and engineers, and so I couldn't agree more. What role can our universities play to enhance that situation, to improve that situation?

Dr. ROBERTSON. Thank you for that question. That is the fundamental role of the universities, and the colleges, and our training programs across the country, to do that. You know, we facilitate the workforce that goes into our fantastic National labs, and into the governments, and into our private companies, and it is our role to take young raw talent, educate them, teach them to be innovators in that space, and then put them into these different companies or institutions. And in the marine energy space, there is no lack of interest in those new recruits. Fundamentally our issue generally is funding to do the research and the training to put them through so they can do it, so we can put them into the labs, put them into companies, and put them into government.

Mr. MCNERNEY. So Federal grants, and so on, are very important in that process?

Dr. ROBERTSON. Exceptionally important. Both the grants and the vision associated with them so that we can make sure we attract and maintain the best faculty members within the universities to focus their research enterprise in this space so that they aren't attracted by something else where there is research and investment, so——

Mr. MCNERNEY. Thank the Chairman for the indulgence, yield back.

Chairman LAMB. And recognize Mr. Baird for 5 minutes.

Mr. BAIRD. Thank you, Chairman Lamb, and Ranking Member Weber, and I want to thank all the witnesses for being here today, and sharing your knowledge with this Committee, because we're in a constant search for reliable, cost-effective sources of energy. So I'm going to start with Ms. Richards. In your prepared remarks, you described how expanded geothermal energy generation could benefit rural communities, and ease the pressure placed on cooperative electric facilities. District 1, that I represent in Indiana's Fourth congressional District, is largely rural. So could you expand on how increased geothermal energy generation could benefit these rural districts, and our rural cooperatives?

Ms. RICHARDS. Yes. Geothermal, because it's everywhere—as Joe said, it's right below us even, right here, has the ability to build small or large, depending on the high-temperature or low-temperature resource that is there, but then to either build electricity, or offset the need for electricity through something as basic as a geothermal heat pump for a home, or a building, or a school. But it also has the ability to then stabilize the grid with distributed, and with the storage of—like we talked about earlier. And so it's the idea that through—especially sedimentary basins, and being in Illinois, there's a sedimentary basin there that could be tapped into for a distributed system.

Mr. BAIRD. So would any of the other witnesses care to comment on that question about the impact in rural areas?

Dr. ROBERTSON. I couldn't speak to the geothermal aspect of that question, but I think it's important to highlight the multitude of scales that both of these technologies can work at, whether you're using a heat pump for a single community, or whether you're developing a large scale facility to power an electric grid, I think the same opportunities exist on the water power technology side. There the DOE has funded a fantastic project to put an in-stream hydrokinetic turbine in Igiugig, Alaska to provide power to a community that's pretty much inaccessible most of the winter, and 100 percent relying on diesel generation. And these are the sorts of technologies that you can create smaller scale and deploy for rural and remote communities. Additionally, it's not just coastal communities that also get to benefit from this. There are also communities that are landlocked, through technology innovation.

Dr. SOLAN. So where there's current expression, and obvious resources, for geothermal for conventional hydrothermal systems, these tend to be in pretty rural areas. So these provide important jobs for specific areas, whether it's in parts of Wyoming, or Utah, or Idaho, like Raft River, or Neal Hot Springs in eastern Oregon. These tend to be communities where it's an important employer. And also it's an innovative technology, so it does attract talent also from outside the region.

Dr. MOORE. May I follow along with a comment? FORGE Utah, in fact, is located near a community of 1,400 people. We employ the local residents. We employ the students at the local high school. They're excited about renewables. They take that information to their parents. We provide jobs for the neighboring towns. So it's an important resource, and heat pumps—in terms of rural communities, heat pumps are not geologic-specific, and so they can be used anywhere, and they are being used. Electric and direct use require population centers, but, with enhanced geothermal systems, I think that's a viable alternative for rural communities as well.

Mr. BAIRD. Thank you very much, and I yield back the rest of my time.

Chairman LAMB. Thank you, and Mr. Foster for 5 minutes.

Mr. FOSTER. Thank you, Mr. Chairman. Thank you to our witnesses. As we put more renewables on the grid, that obviously makes a bigger premium on energy storage, which is something I've been worried about a lot. I'm proud to have introduced what's called the *Better Energy Storage Technology Act* (*BEST Act*), which now has 38 bipartisan co-sponsors. It would reauthorize and reorient the DOE's grid scale storage, research, development, and demonstration efforts around ambitious technology goals to facilitate breakthroughs. And the *BEST Act* directs the Secretary of Energy to establish moonshot goals of up to five demonstrations of grid scale energy storage that will meet aggressive commercialization targets for cost, performance, and durability, and so I have several questions about that.

First, could you elaborate on how you see the horse race between the different things like pumped hydro, and so on, and how they are going to compete against the rapidly falling prices of batteries, for example, and where you think that's going? Dr. Solan?

Dr. SOLAN. So right now hydro actually accounts for, in pumped storage, 95 percent of our actual storage for the——

Mr. FOSTER. Currently the winner, right.

Dr. SOLAN [continuing]. Which a lot of people don't know, but it's kind of taken for granted. It's also a great example, thinking about how pumped storage operates, how the grid's changing, because it used to be you'd pump the water at night, when rates are low, and there wasn't much demand, and then, as load ramped up during the day, and there was a peak, you'd let the water down, and you'd produce some power. Now things are changing, actually. So we have a couple studies that WPTO is working on with Argonne National Laboratory to take a look at some of these issues, and the preliminary results are actually showing, from actual pumped storage facilities, that that's not the way that they're necessarily operating anymore.

So, for example, in California, where there's a lot of solar, and there's a lot of generation at certain points in the day, it turns out that, for arbitrage, and, based on the rates, that they might actually pump up during the day, and then have, like, a sort of a head-and-shoulders pattern, where, as solar comes down, then you start letting the hydro out. So it's actually illustrating how the grid is changing as we get more variable resources with that.

A lot of companies are looking at grid-scale storage in the near term with lithium ion. It depends on what their targets are, as you were saying, if you set different goals for different, say, durations of power, or different materials. So DOE Office of Electricity is actually looking at batteries that are for grid scale, but don't necessarily use——

Mr. FOSTER. Yes. Well, the legislation we've introduced is deliberately technology neutral. I was wondering how it was likely to end up. And, you know, Ms. Richards, you mentioned the idea of just pushing the heat back in the ground, and maybe then cycling that, which is a concept I wasn't familiar with. I'd presume that does not ramp on and off very rapidly, or does it?

Ms. RICHARDS. It could be done daily.

Mr. FOSTER. Daily, yes——

Ms. RICHARDS. Right.

Mr. FOSTER [continuing]. But not when a cloud goes over the solar array? It's not going to respond to that time scale, I would assume?

Ms. RICHARDS. I would agree with that. Yes.

Mr. FOSTER. So it may well be that optimized storage will have a mixture of many technologies. Are pumped hydro—is that essentially a mature technology, that turbines have been designed by geniuses back in the 1930s——

Dr. SOLAN. There actually are some new types of designs that are coming out, but a lot of this was built a long time ago.

Mr. FOSTER. Yes.

Dr. SOLAN. And one thing that we're discovering on the innovation side that is not necessarily on the actual power production side, the Water Power Office sponsored a FAST Prize to commission pumped storage hydro faster, and a couple of the winners recently—they were actually tunneling and construction companies who said, this is not the way we would do things today. We could reduce the costs with these technologies that we've been developing for different types of industries. So that's where some of the innovation is heading.

Mr. FOSTER [continuing]. Underground reservoir is potentially on flat areas, like the 11th District——

Dr. SOLAN. Yes, and there are some innovative sub-surface—there's closed loop, which is not connected to natural hydro systems.

Mr. FOSTER. OK. Dr. Moore, when I recall last looking at enhanced geothermal, there were problems that were—the development of hydraulic shorts between the injection and production wells induced seismicity, corrosion of the produced water causing lifetime problems, and then just the difficulty of dumping the heat. You'd obviously need a nearby river, or some sort of—you need a source of cold, as well as a source of heat, to get your Carnot engine, what's the status of those?

Dr. MOORE. We can take them one by one. In terms of the thermodynamics, that's been resolved. We can use single flash, double flash, multiple turbine systems for electric——

Mr. FOSTER. OK. I was referring to, you know, you have a production injection and an extraction well, and that you'll get one channel carrying all the burden, and you won't really extract heat from the whole rock mass.

Dr. MOORE. That's a potential problem, or a challenge, in any geothermal system. We're looking at Utah FORGE in a different way. Most of the—in fact, all of the EGS projects prior to this have looked at large sections of open hole, and tried to fracture those large sections, and in that case you will tend to get a single fracture that controls fluid flow. We're actually taking a step back and using oil and gas technology. So, at the FORGE site, we'll be casing the well, and then using isolation equipment to isolate small sections of the well, stimulate those sections behind casing. In fact, we had the first test in April. It was very successful. So this is a mechanism to avoid that short circuiting.

Mr. FOSTER. OK. And, Mr. Chair, could I have another 30 seconds?

Chairman LAMB. Yes.

Mr. FOSTER. All right. Yes, so the corrosion for the rock types you're looking at, is that not an issue?

Dr. MOORE. Corrosion is not an issue in geothermal systems. It tends to be a problem in the Salton Sea, with the solid contents of 300 thousand parts per million plus, and the fluids are acidic. In most geothermal systems, fluids are benign, and corrosion is not an issue.

Mr. FOSTER. OK. And then, finally, the location, do you need a river nearby to dump the heat? Or what is the cold source of——

Dr. MOORE. No, you can't dump the heat. This is a recirculating system, and so the fluid that comes through the turbine——

Mr. FOSTER. But you need a Carnot-cycle engine going from hot to cold, and——

Ms. RICHARDS. Actually, what I'm understanding is—in our binary technology systems, that those systems have a hot and cold side, and so the hot fluids coming out of the Earth go back down, and get re-injected. But in order for the binary surface part to be able to have that Carnot difference, you have the cold source, which is either air cooled, or that's where the river comes in, or the idea of some sort of water source at the surface that is a cold—to create a difference in temperature.

Mr. FOSTER. Right. OK.

Ms. RICHARDS. But not at a large power plant.

Chairman LAMB. I may just have to stop you there so we can recognize Ms. Bonamici, and thank you for your patience.

Ms. BONAMICI. Thank you very much, Mr. Chairman and Ranking Member, for allowing me to participate as a full Committee Member, but not a Member of the Subcommittee. I am so glad I'm here today. This is a great discussion. Thank you to the witnesses. The ocean covers more than 70 percent of the surface of our planet, and we know that the waves, and currents, and tides can be used as a plentiful renewable resource. And as we transition to a clean energy economy, we need to recognize that potential of marine energy. According to the U.S. Department of Energy, there's enough kinetic energy in waves and tides along the U.S. coastlines to meet a significant part of our Nation's power, and Dr. Robertson thank you for clarifying that in your testimony—reinforcing that.

Oregon is at the front of marine energy, thank you for recognizing that, with Dr. Robertson, you being here today, and it's in large part because of the leadership of Oregon State University, the Pacific Marine Energy Center, and pioneering businesses like Vigor, one of our great shipbuilders in Portland. Last month I had a chance to see the ocean energy device Vigor built in collaboration with the Marine Energy Center before it before it got tugged off into the Columbia River, and it's on its way to the coast of Hawaii.

It wasn't until I was actually standing in front of it, and actually got to climb onto it and explore it, that I understood and grasped the scale of this resource, but also the potential. Importantly, we can recognize that efforts to extract power from moving water can be done without jeopardizing the integrity of marine environments. And I know, from representing the north coast of Oregon, we can get that done.

We know the potential of marine energy, and Federal investment can help unlock it. I'm continuing to lead my colleagues in advocating for robust funding for the Department of Energy's Water Power Technologies Office. This funding supports the leading research and development efforts at the Pacific Marine Energy Center, but will also help efforts to establish a wave energy test facility off the coast of Oregon. I'm also pleased to be co-leading the *Marine Energy Research and Development Act* with Congressman Deutch from Florida. Our bill will accelerate the introduction of marine energy production in the United States.

So, Dr. Robertson, you mentioned in your testimony—you talked about how the development of marine energy technologies is a challenge, so can you talk about the current barriers for the demonstration of technologies, and how Congress can better support these efforts to make sure that marine energy doesn't fall within that commercialization valley of death? We want it to be deployed at scale.

Dr. ROBERTSON. Thank you very much for the question. I think there's a host of ways that, through supportive funding, and through collaborative efforts between the National labs, the universities, and industry we're looking at these questions of how do we avoid the valley of death, and how do we get at some of the hurdles? So, first, working in the ocean is just more expensive. You need to use vessels, you need to wait for the waves to die down, you need to be able to access the ocean. It's a lot more expensive than having a pickup truck, and driving out into a field, and testing a wind turbine. It just takes longer. There are seasonal effects as well. Off the coast of Oregon, there is about 6 months of the year where we would not be able to access it. So it does take longer to do this innovation, but we are achieving significant successes, the ocean energy buoy on its way to Hawaii being one of those examples.

The development of the PacWave test facility off the coast of Oregon is a significant step in that direction. It provides a baseline, or an environmental impact, of marine energy. It provides a final demonstration site for U.S. technology developers to prove out their products before selling them into the domestic market and internationally. It allows us to compete with our European partners, who are also active in that space. So it's a big part of the effort as we go along.

The other thing I think—one of the biggest hurdles we continue to face in this space is going through the environmental permitting process, but there are opportunities of great collaboration. In that realm, I've got to acknowledge the efforts of Dr. Andrew Copany of PNNL, the Pacific Northwest National Lab, who writes, for the International Energy Association's Ocean Energy Systems Report, "State of Science," where are we in this space, so that we can start to work with regulators to accelerate the development——

Ms. BONAMICI. I'm going to try to get another question in the remaining time.

Dr. ROBERTSON. Sorry.

Ms. BONAMICI [continuing]. No, that's OK. I want to really focus on how Congress can better support the development, but I appreciate that you talked about the holistic view of the development pathway. So what are the advantages of partnerships, and, based on your understanding of the *Water Power Research and Development Act* discussion draft——

Dr. ROBERTSON. Um-hum.

Ms. BONAMICI [continuing]. Are there additional resources that the centers would need to thrive and compete with other energy sources?

Dr. ROBERTSON. Yes. You know, I think we have a great collaborative model, with the Marine Energy Centers representing the academic institutions, with the National labs being actively involved. With the industry being part of the sector, it's very collaborative. This isn't a competitive industry. This is one where we all identify collaboration as the only way for us to move forward.

I see one of the hurdles right now, as my previous comment said, was training the workforce to enter these National labs, enter these industries, so they can continue to thrive. We need to make sure that the smartest, the brightest people end up in the space, and drive the innovation pathway, and do it quickly. So it's the combination of the training to get the people into the industries, and providing the infrastructure to allow them to test quicker, test cheaper, and test more rapidly.

Ms. BONAMICI. Terrific. As a Member of the Education and Labor Committee, we're working on that as well, from that perspective. Thank you again, Mr. Chairman and Ranking Member. I yield back.

Chairman LAMB. Thank you very much. Mr. Cohan, in your testimony you talked a little bit about the role that you all play in investing technologies that have not been proven to work as a first of a kind demonstration, but don't yet have the capital and infrastructure to move beyond that. So I was kind of hoping you could maybe elaborate for us a little bit on your theory of where the government is best involved here, and where it's not, particularly as you get closer toward demonstration scale. What's the balance between government and private sector involvement? Where have you seen us work well together, where do you think we should be doing more, or just doing better?

Mr. COHAN. You know, I think that there are opportunities all across the value chain. I think when we think about the commercialization valley of death, and sort of the barriers to commercialization, or the technology valley of death, it's actually a series of mini-valleys. There's a series of pitfalls all the way down and all the way back up that I think would benefit from support from government services. I'm glad we're discussing Vigor and the ocean energy device. I think they make a good example.

Principally, I think there's a number of ways. One is, you know, I think in terms of supporting programs for partnerships between large industrials and startups, government has a larger and broader view. But I think more importantly, government has a way of supporting the groundwork for these things to happen. So not just the development of technology, but development of infrastructure around these technologies. The creation of, for example, in the marine energy business, onshore heavy industry to build the infrastructure to build offshore devices. I think this is really important from an education standpoint, I think it's important from a skills standpoint, and it's important from a technology and infrastructure.

The ocean energy device, for example, is enormous. You can't build that every day, and you can't build that in your backyard. And so support for, you know, and then support for that can come from any number of ways, from, you know, a loan guarantee program to specific challenges and programs to focus and develop industries around technological advancement.

Chairman LAMB. Do you think loan guarantees have proven to be an effective method for enlarging some of these projects?

Mr. COHAN. They are a method I would say. I would say that, you know, the idea here is not to specifically mandate a technology, because I think there are different needs, and different ways, and it's very hard for anybody to see in the future, but I think the role here is to create the bandwidth, and the environment, and the space for industries, and National laboratories, and startups to work together. And so that can be, you know, everything as light, as I said, you know, a water power challenge, but it can also be specific programs to drive partnerships into a marketplace, or create a marketplace in industry.

Chairman LAMB. Thank you. That's very consistent with what we've heard many times this year. And with that, I yield to Mr. Weber for 5 minutes.

Mr. WEBER. I thank the Chairman. 5 minutes is never going to get it, but we'll start. To all the witnesses, when it comes to advancements in water and geothermal power technologies, how important, or have you considered is it important, the role of international collaboration, first question. If so, who are our main international collaborators in this space? And, third, who are our competitors? Dr. Solan, I'll start with you.

Dr. SOLAN. That's a great question. In terms of geothermal, we've actually been very active in working with New Zealand. New Zealand's been helpful in supplying data for us to actually do some machine learning AI (artificial intelligence) type projects, and we have an agreement with them. But the Geothermal Office is also working directly through Geothermica, which is working with the EU, and essentially leveraging both resources to provide some shared projects. So we've actually been working with them, and they've been——

Mr. WEBER. So is it important we've got collaboration with those? Who's our competitors?

Dr. SOLAN. From what I understand, of course, China is pursuing all areas of energy.

Mr. WEBER. I'm sure they're going to convert their coal plants to geothermal.

Dr. SOLAN. I did want to mention, though, also on the water power side, they're very involved internationally, and we're actually hosting, for the first time ever in the U.S., an international conference next year related to marine and ocean energy, and that's a great opportunity for the U.S. to show leadership.

Mr. WEBER. Let me jump over to Dr. Robertson. Is it important, international collaboration?

Dr. ROBERTSON. Without a doubt. It's key. You know, we need to leverage every dollar in every part of the world to facilitate the development of this industry, and there are huge lessons learned—so over the past year. I've traveled to our main competitors and collaborators, if we count the EU and Australia. There are other countries who are spending significant dollars in this space. I would say the U.S. plays a leadership role through the Water Power Technologies Office, understanding that we need to open the aperture of what we consider marine energy to do.

Mr. WEBER. I need to move on. Dr. Moore, is it important?

Dr. MOORE. It's critical, especially in this enhanced geothermal environment. These are extremely expensive experiments——

Mr. WEBER. OK.

Dr. MOORE [continuing]. And we need to leverage what we can. Right now we are working closely with China, who has their own EGS experiment——

Mr. WEBER. Are you afraid they will steal our technology?

Dr. MOORE. There's no technology to steal here. We need to learn how to do this——

Mr. WEBER. We already know how to do all this.

Dr. MOORE. I wish we did.

Mr. WEBER. OK. That's what I'm afraid they're stealing from us. Ms. Richards, how about you? Is it important?

Ms. RICHARDS. Yes, in terms of China. They're the ones who developed the first oil and gas field into geothermal——

Mr. WEBER. OK.

Ms. RICHARDS [continuing]. So they did it before Texas.

Mr. WEBER. Well, we need to steal—I mean we need to talk them about that technology.

Mr. WEBER. Mr. Cohan?

Mr. COHAN. I think international collaboration is critical, but that's because I'm biased because my job is 100 percent about international collaboration.

Mr. WEBER. OK.

Mr. COHAN. I'm the link between our U.S. and Italian operations.

Mr. WEBER. Yes.

Mr. COHAN. You know, thinking about, you know, collaboration versus competition, there are more projects than money or people right now, and so, you know, there's only outside, and there's only collaborative outside. The reason why we're operating in Chile is because there is a positive effort from the Chilean government to build a marine energy business there.

Mr. WEBER. I need to move on, if I may, so let me talk about the wave energy that you talked about. I'm from a coastal area. I have the first three coastal counties of Texas, starting at Louisiana, that other foreign country, and then going down southwest. So is there any thought to when you have that kind of a structure, and you harness the power of waves, does it reduce the amount of erosion on that beach? Has that been looked at, do you know?

Mr. COHAN. I don't have any specific expertise in that area, but I can find out for you.

Mr. WEBER. OK. One would assume that if you harness the power of the waves, and slowed them down, the surfers might complain about that, right? They have to get out in front of that barrier to do the surfing. But that's something interesting, if you can get back to that. Let me——

Mr. COHAN. I suppose—to that end, I suppose it depends on the technology. It depends on how far out in the ocean you're talking about.

Mr. WEBER. Sure.

Mr. COHAN. So, you know, a lot of wave energy technology that we develop, we're pretty far out there.

Mr. WEBER. Well, so what's the distance? You're going to have the infrastructure, the transmission lines, as it were, albeit buried, you know, beneath the waves on the ocean floor. How deep's the ocean floor, how big is the line, what's the miles? What's the furthest out you all have contemplated going?

Mr. COHAN. We haven't gone too far out. As I said, these technologies are sort of in early stages, but you're talking about in the hundreds of meters to kilometers.

Mr. WEBER. OK.

Mr. COHAN. So, you know, when you're talking about the Gulf, you know, we have offshore rigs that are about the——

Mr. WEBER. Yes. We're going 20 miles to 40 miles out——

Mr. COHAN. Right.

Mr. WEBER [continuing]. With oil export terminals.

Mr. COHAN. And you could piggyback on the infrastructure. I mean, that's——

Mr. WEBER. Well, that's the point.

Mr. COHAN. Yes.

Mr. WEBER. Sure. You bet. Mr. McNerney and Dr. Robertson, that was about the beach erosion. I'm jumping back. Ms. Richards, you talked about injecting the fluid that it was hot, you didn't need it, and you injected it at night, and you brought it back during the day. Do you remember that?

Ms. RICHARDS. Yes, I did.

Mr. WEBER. OK.

Ms. RICHARDS. Correct.

Mr. WEBER. You're going to lose temperature at some point. You're going to have a temperature drop. Have we calculated how much of a heat loss we have at that point?

Ms. RICHARDS. So there are people who have worked on that, and I can get back with you in more detail.

Mr. WEBER. OK. And then, finally, Mr. Robertson, you were talking with Congressman Baird about a community in Alaska that had a potential project. What's the population of that community?

Dr. ROBERTSON. I don't know the number off the top of my head, but it's less than 100.

Mr. WEBER. Less than 100? I would say that's a fairly small-scale plan.

Dr. ROBERTSON. Without a doubt.

Mr. WEBER. Yes. And you said they do diesel power. Are you aware of Newfoundland, I was there about 10 years ago, give or take, and they use a lot of diesel power. Do you know if they still do?

Dr. ROBERTSON. Newfoundland?

Mr. WEBER. Yes.

Dr. ROBERTSON. They do, and they've got their large-scale hydro system that they're also building. Part of the value of these small communities is that we can build economies of scale, and we can build small prototypes that are cheaper.

Mr. WEBER. OK. All right. Well, I don't want to keep everybody. Thank you, Mr. Chairman.

Chairman LAMB. Thank you. And Mr. Foster for an additional 5 minutes.

Mr. FOSTER. Thank you, Mr. Chairman. Mr. Cohan, could you say a little bit about collaborations with the National labs, and how you see this fitting into things? Dr. Solan, I'm sorry.

Dr. SOLAN. Yes. We've worked directly with the National labs in all of our programs, so we utilize the universities, we utilize the National labs. It depends on the program which specific ones that they work with, but National laboratories are—foundation of knowledge, as far as—and doing certain work that is mission driven, based on our programs. And they also work directly with businesses.

Mr. FOSTER. Is the handling of the intellectual property, which we've sort of touched on, you know, is there a clearly understood national goal that's in, you know, I sort of view the decarbonizing the world economy as two problems. One, the U.S. You know, we have enough money in this country to decarbonize our own economy, but unless we can develop cheap technologies, that's not going to be enough for, you know, India, South America, other places with less money, so we have to work on knocking down the costs of these things.

And part of that is that we're not doing this entirely as a profit-making enterprise for the United States. We have to understand we're providing technologies that will be used worldwide. And I guess, Mr. Cohan, what is your sort of attitude about the worldwide goals in this? Are there a bunch of for-profit entities that are trying to go and dominate the market here, or are they really trying to all solve the problem with whatever technology ends up working?

Mr. COHAN. We see this mission as part of—we see them as one in the same, frankly. We see corporate sustainability as part of environmental sustainability. So we've made a very specific decision as a company to pursue clean energy as a means of maintaining ourselves as an entity going forward. And so, you know, our core mission is an idea of open power, the idea that, as we create things that benefit the communities we operate in, we too survive as a corporation.

Mr. FOSTER. Yes, Ms. Richards?

Ms. RICHARDS. I'd like to point out that many of the small technologies for turbines that have come through United States that are companies that haven't succeeded, and now one of the companies that is pushing forward is a company called Climeon, who's out of Norway, or Sweden, up in that part of the world, and coming in, and is, like, the new, exciting one that people are also looking at. And that's a case where we are losing out because it is needed technology around the world, and if we could support these small companies, we would have a technology to export.

Mr. FOSTER. OK. So there's still a problem with tech transfer in this? That, you know, there's a long list of things that were developed at U.S. labs and commercialized offshore, including many money-losing enterprises offshore.

Mr. COHAN. Can I add to that? On tech transfer, you know, when we partner with startups, and when we partner with National labs, we have a very clear delineation between IP that we create mutually, and IP (intellectual property) that the startup brings to the community, and we try to focus, as a company, on our core mission, which is producing reliable electrons, and valuable electrons. And so our goal is to support the development of this R&D, and to support the development of intellectual property. And so, you know, if we were to—it, it would get in the way of our actual mission.

Mr. FOSTER. Now, someone who—may have been Dr. Solan, mentioned salinity gradients as a source of potential power. What's the status of that, and are there near-term projects? Dr. Robertson, it's yours? Your testimony also mentioned charging stations for underwater things. Is there a bunch of military money going into that for drone swarms and stuff? If you'd just give a quick update on those two things?

Dr. ROBERTSON. So, on the first one, I would have to get back to you on it. I'm not familiar with the current status of ocean thermal and ocean salinity. On the second one, the UUV, underwater vehicle recharge, yes, there's definitely military interest in that space, but there's also great oceanographic interest too. We don't understand the ocean yet. That is purely due to the fact that we can't provide reliable power to sensors in the deep ocean, and we need to be able to overcome that barrier. We have the sensors, but we can't power them. So marine energy provides an opportunity for us to be able to power those sensors so we can understand the ocean. We also have military applications that those would provide a huge benefit to.

Dr. SOLAN. We did mention in testimony thermal conversion. In terms of the priorities of the WPTO, we spend the most, in terms of marine energy, on wave energy, because that's our biggest resource, and probably thermal conversion is probably an area where we provide the least, just because of the opportunities, and where our budgetary priorities are.

Mr. FOSTER. All right. Thank you, and yield back.

Chairman LAMB. OK. Thank you again to all the witnesses for joining us. This was a tremendously helpful hearing, as we get ready to finalize this legislation. Just a reminder the record will remain open for 2 weeks for any additional statements from Members, and for any additional questions the Committee may have for the witnesses. With that, the hearing is now adjourned.

[Whereupon, at 3:41 p.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. David Solan

U.S. House Committee on Science, Space, and Technology
November 14, 2019 Hearing: "Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation"
Questions for the Record Submitted to Dr. David Solan, Deputy Assistant Secretary for Renewable Power, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

QUESTIONS SUBMITTED BY REPRESENTATIVE CONNOR LAMB, CHAIRMAN, SUBCOMMITTEE ON ENERGY

Q1. The industrial sector, which contributes the 3rd most greenhouse gas emissions in the U.S., is difficult to decarbonize because, amongst other reasons, it often requires high temperatures that fossil fuel combustion is well-equipped to provide.

- Since geothermal energy technologies can tap extremely high temperatures, is DOE's Geothermal Technologies Office (GTO) studying heat provision for industrial or heavy manufacturing processes, such as steel production?
- Is there any industry, sector, or manufacturing process that looks most promising as an application for geothermal heat provision, from early studies?
- Does GTO coordinate with DOE's Advanced Manufacturing Office in any of these efforts to use geothermal heat for manufacturing processes?

A1. Geothermal energy can contribute to decarbonization in a number of ways, at both high and low temperatures. For instance, higher-temperature (>150° C) geothermal resources can provide direct electricity production, potentially offsetting industrial energy needs.

Looking longer term, the DOE's Geothermal Technologies Office's (GTO) concerted early-stage R&D efforts are aimed at technologies that can yield reliable and cost-competitive enhanced geothermal systems (EGS) that will enable the use of geothermal resources essentially anywhere, including in high-temperature direct-use applications that could serve heavy-industrial process energy demands. Further, a GTO-sponsored Task Force Report[1], released alongside the *GeoVision* report in May 2019, reported the potential for geothermal hybrid energy applications, including hybridizing with solar energy, thermoelectric power generation (natural gas and coal), algal hydrothermal liquefaction, and compressed-air energy storage. This analysis indicated opportunities for hybrid electricity production that could power a number of industrial and manufacturing uses.

[1] https://www.osti.gov/servlets/purl/1460735

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Future opportunities exist for uses beyond 250°C, such as coal-geothermal hybrids for boiler feedwater preheating or natural gas-geothermal hybrids with geothermal providing the feed-air precooling. Higher-temperature stable resources could potentially drive higher output that can benefit industrial processes as well as reduce levelized cost of electricity and improve efficiency.

In the near-term, a variety of opportunities exist for low-temperature geothermal resources (below 150° C), which are currently underutilized across the United States. About 25% of U.S. energy use occurs at temperatures less than 120° C, most of which is from burning natural gas and oil. The greatest of this demand is for water heating and space heating between 60°-80° C or 140°-176° F. Direct use of lower-temperature geothermal resources ($<150^{0}$C) can provide many benefits, including electricity, storage, heating and cooling solutions, and additive value in mineral recovery and desalination. Industrial processes that requires only heat and not steam, such as food processing, dehydration, and greenhousing, can potentially utilize low-temperature geothermal resources.

GTO collaborates with the Advanced Manufacturing Office (AMO) on several programs, including identifying pathways to introduce advanced manufacturing processes for improving geothermal tools, components, and equipment, as well as on critical materials.

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QUESTIONS SUBMITTED BY REPRESENTATIVE BILL FOSTER

Q1. In your testimony, you briefly discusses salinity gradients as an area of marine energy research within the Water Power Technologies Office. Salinity gradients are also considered under the definition of marine energy in the draft Water Power Research and Development Act of 2019 discussed during this hearing.

- Are ocean salinity gradients a viable energy source? What is the current status of this research, and any near-term projects DOE is involved in? What plans does the Department have for future research in this area?

A1. The oceans around the United States contain a tremendous amount of untapped energy in many different forms and are therefore an exciting area for early-stage research for the U.S. Department of Energy (DOE). Ocean salinity gradient technologies are one of several ways to harness energy from the ocean.

Historically, the Water Power Technologies Office (WPTO) R&D portfolio has not focused on salinity gradients, and salinity gradients are not explicitly mentioned in the program's authorizing language. However, ocean salinity gradient research may be an area with future potential if it can meaningfully contribute to reducing energy constraints for a number of different existing and prospective at-sea applications or maritime industries, as described in the DOE's "Powering the Blue Economy" report in April of 2019.[2]

WPTO has funded one R&D project in the area of salinity gradients, using it as an opportunity to learn more about the technology space. This project was selected for Phase I of a Small Business Innovative Research (SBIR) grant in 2017 and began Phase II in 2018. It is an ongoing project. The system uses a salinity gradient between river and seawaters and generates electrical power. The electrical power is then converted into hydrogen in low-pressure metal-hydride storage.

[2] https://www.energy.gov/eere/water/powering-blue-economy-exploring-opportunities-marine-renewable-energy-maritime-markets#pbereport

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WPTO's plans for future research in this area will depend on the results of the SBIR project as well as further developments in this space.

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QUESTIONS SUBMITTED BY REPRESENTATIVE PAUL TONKO

Q1. The Department of Energy's GeoVision report sets a goal of increasing geothermal electricity generation and heat production "26-fold by 2050". The report states that to reach that goal, geothermal resources must be capitalized in areas with high 'economic potential' – i.e., areas in which geothermal energy is physically available, technologically feasible, and economically viable. That same report clearly shows that the greatest economic potential for geothermal energy exists in the Northeastern and Midwestern states (see: Figures 4.7 and 4.8). However, most pioneering research, development, and commercial production of geothermal energy (such as the FORGE sites) has traditionally occurred in the Basin and Range province of the American West, where the resource is easily-accessible but, as GeoVision shows, the economic potential is the lowest in the United States.

- What steps could be taken to ensure that the research, development, and commercial production of geothermal energy occurs in the same places where the economic potential is highest?

A1. DOE's Geothermal Technologies Office's (GTO) research directives focus on areas of high potential and economic viability with considerations for variances among geothermal resource types, recognizing geothermal energy as a 50-state solution. For instance, direct use of geothermal energy can make heating more affordable and ease the need for natural gas and other fuels, as well as reduce demands on the electricity grid. These benefits are of particular value in the Northeastern United States, which has high district-scale energy demands. As a result of this demand, the Northeast has high economic potential for geothermal Deep Direct-Use (DDU) district-scale heating and cooling of homes, buildings, industrial complexes, university campuses, and military installations.

To understand other regions of the country where district-scale energy demand is also high, GTO has invested $4 million in six DDU studies to determine the technical and economic feasibility of using geothermal resources underlying several diverse geographic spots in the United States—including Portland, OR; Champaign-Urbana, IL; Morgantown, WV; Ithaca, NY; Longview, TX; and Hawthorne, NV. The Department of Energy's FY 2020 Congressional Budget Request included $6.5 million in support of the

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Advanced Energy Storage Initiative for GTO to competitively select projects for Reservoir Thermal Energy Storage (RTES) R&D including deep direct use (DDU) engineering, design and systems research; this R&D is critical for modernizing the nation's electrical grid and minimizing impacts from variable energy sources, as RTES provides an on-demand "earth battery," holding hot water in storage.

GTO research in the western portion of the United States focuses on unlocking the potential of commercial enhanced geothermal systems (EGS) resources. Once EGS becomes cost-competitive, geothermal resources can be used anywhere and geographic restrictions largely disappear.

The determination as to whether EGS resources are used for power generation or direct-use applications will depend on the temperature of the resource at accessible depths. The Northeast has significant low-temperature geothermal resources that make them well suited for district-scale heating systems or other industrial applications with a heat demand that does not require process steam. The technologies developed from GTO's Frontier Observatory for Research in Geothermal Energy program, or FORGE, will be directly applicable to enabling power generation and direct-use geothermal applications throughout the United States.

Q2. The President's 2020 budget request proposed to cut funding for the Geothermal Technologies program by two-thirds. The House rejected that proposal, and instead recommended a funding increase ($90 million, up from $84 million) for the program.

- Are these funding levels adequate for you to ensure that the ambitious goals of the GeoVision report are met?
- Will that funding allow the research, development, and demonstration projects on the scale necessary to reach all the milestones identified in the GeoVision roadmap to be viable?

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A2. The targets in the *GeoVision* report are indeed ambitious. There are a number of non-technical challenges that will need to be addressed in order to meet the targets laid out in the *GeoVision* report, such as reducing permitting time, analyzing and documenting the full value of geothermal energy, and educating energy stakeholders about geothermal. It should be noted that addressing many of these non-technical challenges are not within DOE's authority, but are called out based on their importance in achieving commercial adoption at the levels envisioned in the report.

The President's FY 2020 Congressional Budget Request supports technical R&D activities that make progress towards the goals laid out in the *GeoVision* report.

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Questions for the Record Submitted to Dr. David Solan, Deputy Assistant Secretary for Renewable Power, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

QUESTIONS SUBMITTED BY REPRESENTATIVE DAN LIPINSKI

Q1. Geothermal energy research discussions are primarily focused on large-scale power plants. However researchers in the Midwest, including at the University of Illinois, are more focused on advancing low-temperature direct-use technology.

- Can you please describe research needs to advance low-temperature direct-use geothermal applications? What are the Department of Energy's plans to advance research on low-temperature direct-use?

A1. As indicated in the *GeoVision* report released by DOE's Geothermal Technologies Office (GTO), geothermal energy features numerous attributes that make it uniquely valuable in the energy sector. One key attribute is the diverse array of geothermal resource types and applications, which offer potential for geothermal use far beyond electric-power generation. For example, the economic potential for district-heating systems using existing direct-use geothermal resources combined with technology advances in enhanced geothermal systems (EGS) is more than 17,500 installations nationwide, compared to just 21 such systems currently installed in the United States.[3]

GTO addresses this broad range of research opportunities by leveraging R&D investment in cross-cutting initiatives to advance resource use for non-electric power generation. For example, the technologies developed through GTO's Frontier Observatory for Research in Geothermal Energy (FORGE) program will directly enable the development of low-temperature geothermal resources for district heating and other industrial applications.

Additionally, GTO spends $8–10 million annually on projects specific to low-temperature geothermal resources. Through an interagency agreement with the United States Geological Survey, GTO is currently supporting an update to the national geothermal resource assessment for low-temperature resources. In GTO's FY 2017 FOA, "Deep Direct-Use (DDU) Feasibility Studies," six teams were funded to estimate the Levelized Cost of Heat and conduct feasibility studies of DDU on military bases,

[3] https://www.energy.gov/eere/geothermal/downloads/geovision-harnessing-heat-beneath-our-feet

university campuses, and industrial and hospital complexes. One of these projects included a collaboration among the University of Illinois at Urbana-Champaign, the U.S. Army, and the University of Wisconsin to examine the requirements for developing a heat recovery complex that integrates geothermal energy sources with existing district-scale heating and cooling systems at the university campus.

GTO will continue to prioritize R&D into low-temperature, non-electric sector geothermal resource use, including a focus on the feasibility and systems engineering of geothermal direct-use applications.

Responses by Dr. Bryson Robertson

Bryson Robertson, Ph. D.
Co-Director, Pacific Marine Energy Center at Oregon State University
Associate Professor, Civil and Construction Engineering

Before the Subcommittee of Energy
Of the Committee on Science, Space and Technology
U.S. House of Representatives

Questions for the Record (QFR)

December 6th, 2019

Q1: In your testimony, you briefly discussed salinity gradients as a potential source of marine energy. Salinity gradients are also considered under the definition of marine energy in the draft Water Power Research and Development Act of 2019 discussed during this hearing.

- *Are salinity gradients a viable marine energy source? What is the current status of this research, and any near-term projects?*

Unfortunately, salinity gradient marine energy is outside my area of professional expertise, and I am not suitably aware of progress in this arena to appropriately answer this question.

I might suggest the International Renewable Energy Agency (IRENA) report *"Salinity Gradient Energy: Technology Brief"* or the *"Salinity Gradient Energy: Current State and New Trends"* article in the Engineering Journal as excellent starting points to better understand this energy resource.

Sincerely,

Bryson Robertson
Co-Director, Pacific Marine Energy Center
Associate Professor, Civil and Construction Engineering
Oregon State University

Responses by Dr. Joseph Moore

House Committee on Science, Space and Technology

"Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation

Questions submitted by Representative Stevens

Q1-1. *The term geothermal energy can encompass several different technologies.*

Could you briefly describe the main types of geothermal energy technologies being used today and those with the most promise for future development. Namely electric power generation, direct-use of fluid, and shallow heat pumps for heating and cooling.

The three main types of geothermal energy are all substantially under-utilized, compared to their potentials. Expanding the use of all three would make important contributions to the economic and environmental health of our communities. The differences between them revolve around thermodynamic potential and economic risk.

- Electric generation is the gold standard of geothermal energy development. Electricity is our most transportable and universally useful form of energy. As such, it has the highest economic value and replaces the most hydrocarbon fuel.
    - Generating plants use water that is hotter than most direct use applications, typically greater than 350°F. The hot water is produced at high pressure from deep wells, passes through the generating plant, and is injected back into its original formation. The generating plant extracts a portion of the heat from the water either by reducing the pressure to boil off steam ("flash") to drive a turbine, or by passing it through a heat exchanger to power an Organic Rankin Cycle ("binary") generator.

    - Most of the economically accessible geothermal systems suitable for electric generation have been found, primarily in the western states. The current technology for geothermal electric generation is highly dependent on favorable hydrology, geology and transmission availability. Even in the west, the cost of well drilling deep into bedrock is often the factor limiting development of a known resource. The Utah FORGE project aims to remove those constraints of hydrology and geology that have limited geothermal electric generation to the west, thereby extending its benefits nation-wide.

- The second thermodynamic tier of geothermal energy is direct use of hot water, typically at temperatures less than about 300°F.
    - Hot water is commonly used for spas, space heating (e.g. residential and office buildings, greenhouses), aquaculture (growing fish and prawns), vegetable drying and various industrial processes. The produced hot water is passed through a heat exchanger, where the heat can be transferred to culinary water for consumption and heating, before being reinjected. In a few cases, the water source for a direct use project is a geothermal electric plant. For example,

outflow water from a generating plant has been used to dry wood chips for a co-located biomass generating plant, increasing its output and efficiency.

- Wells for direct use applications are typically shallower and cheaper than the wells needed for electric generating projects, but deeper and more expensive than those required for heat pump applications. Depths ranging from several hundred to a few thousands of feet may be required, and production may come from aquifers in either the bedrock or alluvium.
- Direct use applications will continue to grow, but because hot water is required, they are dependent on geology. Geothermal systems suitable for direct use applications are found throughout the country. Hot springs resorts are found in the Appalachians from Maine to Georgia. Spas and district heating systems are found in states like Arkansas and South Dakota. Although the water can be piped for use at locations far from their sources, as in Iceland, economic considerations dictate colocation of the resource and application. The primary challenges are locating suitable sites for production and injection wells, managing the resource in a sustainable manner, and minimizing drilling and installation costs. The surface technologies are mature and low risk.

- The third thermodynamic tier of projects is the most universally applicable. Heat pumps are already being deployed throughout the country, making them the fastest growing form of geothermal energy use. Geothermal (aka ground-source) heat pumps use the shallowest formations of the earth as an energy piggy bank, to store or extract heat for heating and cooling.
    - During winter, heat is extracted from the earth and transferred to the building heating system in place of boiler-heated water.
    - In the summer, heat is removed from building air and rejected to the earth. Heat pump installations generally require the drilling of shallow wells in alluvium, from several tens of feet to several hundred feet in depth. In many commercial installations, piping is laid in trenches underneath parking lots.
    - Heat pumps use mature HVAC technology, which is very low risk. They do not require hot water or any particular geology.

- Enhanced Geothermal Systems (EGS) represent the future of geothermal development. Conventional geothermal electric generating systems are dependent on finding naturally occurring hot rock with a "just right" amount of permeability and water in place. EGS technology aims to create the necessary permeability to circulate water in the hot rocks found everywhere. Rocks suitable for EGS development for both direct use and electric generation can be found across the country. We can reach these depths using conventional drilling technologies. EGS hold the greatest promise for tapping the earth's heat.

Q1-2. *Could you discuss some of the unique advantages geothermal energy production possesses compared to other energy sources?*

Geothermal energy shares some attributes with other renewables but also has some unique advantages. There are no chemical pollutant discharges and the resource is renewable. In contrast to other renewables, geothermal energy is available 24 hours per day, can be load following or intermittent, has a small footprint, and is environmentally friendly to humans and wildlife.

Q1-3. *Could you discuss some of the immediate barriers to geothermal energy technology deployment and how DOE research could address these issues?*

The primary barrier to the development of conventional geothermal electric systems is the initial cost.

- Drilling currently accounts for approximately 50% of the total project costs. If sufficient permeability cannot be found in the initial wells, additional wells must be drilled, or the site abandoned. Enhancing or creating permeability, thus reducing the number of wells, will significantly reduce development costs. Creating permeability in an environmentally friendly way is a technology we need to further develop. It is also essential for EGS development.
- DOE can support technology development in several ways. Basic research on the mechanical properties of rocks can be conducted at the laboratory scale. Research done at an intermediate scale on blocks of rocks 10s of meters across, such as the work being done underground on the DOE-funded Collab project, can provide testing of predictive models and proof of concept.
- Ultimately, geothermal demonstration of commercial viability requires field demonstration projects like the Frontier Observatory for Research in Geothermal Energy (FORGE) and past EGS demonstration projects where new technologies, tools, and monitoring techniques can be proven at the commercial scale.

Thank you for your interest in geothermal energy and the opportunity to address these questions.

Respectfully submitted,

Joseph Moore
Utah FORGE Managing Principal Investigator
University of Utah

House Committee on Science, Space and Technology
"Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation

Questions submitted by Representative Tonko

Q1-1. *The Department of Energy's GeoVision Report attributes a large share of the vast future economic potential of geothermal energy to the development and expansion of "Enhanced Geothermal Systems (EGS). However, Chapter 2 of the Report notes that for that full economic potential to be realized, substantial research and development of EGS must be undertaken. EGS is particularly well-suited for heavily-populated areas with warm, but not hot rock (~150ºC). The Northeast and Midwest fit these criteria well; however, to date all EGS test and research sites in the U.S. are occurring in the West.*

- *How might the lessons learned from western research sites inform the development of sites in areas where it could have the most direct impact on energy production and economic development, such as New York State?*

The original criteria for the location of the FORGE site were designed to ensure the technology developed there would be applicable across the nation. Among the key elements considered by the DOE in selecting the Utah FORGE site were:

- the reservoir rock type is representative of most areas across the country
- the environmental impact of the project and the risk of induced seismicity are low
- the required minimum reservoir temperature of 175ºC can be reached at a cost-effective depth for research

DOE concluded that granite is the best rock type for EGS reservoir formation. Granite is the basement rock at the Utah FORGE site and is the most common rock type at depth throughout the U.S. Large expanses of granite at drillable depths are found in New York and many other eastern states.

The Utah FORGE site is ideally located for EGS research and development. The site is situated in a valley with no population. Milford, the closest community is 10 miles away. The town has a population of 1400 and is very supportive of the project. Environmental risks at the site are low. The groundwater is not potable. It cannot be used for human consumption or agriculture and there are no endangered fauna or flora. All NEPA requirements have been met. Seismic monitoring has been ongoing since 1980 and the results indicate the risk of induced seismicity is low.

EGS research has been focused on the western states because appropriate temperatures are found at relatively shallow depths. This allows more research into permeability enhancement and instrumentation to be done within any given budget. However, temperatures suitable for direct use or electricity generation can be reached anywhere in the U.S. if we drill deep enough. Because temperatures at similar depths are lower in the eastern states than in the west, wells much deeper than those at the Utah FORGE site will be required for EGS development. Drilling deep wells is a well-established technology, but is now extremely expensive. Drilling research is going on concurrently in the petroleum industry, and we expect to take advantage of cost reductions in the next few years. Rather than focus on drilling deep wells, the goals of the Utah FORGE project are to develop and test tools and technology for EGS reservoir creation and sustainability. These technologies are not unique to the Utah FORGE site. We consider the Utah FORGE project to be an essential stepping stone to EGS development elsewhere and to commercial development.

Thank you for your interest in geothermal energy and the opportunity to address these questions.

Respectfully submitted,

Joseph Moore
Utah FORGE Managing Principal Investigator
University of Utah

Responses by Ms. Maria Richards

SMU | GEOTHERMAL LABORATORY

Maria Richards, Director
214-768-1975 mrichard@smu.edu
Roy M. Huffington Department of Earth Sciences
P.O. Box 750395 Dallas, TX 75275-0395

TO: Representative Horn
House committee on Science, Space and Technology
Subcommittee on Energy

RE: Response to questions from Testimony on Nov 14, 2019, Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation

DATE: December 12, 2019

Question: Can you speak to the potential of geothermal heat pumps? If deployment of widespread geothermal heat pumps is limited by installation cost, are there existing federal tax incentives helpful address this barrier and should they be extended?

Answer: Having worked at the SMU Geothermal Laboratory for 25 years, we always considered the IGSHPA in Oklahoma State University as the go-to place for public, students, and contractors to learn more about geothermal heat pumps. We agree it is important to keep that organization and knowledge based funded.

The recently released GEO Vision Study predicts the potential for Geothermal Heat Pumps (GHP) residential installations is 28 million in the next 30 years. The study states that federal tax policy is a factor in widespread adoption given the high upfront cost of installations. Currently there is a 30 percent federal income tax credit (ITC) on the total cost of the system. Next year it goes to 26% and the following year to 22% and then to zero. Geothermal Exchange office currently has bipartisan support for a bill they introduced H.R. 3961 to extend the existing 30% ITC through the end of 2024 and then the same two year phase down.

The ability for homeowners to pay for the additional cost of installation of a GHP system is definitely improved with tax reductions. New homes/buildings are the best case scenario as they can spread the cost of the system over the life of their loan, while having a reduced energy bill.

Finding ways for developers to be incentivized to install geothermal systems is an important next step to getting more installations and improvements in overall technology and geothermal system design. As the majority of our new homes today are spec built, the builder is the one who makes the decision on whether or not to install the GHP. Yet it is the homeowner who benefits over the life of the home. We need to stop quick profits and obtain long-term gains.

Thank you for the opportunity to assist you in your understanding of geothermal resources and energy. Please contact me if you have further questions or would like to discuss ideas in the future.

Maria Richards

Bringing Earth's energy into your community.

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TO: Chairman Lamb
House committee on Science, Space and Technology
Subcommittee on Energy

RE: Response to questions from Testimony on Nov 14, 2019, Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation

DATE: December 12, 2019

How close is the coal-fired plant conversion to geothermal power plants to a demonstration?

In the United States there are no current coal plants scheduled for conversion from coal-fired operations to geothermal energy powered. There are four coal plants already reviewed for conversion with projected levelized cost of energy (LCOE) projected to be between $5 & 20 c/kWh after the conversion. These plants are located in New York, West Virginia, Nevada, and Montana. Additional sites are underway for possibility and costs. With approximate 50,000 MW of aging coal-fired power plants needing to be repowered or shut-down, a study of these plant sites for possible geothermal energy conversion is expected to find many more workable locations.

Through the effort of primarily AltaRock Energy, HERO (Hotrock Energy Research Organization), Cyrq Energy, and EPRI there are geological and technological expertise necessary for a demonstration. A possible demonstration is being discussed with a private coal-fired power plant owner. There is interest from the coal plant owners and the communities in many locations as the need for repowering coal plants is too expensive for owners and the community wants to keep jobs and clean their environment.

For specific examples and more details, see the attached presentation by Susan Petty titled, Advanced Geothermal Technology Solutions: Converting Coal Fired Power Plants to Geothermal.

As noted the presentations and additional meeting summary, geothermal power is able to work with other energy industries to improve the pricing of power and stabilize the energy outputs. For the coal-fired plant conversion, working with solar and thermal energy storage are two additions to the site changes for a more strategic long-term power plant solution.

In a study completed this year under the direction of NREL and SMU, we looked at the ability of using low-temperature geothermal heat (200 to 250°F) as a solution for improving inlet temperatures of an East Texas natural gas plant. The cost of project as researched for the site was too expensive for private commercial viability, yet there were examples of near-by merchant natural gas plants that could use geothermal energy as a mechanism for increasing output while reducing gas consumption. For more details on this feasibility study see the attached paper presented in 2018 by Turchi et al. The final report will be available soon under the title: Turchi, Craig, Josh McTigue, Sertac Akar, Koenraad Beckers, Maria Richards, Cathy Chickering, Joseph Batir, Harrison Schumann and Tom Tilman. 2019. Geothermal *Deep Direct Use for Turbine Inlet Cooling in East Texas.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-74990.

For communities where the coal is being mined, the use of the mine as a heat sink for geothermal uses is also being discussed. The possibility of direct use geothermal projects for heating of building or industrial applications are examples of how the mining can become a new resource for the local community.

Below are suggested papers and websites for more information on these topics. The references show that countries all around the world are looking to convert coal plants to resources and geothermal power is one of them.

Coal Plants converted to Geothermal Energy:

Clean Air Task Force, Geothermal Frontiers Forum 2019 on Advanced Supercritical Geothermal Power Systems Workshop, Washington, DC May 7, 2019 https://www.catf.us/wp-content/uploads/2019/06/Advanced-Supercritical-Geothermal-Power-Systems.pdf

Clinton Global Initiative, Coal to Geothermal Initiative, Commitment by Hotrock Energy Research Organization https://www.clintonfoundation.org/clinton-global-initiative/commitments/coal-geothermal-initiative

Bearden, Mark D., Casie L. Davidson, Jacob A. Horner, David J. Heldebrant, and Charles J. Freeman. 2016. "Techno-Economic Analysis of Integration of Low-Temperature Geothermal Resources for Coal-Fired Power Plants." PNNL-24879. Pacific Northwest National Lab. (PNNL), Richland, WA (United States). https://doi.org/10.2172/1435895.

Zhou, Cheng, Elham Doroodchi, and Behdad Moghtaderi. 2014. "Assessment of Geothermal Assisted Coal-Fired Power Generation Using an Australian Case Study." *Energy Conversion and Management* 82 (June): 283–300. https://doi.org/10.1016/j.enconman.2014.03.011.

Vargas, L., T. González, M. Gutiérrez, P. Guzmán, and M. Matus. "Geothermal energy in electricity markets and decarbonisation scenarios: The Chilean case." In *IOP Conference Series: Earth and Environmental Science*, vol. 188, no. 1, p. 012035. IOP Publishing, 2018. https://iopscience.iop.org/article/10.1088/1755-1315/188/1/012035/meta

Abandoned Coal Mines converted to geothermal energy:

Guo, Pingye, Liange Zheng, Xiaoming Sun, Manchao He, Yanwei Wang, and Jingshi Shang. "Sustainability evaluation model of geothermal resources in abandoned coal mine." *Applied Thermal Engineering* 144 (2018): 804-811.

Menéndez, Javier, and Jorge Loredo. "Low-enthalpy Geothermal Energy Potential of Mine Water from Closured Underground Coal Mines in Northern Spain." In *E3S Web of Conferences*, vol. 103, p. 02007. EDP Sciences, 2019. https://doi.org/10.1051/e3sconf/201910302007

Thank you for the opportunity to assist you in your understanding of geothermal resources and energy. Please contact me if you have further questions or would like to discuss ideas in the future.

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TO: Representative Stevens
House committee on Science, Space and Technology
Subcommittee on Energy

RE: Response to questions from Testimony on Nov 14, 2019, Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation

DATE: December 12, 2019

Question: Briefly describe the main types of geothermal energy technologies being used today with the most promise for future development. Namely electric power generation, direct-use of fluid, and shallow heat pumps for heating and cooling.

Answer: *Electric Power Generation*: Power from geothermal resources is converted to electricity using technologies based on the temperature of the fluid produced from a well. The US geothermal power plants are in Western US. There is a small (500 kW) system at Chena Hot Springs, AK and a small plant in North Dakota, currently off-line because of equipment issues. The focus for the geothermal community has been on high-temperature sites with large-scale (>5 MW) power plants. Yet as the demonstrations proved, there are advantages to small-scale (15 kW to 5 MW) local power production. These low-temperature geothermal demonstration sites were at RMOTC near Casper, WY and the Denbury Resources site in central Mississippi, and Pleasant Bayou site near Freeport, TX. The small binary technologies (using a hot cycle and cold cycle) associated with the small –scale projects are new to the market and designed for either geothermal heat or waste heat projects < 1MW. They are able to be built off-site and shipped via a semi-truck, with the equipment ready for installation and operation within a day. The primary companies with such equipment are ElectraTherm Inc, Ormat Technologies, Access Energy, and a new possible entry is PwrCor, Inc. Outside the US there are numerous companies such as Climeon, Turboden, Fuji Electric, Toshiba, etc.

Direct use: There are a series of new Deep Direct-Use feasibility studies under the DOE Geothermal Technologies Office. The studies looked at using the heat for different applications in NY, IL, WV, TX, NV and OR. The study I participated in under the direction of NREL, SMU looked at the ability of using low-temperature geothermal heat (200 to 250°F) as a solution for improving inlet temperatures of an East Texas natural gas plant. The cost of project as researched for the site was too expensive for private commercial viability, yet there were examples of near-by merchant natural gas plants that could use geothermal energy as a mechanism for increasing output while reducing gas consumption. For more details on this feasibility study see the attached paper presented in 2018 by Turchi et al. The final report will be available soon under the title: Turchi, Craig, Josh McTigue, Sertac Akar, Koenraad Beckers, Maria Richards, Cathy Chickering, Joseph Batir, Harrison Schumann and Tom Tilman. 2019. Geothermal *Deep Direct Use for Turbine Inlet Cooling in East Texas.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-74990.

Geothermal Heat Pumps: There are many companies producing geothermal heat pump equipment. ClimateMaster, WaterFurnace, American Standard/Trane, Bosch, Carrier, Dandelion Energy, etc. They are priced at different levels based on quality and size, thus similar to the auto industry. The ability to install this equipment in a home or building setting is related to amount of available space (either horizontal laterals or vertical boreholes).

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Question: Could you discuss some of the unique advantages geothermal energy production possesses compared to other energy sources?

Answer: There are many advantages of geothermal resources being used.
Geothermal resources are secure, as they are below ground
Geothermal energy sourcing is good for the environment because it is in either closed loop systems (heat pumps to binary power plants) or releases few to no steam contaminates.
Geothermal is a reliable source of renewable energy, thus the Earth does not turn off or go behind a cloud.
Geothermal system tend to be higher efficiency than what they replace.
Geothermal system maintenance is less than other power plants as it is cleaner & more efficient.
Geothermal systems used in homes/schools last for 30 to 100 years. Basically the life of the building. Once paid off, it is an energy savings for the owner and the grid.
Geothermal power plants are on the smallest footprint for acreage as the resource is below ground and surface equipment is relatively small.
Geothermal energy is able to work with other industries from storage, other renewable industry, waste-heat-to-power, natural gas, coal, etc.
Geothermal direct-use reduces industrial cost for drying demand, e.g., wood, food, fish, etc.

Question: Could you discuss some of the immediate barriers to geothermal energy technology deployment and how DOE research could address these issues?

Answer: One area that need more research/focus by DOE are the ability to develop geothermal power or deep direct-use systems for small-scale projects in sedimentary basins. The smaller systems have the ability to be incorporated into oil and gas fields, thus following behind that industry and using their well-field data to find opportunities to produce small (yet helpful for the local community) power. Rather than needing to build large grid lines connecting power to the user, these small geothermal power plants could operate on secure local grids. As they are small systems, they are easy to operate off-site and have low visual impact. Yet with the current price of natural gas so low, oil and gas are not interested in the reuse of their fields. The typical developer of technology is in it for profit and these systems are often 5 – 10 year payback, thus too long.

The second area for improvement in geothermal use is related to the heat pump installations. Suggestions for research by DOE to improve adaptation of them includes increased confidence of homeowners, electricians, and communities as a whole. Here is a list of items to consider to reduce barrier for entry:

- DOE assist the GHP industry by calculating the thermal energy avoided by GHPs and equating it to electricity produced by clean production. It would probably done using a carbon reduction calculation methodology;
- The GHP industry research an apples to apples comparison of the energy efficiency expressed as a COP between ASHPs and GHPs in a cold climate condition with measurements done at 40, 30, 20, 10, 0, -5, -10, -15,-20 degrees ambient °F;
- Improved technology and knowledge of how to install systems for cost reduction for installing ground heat exchanger (ground) portion of system; and
- Expand on the potential for grid-integrated thermal storage.

Finding ways for developers to be incentivized to install geothermal systems is an important next step to getting more installations and improvements in overall technology and geothermal system design. As the majority of our new homes today are spec built, the builder is the one who makes the decision on whether or not to install the GHP. Yet it is the homeowner who benefits over the life of the home. We need to stop quick profits and obtain long-term gains.

Maria Richards

Maria Richards

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Responses by Mr. Sander Cohan

Enel Green Power North America, Inc.

100 Brickstone Square, Suite 300 – Andover, MA 01810 – USA

Sander Cohan
Enel Green Power North America, Inc.
December 18, 2019

Response to Question from Representative Kendra Horn of Oklahoma from November 14, 2019 Testimony to the House Subcommittee on Science, Space and Technology Energy Committee in Support of Geothermal and Water Technology R&D: "Water and Geothermal Power: Unearthing the Next Wave of Energy Innovation"

"Can you address the overlap between the oil and gas and geothermal energy industries? Can you speak to the intersections across industries where geothermal companies have worked collaboratively with oil and gas companies?"

There is substantial technological overlap between the oil and gas and geothermal energy industries. Early development of the US geothermal industry was pioneered by oil and gas, notably Unocal and Chevron. Companies like Shell and Engie still maintain substantial geothermal interests.

Innovations developed in one sector often have applications to the other. Oilfield services companies often serve dual duty, and Enel works extensively with entities such as Schlumberger and Baker Hughes.

Finally, almost all of the technology areas described in the proposed legislation have a parallel application in the oil and gas industry. Breakthroughs and new skill sets in one can benefit both industries.

Enel's US experience highlights two areas of direct intersection between the geothermal and oil and gas industry:

Enel collaboration with oilfield services provider Baker Hughes in Oklahoma and Utah: In this project, Enel worked with Baker Hughes to develop a device to capture the energy of geothermal brine being re-injected back into the ground at our Cove Fort Geothermal project in Utah. The "downhole generator" was designed and tested at Baker Hughes' R&D facility in Claremore, Oklahoma.

While Enel's interest in the technology was to improve the economics of geothermal energy, the applications of the downhole generator are more far reaching than that, with potential use in any sort of wellfield application. Indeed, Enel's role in the technology development does not preclude the use of the program's lessons learned in applications outside of renewable energy.

Enel participation in the Society of Petroleum Engineers (SPE) workgroup on Electric Submersible Pumps (ESP): All three of Enel's geothermal plants rely on electric submersible pumps (ESP) to pull geothermal brine out of the ground for use in the plant. As a result, we have built a substantial body of expertise on the operation and maintenance of this technology. As this technology disseminates through oil and gas as well, Enel personnel are in active collaboration with the oil and gas industry on this topic.

Beyond these two immediate applications, areas of common interest between Enel's geothermal operations and the oil gas industry include the following:

Breakthrough drilling technologies: Drilling costs are one of the major components of the entire geothermal project. Technologies that can reduce this cost have a formidable impact on savings for future projects. In the EU, the GeoWell (http://geowell-h2020.eu/) and Deepegs (https://deepegs.eu/) projects are supported by both Enel and European oil majors.

Geothermal exploration and monitoring technologies: Reducing drilling risk through better surface exploration techniques, applying modern models to seismic, gravity and magnetotelluric data. This can have substantial implications to reducing the upfront cost of geothermal development

New approaches to reservoir stimulation: Utilization of alternative chemicals for well stimulation; utilization of hydraulic/thermal stimulation, including radial jetting. For geothermal, this technology can improve overall operations.

Corrosion scaling monitoring and control: Corrosion is a major issue for steam systems, while scaling is more critical for water systems. Both the phenomena can create severe damage in wells, piping and turbine inlet. Similarly, breakthroughs in this technology can extend the life of systems and components.

Farther afield, Enel's innovation group continuously evaluates projects and partnerships with next generation technology companies like Eavor, Fervo, and Quidnet. All three of these firms rely on innovations from oil and gas to create opportunities in geothermal.

Appendix II

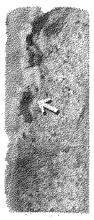
ADDITIONAL MATERIAL FOR THE RECORD

Next-generation Energy

Enhanced Geothermal Systems (EGS) represent an enormous source of energy for the USA. The resource potential of EGS is much greater than the energy needs of our country.
Natural geothermal systems consist of a heat source, permeable pathways (fractures or permeable aquifers), and a fluid to transport the heat.
Enhanced Geothermal System reservoirs are hot, dry rocks that lack the natural permeability required to generate energy pathways.
Temperatures sufficient for electric generation can be found at drillable depths throughout the country. For EGS cold water is injected into hot rocks to transfer the heat to the surface to create electricity.

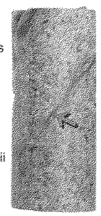
Geothermal Systems

Conventional



- Natural open fractures
- Water circulates in hot rocks
- Producing systems in the USA are restricted to the western USA and Hawaii

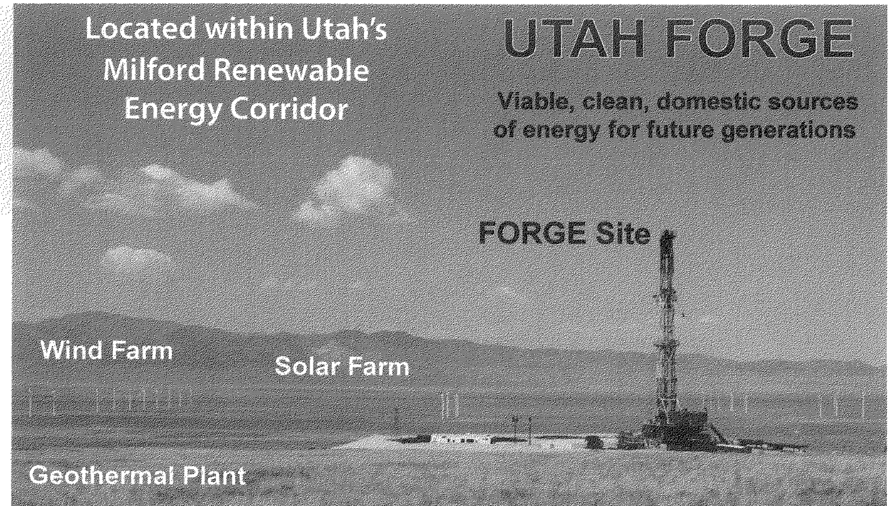
Enhanced

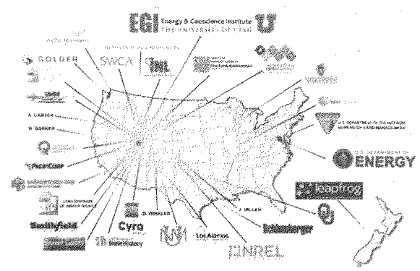


- Dry, hot rocks
- Hydroshear the sealed fractures to create permeability
- Can be developed across the USA

EGS Benefits the U.S.A.

✓ Energy Security
✓ Enormous Resource Potential
✓ Environmentally Friendly
✓ Sustainable for Generations
✓ Cost-Effective
✓ Low-Risk and High-Reward
✓ No or Low Emissions
✓ No Potable Water Required





UTAH FORGE
U.S. Department of Energy

Frontier Observatory for Research in Geothermal Energy

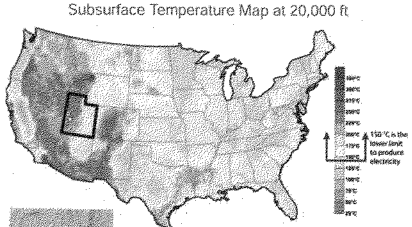
www.UtahFORGE.com

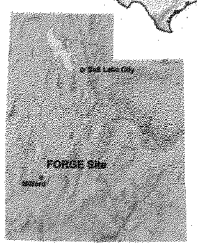
What is FORGE?

*Frontier **O**bservatory for **R**esearch in **G**eothermal **E**nergy*

Utah FORGE is a dedicated underground field laboratory sponsored by DOE for developing, testing, and accelerating breakthroughs in Enhanced Geothermal System (EGS) technologies to advance the uptake of geothermal resources around the world.

Subsurface Temperature Map at 20,000 ft





The basement rocks forming the reservoir are hot and impermeable, and they are representative of potential EGS sites across the USA. The findings and achievements at Utah FORGE will be the critical stepping stones to widespread development of geothermal energy and renewable power generation.

Utah FORGE Project focus:

Heat transfer & fluid flow networks in crystalline rock
High temperature tools for borehole and reservoir imaging
Seismic monitoring and induced seismicity
Stimulation & isolation technologies
In situ stress management & monitoring
Water-rock interaction
Numerical simulations of fracture development & fluid flow
Best practices for EGS development
Improved public awareness & confidence of geothermal technologies
Educational opportunities at all levels
Management & prediction of induced seismicity

UTAH FORGE Site Characteristics

Reservoir attributes
- Temperature greater than 175 °C (~350 °F)
- At a depth of 2 km (~6500 ft)
- Reservoir formation in crystalline rocks (granite)

Environmental considerations
- Free of protected flora and fauna
- No identified risks to groundwater

Water rights and use
- No competition with human or agricultural water use or access
- Extensive supply of nonpotable water available
- Only nonpotable water will be used for EGS development

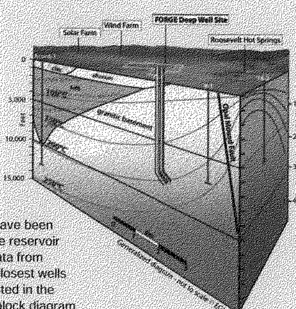
Seismic considerations
- Monitoring by University of Utah seismic stations since 1981
- Low risk of local and regional seismicity

Infrastructure
- Within the Utah Renewable Energy Corridor
- Adjacent to major highways, secondary roads, railroads, and airport

Access for scientists
- Resident and visiting scientists will have 24/7 access
- Supportive federal, state, and private landowners
- No high security or sensitive operations exist on the Milford site

Data
- Area has been subject of intense investigation and drilling by scientists, students, and geothermal companies since mid 1970s

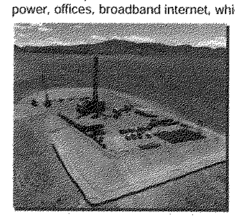
Milford FORGE Utah Site



Many wells have been drilled into the reservoir formation. Data from three of the closest wells are incorporated in the generalized block diagram

The UTAH FORGE Laboratory

The field laboratory comprises a large volume of hot (175-225°C) crystalline granite between two deep directionally drilled wells at around 8000 feet depth below the surface. On site facilities include water, power, offices, broadband internet, which will be required for drilling,



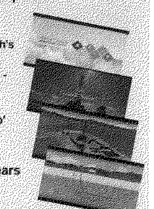
stimulation, and injection -production activities.
The facility is managed by a multi-disciplinary team of engineers and scientists led by the University of Utah, with expertise in geosciences, drilling, rock mechanics, reservoir engineering, environmental monitoring, outreach and communications.

www.UtahFORGE.com
www.facebook.com/forgeutah

Outreach Program

The outreach program is responsible for maintaining and improving the already strong community support from the residents, businesses and government agencies that are based in and around Milford and in Beaver County. Regular updates of activities, announcements, and events are available on our website and social media.

Multiple videos highlighting the project were produced in collaboration with the **Governor's Office of Energy Development**.
The videos are available on our website.



Video 1 **'Energy Success Stories: Discovering Utah's Geothermal Potential'**
Video 2 **'FORGING' New Geothermal Technologies - Part One'**
Video 3 **'FORGE: Exploring Utah's Potential for Enhanced Geothermal Systems - Part Two'**
Video 4: **'Unearthing the Utah FORGE Site's Data'**
Video 5: **'FORGEing into the Future'**

Utah FORGE team members have 250+ years of Geothermal Experience and Expertise

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Invited Contribution

Geothermal Energy - Challenges for EGS Development: An Editorial Perspective

John McLennan, Department of Chemical Engineering, University of Utah,
Joseph Moore, Energy & Geoscience Institute, University of Utah,
Richard Allis, Utah Geological Survey

Introduction

The attractiveness of geothermal energy is manifest. For centuries, humans have been exploiting indirect uses ranging from heating to cultivation to aquaculture. More recently, hydrothermal geothermal operations have generated electricity. The viability of hydrothermal power generation has improved with organic Rankine cycle technology that affords somewhat lower temperature working fluid. Electricity generation is feasible at ~200°C while direct use can use temperatures less than 150°C.

Drilling for hydrothermal systems has confirmed that there is a vastly greater volume of relatively tight, hot rock compared to naturally fractured rock. If there is a way to extract this heat, the potential for geothermal could be at least an order of magnitude larger than what is developed for power today. For the last half century, the aim has been to extend the geographic and geologic reach of geothermal energy sources to scenarios where heat is present but conductive fracture networks and in-situ fluid are missing. This started with the Hot Dry Rock (HDR) pilots at Fenton Hill, United States, Soultz sous Forêts, France and other programs. Commerciality has always been one step away. A reinvigoration of these same concepts of developing high temperature (>200°C) but non-conductive fractured reservoirs has been coined as Enhanced Geothermal Systems (EGS). The greater the temperature, the greater the efficiency at the surface for conversion to electricity. Conversely, with greater temperature, tool design and performance (seals, packers, motors ...) becomes more problematic. The premise is to drill injection and production wells, not always concurrently, and hydraulically connect these by reactivating and extending existing fractures or possibly by creating new fracture networks. The premier example of this is the U.S. Department of Energy's FORGE initiative. FORGE is an acronym for Frontier Observatory for Research in Geothermal Energy[1,2,3]

The FORGE program is intended to provide an underground laboratory for developing and testing innovative tools and stimulation techniques for developing EGS reservoirs. This will provide a new opportunity to extend existing technologies developed for the oil and gas industry beyond current capabilities to successfully produce electricity from hot crystalline rocks. This is an opportunity to demonstrate technologies for application outside of hydrothermal plays and will provide funds for research to expand future energy availability. It will demonstrate suitability and safety of large-scale geothermal energy development to the public. This testing and research initiative is required because of ongoing challenges to commercially produce from enhanced geothermal settings. The challenges encompass exploration technologies and reservoir characterization, well construction (drilling, completion and stimulation) and reservoir management (heat management, diagnostics, induced seismicity ...). The challenges are discussed and research efforts for the entire subsurface community are indicated, allowing development of an exceptional energy opportunity. This research portfolio is building on the technical successes in the last five decades. Within the oil and gas sector drilling efficiencies have advanced rapidly in the last decade. Similar progress has been seen for solar panels and wind turbines. Geothermal has not necessarily kept pace. However, the development of new, cost-effective technologies in EGS has the potential to revolutionize geothermal power generation and make it an attractive, base-load option in future decades.

Challenges for Reservoir Characterization

This broadly encompasses research needs for exploration and then subsequently quantification and visualization of the potential reservoir and its surroundings, some of the same issues for other subsurface disciplines (see for example, Green, this issue).

What Have We Learned?

Although hydrothermal systems usually have some near-surface indicators (such as hot springs) or anomalous heat at depth, impermeable hot rock may be geophysically featureless – no surface geologic expression of thermal potential. In any case, delineation of reservoir temperature and fracturing potential is complicated. Gravity, magnetic, and magnetotelluric surveys may not have the resolution to circumvent the necessity for exploratory drilling. Specialists argue whether conventional seismic exploration will have the resolution to identify contributing fractures. Seismic reflection imagery of deep stratigraphic sequences has been crucial for identifying drilling targets in oil and gas reservoirs. However the seismic reflectivity of hot intrusive rocks has been poorly studied. Subseismic delineation of fracture systems, and forecasting of thermal characteristics remain pre-eminent considerations. This is not fundamentally different from unconventional hydrocarbon recovery. The geothermal explorationist is intent on defining the heat source, ensuring that the thermal reservoir is not substantially faulted and fractured, and ensuring that the heat is not convected elsewhere. In addition, most high temperature hydrothermal systems are also areas of high seismic activity – that is why natural seismicity monitoring can help delineate areas of faulting and fractures that are part of the natural fluid circulation at depth and targets for drilling. Again, outside of a hydrothermal system, could natural microseismicity (or nanoseismicity) be a useful indicator of small-scale fractures in the granite (host rocks) that then become targets for stimulation?

Just as with waterflood techniques for driving oil and gas towards production wells, the effectiveness of sweeping heat out of hot rock with injected cooler water requires a large surface area in the form of a fracture network or interconnected pores. Studies of power generation from hydrothermal systems show effective heat sweep efficiencies in the range of 15 – 25% after several decades of production. So far, EGS projects have shown heat sweep efficiencies of only a few percent because of few interconnected fractures. Typically, a 100 MWe geothermal power plant operating for 30 years requires a reservoir volume of 16 km^3 if the heat sweep efficiency is 10%. This is a reservoir area of 4 km x 4 km with a production zone that is 1 km thick. These approximations assume 200°C production water, 75°C injection water, and 20% power conversion efficiency. Also, if heat is conducted through low permeability matrix between fractures, the characteristic thermal conduction thickness after 30 years of temperature change in the fracture is on the order of 50 m. This implies that nominally an EGS reservoir has to be fractured on a 50 to 100 m scale to sweep out a significant volume of heat over 30 years. These numbers define the challenges for EGS technology development to extract heat for the amortized life of a geothermal plant, or at least a significant fraction of that period. In addition, stimulation economics (ability to provide high enough treating pressures) may require pre-existing weaknesses in the reservoir. A multiplicity of subseismic natural fractures may be required for heat management and effective breakdown. On the other hand, major throughgoing fractures can be undesirable because of the potential for short circuiting where injection water moves from injector to producer with minimum exposure to the thermal reservoir. These larger systems are also undesirable if they contribute to induced seismicity triggered by direct fluid exposure or by reservoir adjustments due to thermal stress evolution.

What Are the Next Research Steps?

Previous EGS research projects have not been restricted by availability of heat. This suggests that with good exploration practices, thermally acceptable reservoirs can be identified. Beyond spatial definition of fractures, apertures, infill and mechanical properties are usually poorly characterized. Imaging logs delineate near surface fracture occurrence and can be significantly inaccurate for forecasting aperture. Very few techniques are available to constrain stochastic predictions of fracture length and effective conductivity. This is supported by observations in oil and gas scenarios where although hundreds to thousands of fractures may be recorded, production logging and distributed temperature surveys suggest very few are contributing to injectivity or productivity. The mechanical characteristics of native fractures is further unknown. Standard assumptions of a 30° friction angle may be unacceptable from the perspective of expenses related to casing integrity and surface horsepower during breakdown of high strength formations. While there are methods for inferring properties on a core scale (**Figure 1** is an example), upscaling these is probably not adequately done. Methods based on RQD or GSI[4] from civil and mining engineering disciplines can be usefully applied (Hoek and Diederichs, 2005;[5] Liu et al., 1999[6] ...) to comprehending and classifying hydrocarbon and geothermal reservoirs.

Improved deep penetrating logging and visualization methods can de-risk the potential for induced sensible seismicity by identifying fractures not intersecting the wellbore. With the natural fractures not always aligned with neo-stress directions, methods for determining the complete stress tensor are essential – a perpetual problem in deep subsurface energy recovery.

Controlled, carefully monitored experiments at a well characterized location would be valuable for improving our comprehension of the role and characteristics of natural discontinuities and their associated stress regimes.

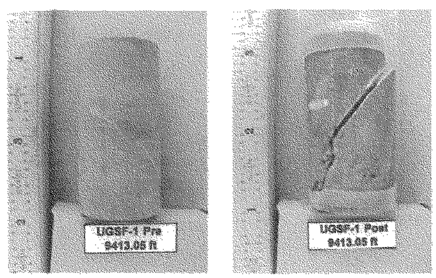


Figure 1. Standard rock mechanics testing, such as triaxial shear can help to delineate peak and residual shear resistance.

Challenges for Well Construction

Compared to hydrocarbons, the energy density for produced heated water requires large circulation rates[7] and efficient, cost effective well construction in a difficult environment.

What Have We Learned?

Techno-economic restrictions mean there is a requirement for lower cost drilling in hard, hot rock, often at significant depth. The geothermal community is obliged to adopt cased and cemented completions with multiple access points. This will – at least for the near future – mandate high angle or horizontal drilling. In the future, more temperature tolerant bits may relax this criterion. However, some steering capabilities will be essential to minimize surface footprint.

High temperature cementing of horizontal and extended reach wells will be challenging. Even when the well is cemented, effective completion and access to the formation through perforating at high temperature, reliable and easily or remotely manipulated sliding sleeves will be required.

To ensure adequate surface area for heat transfer, it is anticipated that there need to be multiple entry points along the length of a wellbore in the reservoir. Fracture networks are ideally activated from each of these access points. Oilfield technology should be adaptable (plug and perf). Even so, isolation technology to allow for discrete zonal stimulation faces some challenges in deep, high temperature, highly stressed environments. Finally, it will be necessary to reactivate or create a multitude of fractures from these access points, communicate these with one or more production wells and guarantee low term hydraulic and thermal conductivity. This will require hydraulic stimulation.

Legacy hydraulic fracturing for EGS, over the last forty years, has been an outstanding technical success. The monitoring and stimulation techniques foreshadowed current methods used for shale oil and gas recovery. Treatments (Brown and Duchane, 1999[8]) at Fenton Hill are reminiscent of those pumped today – high rate, high volume, and slickwater with $CaCO_3$ particulates for diversion or fluid loss control (**Figure 3**). This was an early demonstration of microseismic mapping. These treatments and treatments in the oilfield have helped identify the requirement of multiple existing fractures. Recently, work at the DOE Raft River Project (Bradford et al., 2015[9]) have suggested the effectiveness of hybrid stimulation protocols. This involves periodic, high rate stimulations accompanied by long term, low rate injection with accompanying thermal stimulation. Additional evaluation is important. Finally, the effectiveness of low rate injection and shearing with self-propping (so-called "hydroshearing") continues to be advocated (Boyd, 2014[10]) – demonstration of its viability is important.

What Are the Next Research Steps?

One of the greatest uncertainties in developing an AFE[11] for an EGS well is drilling time and ROP (Rate of Penetration). Issues related to loss of circulation and well control, while critical considerations, can be addressed by modern methods, possibly including managed pressure drilling, MPD, where necessary. Important research is required to optimize bit mechanics. Some new developments are being evaluated, including hybrid bit technologies (Rickard et al., 2014[12]). Practitioners are concerned about torque and drag and tolerance of geosteering equipment at high temperature.

With a feverish development pace in oilfield applications, isolation technologies have dramatically improved. The value of these technologies in the geothermal sector is evident by assessing the proposed isolation methods from only a few years ago (Walters et al., 2012[13]). Horizontal completions and isolation protocols have developed substantially since then (for example, Packers Plus, 2016[14]). Regardless, the issues that need to be resolved – with funding and controlled experimentation include packer simplicity and reliability, component tolerance of temperature, and ability to withstand significant differential pressure (**Figure 2**). Deep, high temperature and highly stressed environments will continue to mandate research on isolation tools (Song et al., 2015[15]).

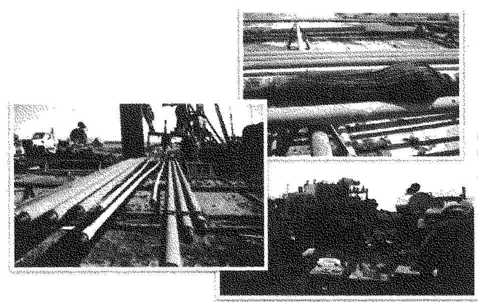


Figure 2. Regardless of the element type (inflatable for openhole or compression packer for casing), high differential pressure (pumping equipment is shown in the lower right) and temperature challenge reliability. Upper right is a failed inflatable packer. Lower left is tubing damaged as a result of energetic packer failure (refer to McLennan et al., 1986[16]).

Stimulation technologies range from moderate volume high rate, short-term, conventional stimulations, to low rate, relatively short term treatments at pressures below the minimum total principal stress (to induce shearing and self-propping) to extended injection periods, also at low rates to encourage thermal stress alteration and fracture modification, creation or evolution. There is likely a place for all of these depending on the specifics of the geologic regime.

Controlled, carefully monitored experiments at a well characterized location would be valuable for improving our comprehension of optimal treatment methodologies.

Figure 3. Part of a substantial frac fleet brought together for high rate, long term hydraulic fracturing at the Fenton Hill site in December 1983 (photograph by John McLennan).

Challenges for Reservoir Management

All the issues to this point are tractable with technology and field experimentation. The greatest uncertainty may be the overall economics and the ability to manage heat extraction for a long term payoff.

What Have We Learned?

Reservoir management requires modeling and forecasting of the fracture networks and reservoir performance (thermal depletion) over time. There has been a proliferation of coupled thermo-poro-mechanical-chemical numerical protocols in the last few decades. These offer important opportunities for simulating performance. Of course, these are all inhibited if reservoir characterization is inadequate. This is particularly true with current limited knowledge and mapping/measurement techniques for natural discontinuities and the in-situ stresses.

Adequate modeling, monitoring and diagnostics will allow an operator to identify deviation from ideality and possibly intervene. Preferred oilfield methods may be misleading because they don't reliably consider extensive fracture networks (many are ad hoc modifications of falloff behavior for a two-dimensional analytic fracture solution or are dual porosity approximations). Injection indices such as the Hall plot have limited value because they do not enable rapid diagnosis since fluctuations are intentionally inhibited. With additional and creative diagnostic tool development (analytical or numerical), specific manipulation of valves should be possible even in aggressive in situ environments (see for example, Abou-Sayed et al., 2002[17]). This is the key to reservoir management – simulation – measurement – injection/production manipulation.

What Are the Next Research Steps?

Numerical simulations either require more quantified data or should be nimble enough to carry out enough realizations to emphasize uncertainty and guide proactive intervention. New generations of diagnostics are desirable. Above all, few existing methods and simulations have been validated – this is an essential need, requiring field testing under controlled conditions.

Safe and sustainable operations are the primary criteria for successful reservoir development. In particular, validating codes for prediction of microseismicity and improving methods for actively and passively monitoring, evaluating and eventually predicting seismic activity is required. This implies processing low magnitude events for evaluating fractured surface area and predicting situations where more serious, sensible events may occur.

With safe operations, the next consideration is reservoir heat management. It is well established that adequate surface area needs to be created to minimize early thermal breakthrough. Ketilsson et al., 2012[18] observed.

> "By stimulating reservoir in a more uniform way .... or by creating multiple conductive fractures connecting injection and production wells, fluid movement becomes more uniform and involves reduced fluid velocities and less differential pressure." (also, Podgorney, 2016[19])

> "This will also require wellbore completion that allows management of the flow at the multiple injection and production horizons. Flow localization is a function of the conductivity of pathways and injection rate-viscosity product."

In order to develop and validate simulation methods and diagnostics and make real evaluations of thermal extraction, once again, *controlled, carefully monitored experiments at a well characterized location would be valuable for improving our comprehension of optimal diagnostics, simulations and intervention strategies.*

Summary

EGS offers exceptional promise for accessing the very large volumes of hot low permeability rock that are in high heat-flow areas of the globe. The challenge is to develop cost-effective technologies. The future FORGE laboratory and other field laboratories are essential to:

- provide technical vision to achieve infrastructure for EGS optimization and validation,
- provide controlled environments for developing comprehensive and meaningful research programs,
- apply technology from other disciplines (in particular oil and gas technology),
- to enfranchise learnings from fifty years of EGS evolution, and,
- optimize and validate simulation and diagnostic methods while validating economic potential in an unbiased fashion.

Acknowledgements

The authors gratefully acknowledge the financial assistance of the Department of Energy, under the FORGE Phase I and 2a awards for Enhanced Geothermal System Concept Testing and Development at the Milford City, Utah, Forge Site, DE-EE0007080.

Endnotes

[1] http://energy.gov/eere/forge/forge-home

[2] http://www.forgeutah.com/

[3] Tester, J.W., et al. 2006. The Future of Geothermal Energy - Impact of Enhanced Geothermal Systems EGS) on the United States in the 21stCentury, November.

[4] RQD is Rock Quality Designation and GSI is Geologic Strength Index

[5] Hoek, E., and Diederichs, M.S. 2005. Empirical Estimation of Rock Mass Modulus, Intl J. Rock Mech. Min, Sci, 43, June.

[6] Liu, J., Elsworth, D., and Brady, B.H. 1999. Linking Stress-Dependent Effective Porosity and Hydraulic Conductivity Fields to RMR, Intl J. Rock Mech. Min, Sci., 36, 581-596.

[7] 240°C water has an enthalpy of 1 MJ/kg whereas oil and gas have enthalpies 40 times this. In contrast to a high flow rate oil well (5,000 – 10,000 bbl/day) a good geothermal well (10 MWe potential) has a flow rate 50,000 bbl/day (100 L/s)

[8] Brown, D. W., and Duchane, D. V. 1999. Scientific Progress on the Fenton Hill HDR Project Since 1983," Geothermics 28(4/5) special issue: Hot Dry Rock/Hot Wet Rock Academic Review (Abé, H., Niitsuma, H., and Baria, R., eds.), pp. 591–601

[9] Bradford, J., McLennan, J., Moore, J., Podgorney, R., and Tiwari, S. 2015. Hydraulic and Thermal Stimulation Program at Raft River Idaho, A DOE EGS, in *Transactions - Geothermal Resources Council.* (Vol. 39, pp. 261-268). Geothermal Resources Council.

[10] Boyd, D. 2014. Hydroshearing for Geothermal Energy, Well Servicing, September/October.

[11] Authorization for Expenditures

[12] Rickard, W., Bailey, A., Pahler, M. and Cory, S. 2014. Kymera™ Hybrid Bit Technology Reduces Drilling Cost Proc., Thirty-ninth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, February 24 - 26, SGP-TR-202.

[13] Walters, J., Thorhallsson, S., and Wood, E. 2012. Zonal Isolation for Geothermal Wells, International Partnership for Geothermal Technology, August.

[14] http://packersplus.com/systems-solutions/

[15] Song, Y., Lee, T.J., Jeon, J., Yoon, W.S. Background and Progress of the Korean EGS Pilot Project, Proc. World Geothermal Congress 2015, Melbourne , Australia , 19-25 April.

[16] Mclennan, J.D., Hasegawa, H.S., Roegiers, J-C., and Jessop, A.M. 1986. Hydraulic fracturing experiment at the University of Regina Campus Canadian Geotechnical Journal, Volume 23, Issue 4, 548-555.

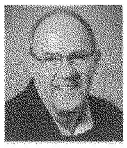
[17] Abou-Sayed, A.S., Guo, Q., Wang, G., McLennan, J.D. and Zaki, K. 2002. Challenges for Monitoring and Verification of Drill Cuttings Reinjection Performance, SPE-78186-MS, SPE/ISRM Rock Mechanics Conference, 20-23 October, Irving, Texas

[18] Jónas Ketilsson, J., Gunnarsson, G., Pálsson, H., Podgorney, R., Fairley, J., Ingebritsen, S., Driesner, T., Giroud, N., Baujard, C., Regenauer-Lieb, C. 2013, Geothermal Reservoir Modeling, Recommendations for Research and Development, International Partnership for Geothermal Technology, August.

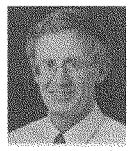
[19] Podgorney, R. 2016. Personal communication, presentation at 2016 GRC Workshop, Sacramento, CA.

Biographies

Since October 2009, **John McLennan** has been an Associate Professor in the Department of Chemical Engineering at the University of Utah. He has been a Senior Research Scientist at the Energy & Geoscience Institute and a Research Professor in the Department of Civil Engineering at the University of Utah, since January 2008. He received his Ph.D. in Civil Engineering from the University of Toronto, in 1980. He has thirty years of experience with petroleum service and technology companies. He worked nine years for Dowell Schlumberger in their Denver, Tulsa and Houston facilities, and later with TerraTek in Salt Lake City, Advantek International, in Houston, and ASRC Energy Services in Anchorage. He has worked on projects concerned with hydrocarbon recovery in a variety of reservoir environments, in domestic and international settings.



Dr. Joseph Moore received his Ph.D degree from the Pennsylvania State University in 1975. After graduation, he worked for the Anaconda Company as a uranium exploration geologist. He holds appointments at the University of Utah as a Research Professor in the Department of Civil and Environmental Engineering and as an Adjunct Professor in the Department of Geology and Geophysics. Since the mid 1970s, Dr. Moore has conducted research on the geology, hydrothermal alteration and geochemistry of geothermal systems throughout the world for the US Department of Energy, private geothermal companies, the U.N., and U.S AID. Dr. Moore currently serves as the Principal Investigator on US Department of Energy Grants focusing on the development of Enhanced Geothermal Systems.



Dr. Rick Allis has extensive geothermal experience, having previously worked on geothermal systems in the Basin and Range (UT and NV), Indonesia, and The Geysers (CA) while a Research Professor at EGI (University of Utah) between 1997 and 2000. Between 1977 and 1997 he worked for the New Zealand geoscience organizations, and was involved in many geothermal and oil and gas projects in New Zealand, Papua-New Guinea, Indonesia, Japan, and Vietnam. During this time he also spent 18 months as a visiting scientist at the Geology and Geophysics Department of the University of Utah on a Fulbright scholarship working on mostly on geothermal topics. He has a PhD from the University of Toronto, has been the Director and State Geologist of the Utah Geological Survey since 2000.

DOCUMENTS SUBMITTED BY MS. MARIA RICHARDS

Converting a Coal Plant to Geothermal: A Win-Win-Win Solution

SMU Geothermal Laboratory, May 2017

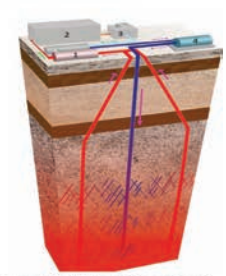
Americans want a bright, secure energy future. By combining the expertise of the coal, oil and gas, and geothermal industries we can find innovative local solutions for energy security. Many of America's coal plants are reaching the end of their design life. It's expensive to retrofit and even to shut down and decommission a coal plant. There are both financial and human costs associated with plant closure. Using expertise from the oil and gas industry, the opportunity now exits to transition coal-fired power plants to geothermal plants. New synergies between energy industries, along with new technologies, provide options for both local communities and energy managers as part of a stable and diversified energy sector.

What is geothermal energy?

Geothermal energy in its most basic form is capturing heat from the Earth. One well-known form of geothermal energy production comes from areas where hot water and stream are venting at the surface – think the Geysers in California. The research and development of Enhanced Geothermal Systems (EGS) is expanding geothermal to include areas with hot, dry (or tight) rock beneath the surface, which exists beyond the west coast. Additional research into Deep Direct Use of geothermal resources is expanding the adoption of our natural resources of stored heat in areas of Texas, New York, and West Virginia to benefit surface applications that include existing power plants and universities (DOE GTO FOA, 2017).

Basic Steps in Developing an Enhanced Geothermal System Power Plant

1. Locate deep ground temperatures over 300°F (150°C) to extract (mine) energy from the hot rock.
2. Drill injection wells and production wells.
3. Enhance and increase the formation micro-permeability using hydroshearing.
4. Connect new pathways within the rock for fluid flow.
5. Capture deep heat resource with a circulating working fluid (water, brine, CO_2).
6. Produce power by spinning a turbine with the heated fluid
7. Reinject cooled fluid for reheating along the connected pathways.
8. Generate consistent clean electricity.
9. Expand available resource by drilling additional wells.
10. Repeat.



Graphic Source: http://elhierro1.blogspot.com/

Geothermal plant costs

The main expenses for a geothermal power plant are associated with drilling the injection and production wells. Once the plant is established, there is no fuel cost; rather, a royalty is paid to the designated owner for heat extraction. The larger the geothermal project, the lower the levelized cost of energy becomes over the life of the power plant. At utility scale, the geothermal capital costs (LCOE 60.8 $/MWh)) are lower than coal plants (LCOE 91.7 $/MWh) (EIA, 2015). Maybe surprisingly, geothermal competes with natural gas pricing with new plants LCOE at 82.6 $MWh for conventional gas. (EIA, 2015).

Geothermal provides baseload power

Electric power operators are seeking firm and flexible applications that can replicate baseload coal plants, thus enabling them to manage resourcefully all awhile keeping the electric grid secure. Geothermal resources are capable of providing secure 24/7 firm and flexible power. [1] Geothermal provides baseload

[1] http://www.energytomorrow.org/all-of-the-above/geothermal-power

power at a local to regional scale from microgrid applications for distributed power to 100s of MW of for utility scale projects.

Adding thermal energy storage makes geothermal generation flexible

If we can develop a geothermal reservoir with temperatures of 200C or higher, we can flash the hot water down to 175C and use the steam fraction in a low pressure steam turbine. By storing excess energy either from the grid or from an on-site solar PV project as thermal energy in a Thermal Energy Storage System (TES), we can make the geothermal project generate more at peak demand times without increasing the flow from the geothermal reservoir. Thermal energy storage has very real advantages over batteries:

- Long system lifespan with little degradation
- Low idling losses
- Simple, low risk, well understood tech
- Readily available, low environmental impact, materials.
- Scalable – some of the largest energy storage installations existing are TES.
- Flexible – TES can decouple charging, discharging, and duration components

By replacing the steam turbine at a coal plant with a specially designed steam turbine for geothermal pressures and superheat, much of the coal plant infrastructure can be repurposed to avoid the huge expense of decommissioning. Only the coal handling facilities would need to be decommissioned. Charging the TES with PV on the coal plant site decreases the overall cost of energy to levels very competitive with other storage solutions and even natural gas fired capacity.

What could the future hold? SuperHot EGS!

As geothermal technology advances allowing for deeper and much higher temperature wells, the potential exists for producing supercritical steam from an EGS reservoir. Not only does going to very high temperatures mean more energy is in the geothermal fluids, but the power cycles that use these supercritical temperatures are much more efficient than what we currently have for geothermal power generation. Add in the direct storage of heat in a thermal energy storage system and geothermal energy can directly replace coal.

Why focus on coal plants?

There are 66,700 MW of aging coal-fired generation in the U.S. today that are in need of expensive repairs to keep them running[2]. There are ongoing examples in the news about coal plant concerns:

> April 15, 2016, "After 63 years, Duke Energy's Wabash River Generating Station has ceased to produce power" in Terre Haute, Indiana.[3]
>
> Jan. 20, 2017, "In response to low natural gas prices and flat demand for electricity, We Energies plans to roll back operations at its coal-fired Pleasant Prairie Power Plant in Kenosha County, Wisconsin"[4].
>
> March 1, 2017, "The largest coal-fired power plant in the Western U.S. will shut down 25 years earlier than expected. A plant closure means the coal mine that feeds the plant would also likely shut down. Together, the Navajo Generating Station and the mine that feeds the plant employ about 800 people."[5]

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[2] https://morningconsult.com/2016/05/03/coal-plants-shutting-without-clean-power-plan/
[3] http://www.indystar.com/story/money/2016/04/15/workers-mourn-indiana-power-plant-shutdown/83069016/
[4] http://www.jsonline.com/story/money/business/energy/2017/01/20/we-energies-idle-one-its-coal-plants-half-year/96847234
[5] http://www.npr.org/2017/03/01/517031278/navajo-workers-at-coal-fired-power-plant-brace-for-its-closing

> March 3, 2017, "JEA and Florida Power & Light Company jointly operate the St. Johns River Power Park", near Jacksonville, Florida. "It's at its economic life's end," said JEA CEO Paul McElroy.[6]

The list keeps going ... closing was the New York Cayuaga Coal Plant in 2015 until the Governor stopped it to preserve jobs/property tax[7]. Luminant plans to shut down the coal mine at its Big Brown plant in East Texas by 2018, putting 200 workers out of a job[8]. The North Valmy generating station in Nevada is slated to close between 2019 and 2025; it is the last utility owned coal plant in Nevada.[9]

Local economies are often built around large coal plants. City and County governments are in need of options that lead towards a smart transition strategy. Mayors understand how sound planning for utilities leads to stronger city economic growth and stable communities (e.g., Seattle, Detroit). The energy community needs new answers for the aging coal plants and so do the regulators, politicians, and the general public. We all want our energy supply system to be strong and viable.

How would conversion work?

A coal plant already has many of the requirements for geothermal energy production including:

a) Power plant, b) Transmission lines, c) Experienced workforce, d) Accessible land, and e) Permits.

To convert to geothermal production on a coal site, you need the following completed:

1) drill wells,
2) develop a working deep reservoir,
3) design and install specialty turbines and binary power plant equipment as power production transitions from coal to geothermal,
4) train employees to maintain wells, piping, and turbines.

Oil and gas companies have over 100 years of expertise in drilling wells and have a proven history of innovations in drilling techniques to "change the game", most recently with horizontal drilling and hydraulic fracturing. Add to this the U.S. geothermal industry's over 60 years of expertise managing power plants, geothermal reservoirs, and well operations. Coal companies have the land area and geology and geophysical data on that land to aid in developing a geothermal resource on the site of the coal mine supplying a nearby coal plant. The DOE Geothermal Technologies Office, National Energy Technology Laboratory and National Science Foundation work with our National Labs, universities and small businesses to advance techniques for enhanced geothermal reservoirs (e.g., FORGE Projects, SedHeat, SBIR) so that this knowledge can be applied to immediate use in coal plant conversion.

Which coal plants are best suited for conversion?

In general, coal plants best suited for conversion are those nearing the end of their design life in areas with high geothermal potential. AltaRock Energy and EPRI (Reference) have already begun assessing which coal plants would be the best candidates for conversion. Recently, Cyrq Energy has begun discussions with several coal plant operators about There are ample data to prove the temperatures exist at economical depths (NGDS: http://geothermal.smu.edu). Reservoir stimulation can be managed using the techniques acquired over decades by the geothermal and oil and gas industries.

New York, Nevada, West Virginia, Montana and Texas are states that could lead the way in initiating a U.S. coal plant infrastructure upgrade to geothermal production (AltaRock Energy – EPRI Study).

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[6]https://www.jea.com/About/Media_Relations/News_Releases/2017/St__Johns_River_Power_Park_Decommissioning_Planned_for_2018/
[7] http://www.ithacajournal.com/story/news/local/2016/02/23/denied-cayuga-power-plant-retrofitting/80807300/
[8] http://www.dallasnews.com/business/energy/2014/08/29/east-texas-coal-mine-closing
[9] http://www.sierraclub.org/idaho/blog/2017/05/beyond-coal-victory-early-retirement-plans-for-nevada-s-valmy-coal-plant

Benefits for local communities

Through advancements in drilling capabilities derived from the oil and gas industry, along with new geothermal resource evaluations and improved surface engineering designs it is now possible for the geothermal industry to work with the coal industry. Rather than retrofitting or shuttering an aging coal plant, we can convert the infrastructure from coal to geothermal for less than the cost of building a brand new coal or geothermal plant. This CO_2 free alternative allows the energy management of the site to continue to offer firm baseload utility-scale power, while adding the ability for flexible power. Utilizing the coal plant sites keeps American coal power plant workers employed on-site as they contribute to the management and maintenance of the converted geothermal plant. This expands US expertise in geothermal power production and utility development, all the while keeping the lights on securely for rural and urban populations.

Geothermal power production does not come online overnight or even in months. This lead time provides an opportunity to work with communities, proving time to retrain employees to work in the upgraded geothermal power setting. Local oil and gas drillers also benefit through the new market of geothermal wells on land owned/operated by the coal plants over a period of months/years reducing, the volatility for upstream employees.

Conclusion

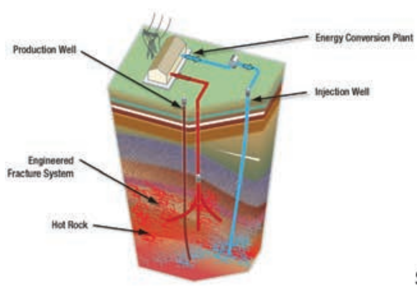
If looking for ways to make US great again, one path forward is to lead the world in clean energy production. At the same time providing the coal industry an opportunity to keep local employees employed while putting geothermal power on the front burner of our coal portfolio, and working as a comprehensive energy team to keep our lights on for generations to come**: A Win-Win-Win Solution.**

Appendix: Tables for 2040

Table A5. Estimated levelized cost of electricity (LCOE) for new generation resources, 2040

	U.S. Average Levelized Costs (2013 $/MWh) for Plants Entering Service in 2020[1]							
Plant Type	**Capacity Factor (%)**	**Levelized Capital Cost**	**Fixed O&M**	**Variable O&M (including fuel)**	**Transmission Investment**	**Total System LCOE**	**Subsidy[2]**	**Total LCOE including Subsidy**
Dispatchable Technologies								
Conventional Coal	85	56.8	4.2	29.5	1.1	91.7		
Advanced Coal	85	69.1	6.9	28.4	1.1	105.5		
Advanced Coal with CCS	85	84.9	9.8	31.8	1.2	127.6		
Natural Gas-fired								
Conventional Combined Cycle	87	13.7	1.7	66.0	1.2	82.6		
Advanced Combined Cycle	87	14.3	2.0	61.9	1.2	79.3		
Advanced CC with CCS	87	25.8	4.2	75.2	1.2	106.3		
Conventional Combustion Turbine	30	38.4	2.8	110.3	3.4	154.9		
Advanced Combustion Turbine	30	24.1	2.7	88.4	3.4	118.6		
Advanced Nuclear	90	62.5	11.8	13.5	1.1	88.9		
Geothermal	94	38.2	21.2	0.0	1.4	60.8	-3.8	56.9
Biomass	83	43.0	14.5	34.8	1.2	93.5		

EIA 2015, U.S. Energy Information Administration, Annual Energy Outlook 2015,April 2015, DOE/EIA-0383, downloaded from: https://www.eia.gov/outlooks/aeo/pdf/appendix_tbls.pdf.



Source – US Energy.gov

Advanced Geothermal Technology Solutions:

Converting Coal Fired Power Plants to Geothermal

DECEMBER 2019

50,000 MW Aging Coal Fired Power Plants

- Plants more than 50 years old
- Currently can't be relicensed because they don't meet emissions standards for mercury, CO2, NOX, SOX, particulates.
- Can't be repowered for coal to meet standards: Too expensive
- Repowering with natural gas
  - Still doesn't solve the greenhouse gas problem
  - Subject to gas pricing volatility long term
  - Many of these plants need expensive difficult or impossible to permit gas pipelines to convert to gas
  - The public and environmental groups push back

Ripe-for-retirement coal generators compared to existing natural gas

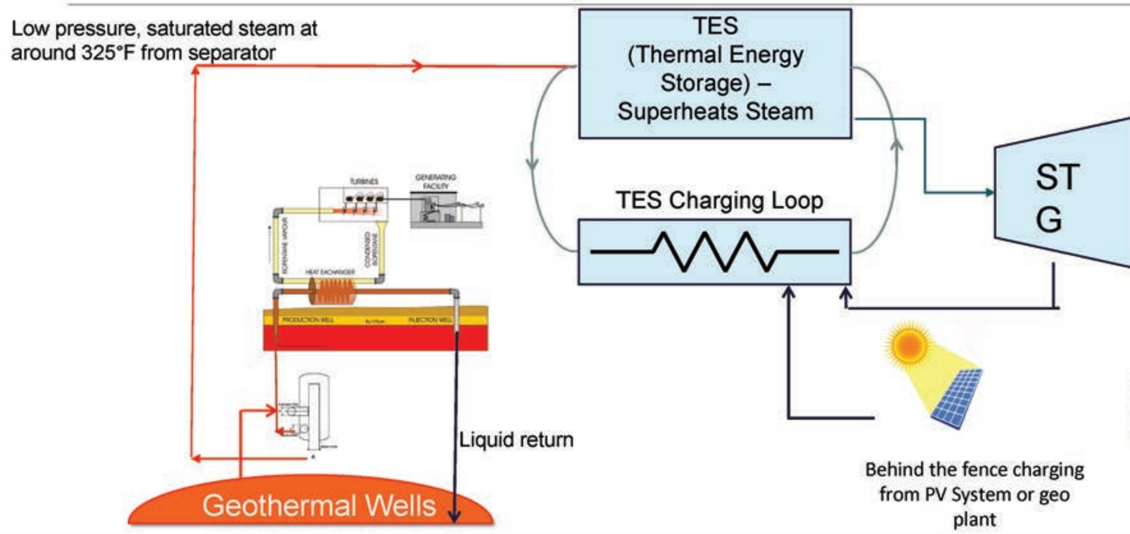
1

The Solution: Advanced Geothermal Technology

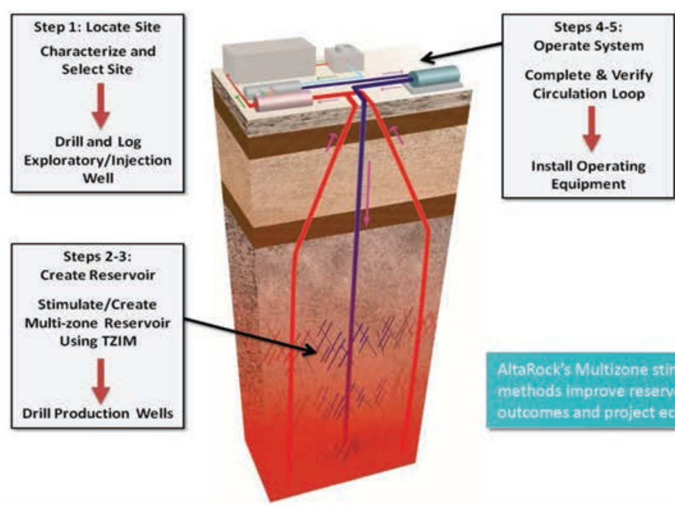
- Need to drill ~10,000 deep geothermal wells to supply 50,000 MW of power with geothermal
- In order to do this over the entire US we need advanced EGS technology
- Adding thermal energy storage can maintain revenues/jobs
  - Uses some of the coal plant infrastructure reducing decommissioning costs
  - Workforce development to transition coal plant workers to geothermal
  - Reduced generation from coal plant as geothermal generation increases reduces emissions
- Low pressure specialty steam turbine to replace existing turbines with binary bottom cycle means no emissions
- Can use waste water from coal plant holding ponds to fill EGS reservoir

Process Flow Diagram: With Geo

System Layout



Engineered Geothermal Systems: How Do They Work?



AltaRock's Multizone stimulation methods improve reservoir outcomes and project economics.

ALTAROCK

AltaRock EGS Technology: Reduce Cost and Risk

High flow rates of water through system to make project economic

Multiple zones stimulated at low pressures without a rig

Increased production potential with better access to production volume of hot rock

No risk from mechanical packers or other downhole equipment

Reduced risk of temperature drop with time due to bigger surface area in contact with hot rock means lower cost to operate

Public acceptance due to no use of chemical additives to fracturing fluids. Clear water only used.

Potential for improved output in brittle rocks with elevated temperature

ALTAROCK

EGS Demonstration at Newberry, Oregon

Injection well drilled and stimulated

Maximum temperature in well 328C

Expected flowing resource temperature >275C

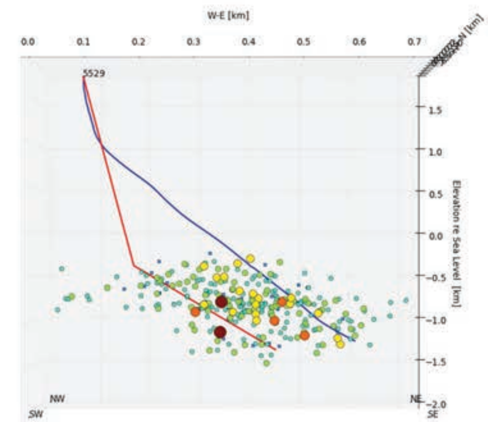
Need to drill into stimulated reservoir for production well

Stimulate to improve connection and reservoir

Well pair could produce up to 7 MW

Demo project could supply power to FORGE

Cost of producer, stimulation, transmission, plant and balance of plant: $21M for 5 MW plant



ALTAROCK

Combining Waste Water Injection and EGS Power Generation

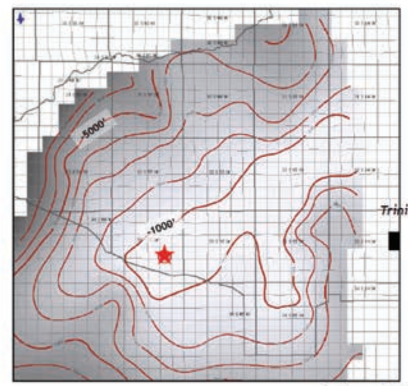
Phased development of geothermal resource uses up waste water while coal plant continues to operate

Put surplus water to work generating electric power
- Use water to develop EGS reservoir
- Lose water to the reservoir during power project operation
- Lose water to evaporation for wet cooling

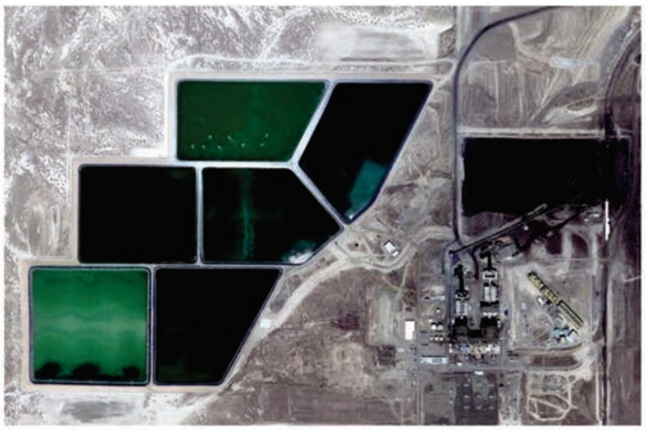
Reduce cost of managing waste water

Use generated power to gradually replace coal fired generation

Take advantage of higher than normal temperature gradients
- Option 1: Drill into sedimentary basin to develop EGS reservoir in basal sandstone
- Option 2: Drill deeper to get higher temperatures in crystalline basement



Surface of T=300°F
CI = 1000'



Western States Coal Plants

Example: NV Energy North Valmy Generating station.

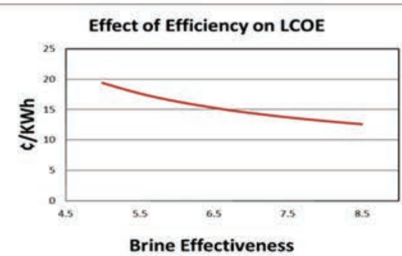
- Valmy plant slated to close between 2019-2025
- High geothermal gradient with ample data.
- Potential for conventional geothermal project as first phase
- Holding residual waste water in holding/evaporation ponds.

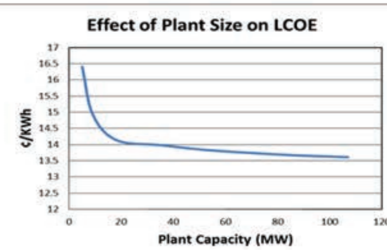
Eastern States Coal Plants

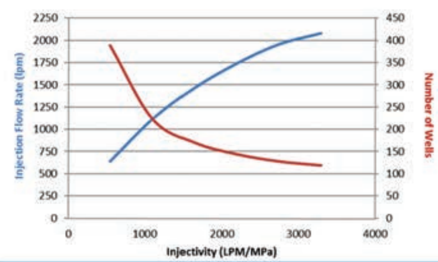
Example: Cayuga Power Plant near Lansing, New York.

- Plant is located in one of the best areas for geothermal energy in the east.
- Slated to close in Feb., 2015 but governor stopped closure to preserve jobs/property taxes
- Gas repower would need expensive pipeline the public doesn't want
- Utility wants to build new T-line, shut down the plant and buy power from the market
- Looking for a solution that makes sense.

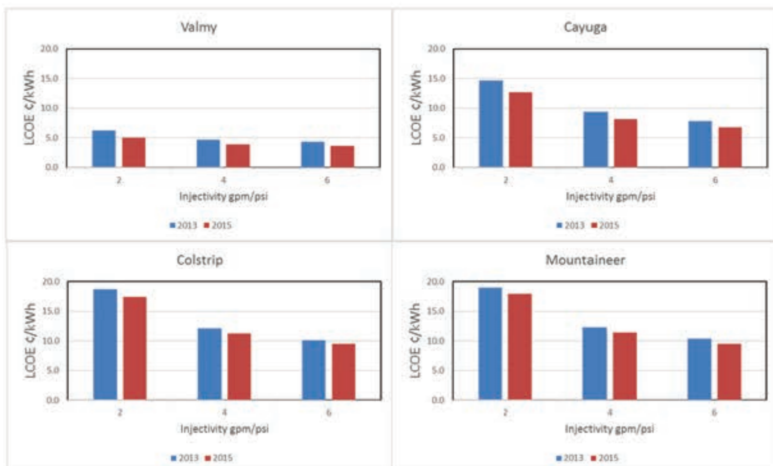
Sensitivity of LCOE to Cost Factors



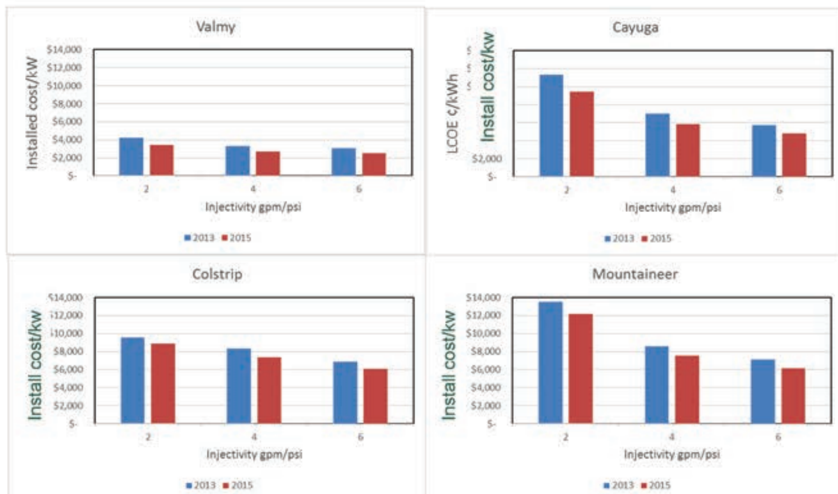




Updated LCOE with Current Drilling Costs

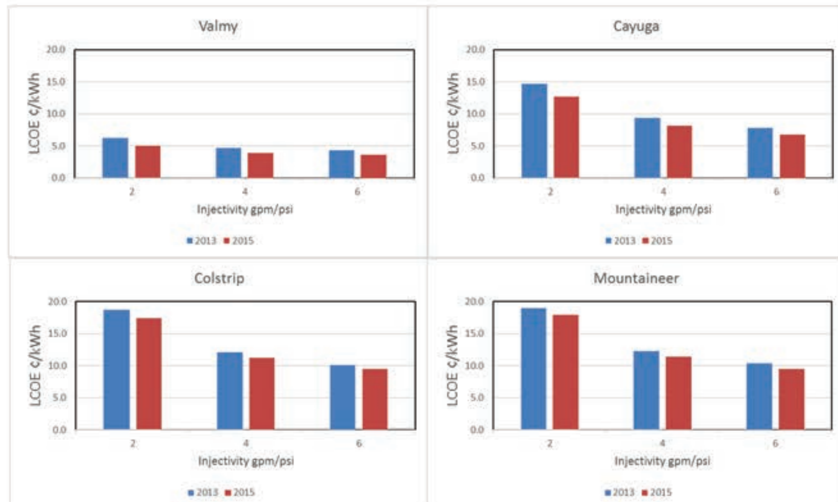


Updated Capital Cost with Current Drilling Costs



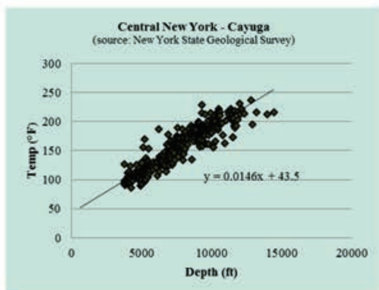
Cayuga

- Costs last updated in 2015. Well completion costs have come down since then.
- Target temperature 170ºC at depths of about 4.5 km
- LCOE below 10¢/kWh
- Below 6.0 ¢/kWh for best case
- Operating cost of large EGS plant is <2 ¢/kWh



Cornell Campus Fossil Fuel to Geothermal Projects

- Cornell Earth Source Heat project will heat campus
- If successful, next step is power generation to replace natural gas
- Data from Cornell project can be used at Cayuga for Coal plant replacement project



Example:
Central New York

Wells drilled for oil and gas exploration in the Finger Lakes region of New York show an elevated temperature gradient of 32-38°C/km.

Areas with high heat flow observed.

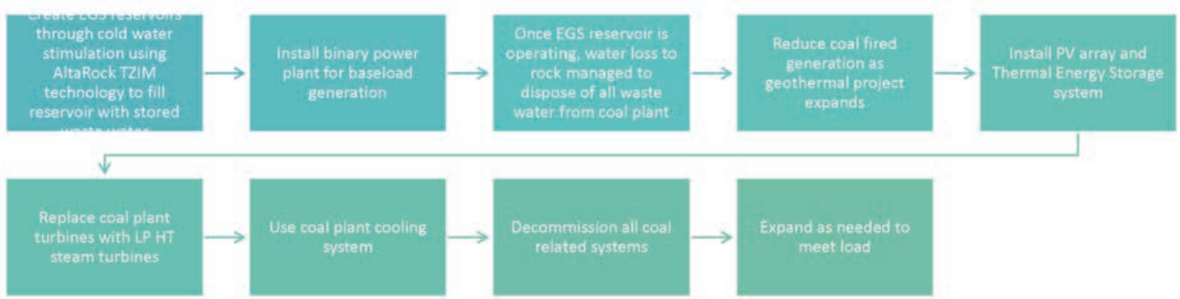
Ample well data available with depth ranging from 1,125 m to 4400 m. Temperature data correlated

200C at between 5-6 km (16,000 – 20,000 ft)

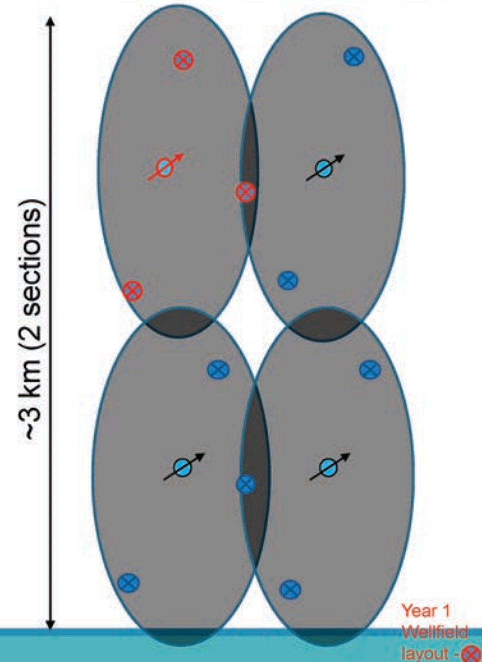
Abundant structure and stress data for stimulation planning

Coal fired power plant near Ithaca offers opportunity for grid interconnect, waste water streams for reservoir fill-up and shared cooling cycle. Large land area next to plant available for PV array for TES charging.

How Would EGS Work at a Typical Site?



EGS Project: Moderate Temperature

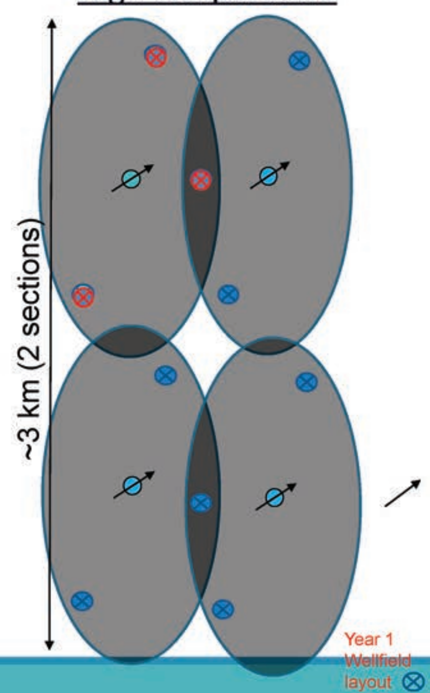


Water use during EGS Reservoir Creation

Year	New Wells	Annual Water Loss from Operations (Mgal)	Annual Water Loss from Stimulation (Mgal)
1	13	344	518
2	12	661	478
3	10	926	398
4	8	1,138	319
5	8	1,349	319
6	6	1,508	239
7	6	1,667	239

- 15,000 ft wells
- 320ºF resource temperature
- Average 3.5-5 MW per producer using TZIM stimulation
- 740 acres can yield 50 MW with little surface disturbance

EGS project – High Temperature



Water use during EGS Reservoir Creation

Year	New Wells	Annual Water Loss from Operations (Mgal)	Annual Water Loss from Stimulation (Mgal)
1	12	741	418
2	8	1235	279
3	8	1728	279
4	6	2099	209
5	4	2346	139
6	4	2592	139
7	0	2592	

- 11,150-16,000 ft wells in basement
- 480ºF resource temperature
- Average 6-8 MW per producer using TZIM stimulation
- 740 acres can yield 80 MW

Steps To Transition of Coal to Geothermal:

Phased approach reduces risk. Transitions jobs

- Phase 1 – Detailed engineering feasibility study
  - Site assessment – geologic, geophysical, seismic temperature and project data evaluation using existing data.
  - Gap analysis with plan for collecting additional data including core hole and additional geophysics
  - Environmental and regulatory compliance assessment
  - Public outreach – webinars, public meetings and conference to educate stakeholders
  - Drill deep core-hole to acquire data on temperature with depth, rock stresses, rock type and drilling conditions
  - Detailed engineering study including well design, stimulation design and cost analysis.
  - Economic analysis including power markets and financing potential
- **Go/No-go decision on Demo Project**

- Phase 2 – Demonstration project
  - Obtain project financing
  - Permitting and regulatory compliance
  - Modify temporary seismic array as indicated from Phase 1 studies.
  - Modify project plan using data.
  - Drill 1 injector and up to three producers and create a stimulated reservoir for small scale power project as demonstration.
  - Construct demonstration power plant
  - Operate facility while designing expansion project
- **Go/No-go decision on Full Scale Expansion**
- Phase 3 – Expansion to utility scale project
  - Obtain project financing
  - Permitting and regulatory compliance
  - Determine from Phase 2 project data the potential for total development of project site
  - Adjust plan using Phase 1 data to optimize project economics
  - Run multiple rigs to drill project wells
  - Stimulate wells
  - Construct full scale power plant

Pilot Project Proposal

Goal: Develop a pilot project at Cayuga using EGS technology

Phase I	Preparatory Phase		Pre
	Task 1.1	Project management	$ 97,120
	Task 1.2	Public outreach	$ 31,536
	Task 1.3	Data collection, review and assessment (e.g., PNNL BWIP data)(Gap analysis)	$ 52,480
	Task 1.4	Geophysical analysis and conceptual modeling: gravity, MT, and/or passive seismic (basement depth??)	$ 181,200
	Task 1.5	Permitting, regulatory and compliance matrix	$ 34,200
	Task 1.6	Permit fees and well drilling bonds	$ 123,000
	Task 1.7	Induced seismicity risk assessment - assuming stimulation	$ 64,280
	Task 1.8	Exploration plan design and drilling plan	$ 194,400
	Task 1.9	Initial economic analysis (including natural gas potential)	$ 143,152
	Task 1.10	Fundraising/financing for demo project	$ 50,528
	Task 1.11	Reporting and presentations , include recommendations and Phase II budget	$ 25,636
	Go/No-Go decision point - Proceed to Phase II		

Deliverable: Cost & Risk Analysis Report with preliminary engineering design

- Go/No-Go Decision: Is development feasible?

If Go, continue to Phase 2: Drill and Stimulate First Well

Phase 2 – Drill/Stimulate 1st Well

Phase II	Drill and Stimulate Exploration/Production Well		$ 11,846,431
	Task 2.1	Project management	$ 130,920
	Task 2.2	Public outreach	$ 40,632
	Task 2.3	Permitting, installation, and monitoring of MSA	$ 282,800
	Task 2.4	Wellfield and reservoir creation design and engineering and planning	$ 418,920
	Task 2.5	Drill 15,000 - 17,000 deep exploration/production well	$ 8,700,022
	Task 2.6	Well logging and completion	$ 258,144
	Task 2.7	Well stimulation including microseismic fracture mapping	$ 1,282,182
	Task 2.8	Well testing	$ 119,462
	Task 2.9	Second (injection) well design based on results	$ 87,360
	Task 2.10	Pilot plant preliminary design and permitting	$ 473,200
	Task 2.11	Updated economic analysis of Cayuga geothermal	$ 52,788
	Go/No-Go decision point - Proceed to Phase III		

Deliverable: First EGS well with testing. Costing update. Final plan for second well.

- Go/No-Go Decision: Drill second well?

If Go, continue to Phase 3: Drill and Stimulate Second Well

Decisions From Phase 2

- Design of second well
- Preliminary power plant design
- Updated economics
- Permitting and regulatory compliance update

Phase 3 – Drill/Stimulate 2nd Well

Deliverable: Second EGS well with circulation testing. Power plant design and construction plan. Final permitting for pilot plant.

- Go/No-Go Decision: Construct pilot plant?

If Go, continue to Phase 4: Construct pilot plant

Phase III	**Drill and Stimulate Second (Injection) Well**		**$ 13,658,630**
	Task 3.1	Project management	$ 181,248
	Task 3.2	Public outreach	$ 32,640
	Task 3.3	Stimulation plan design based on results	$ 256,572
	Task 3.4	Pilot power plant design completion and permitting	$ 131,712
	Task 3.5	Drill second well (low scenario)	$ 6,363,616
	Task 3.6	Drill second well (added for high scenario)	$ 4,218,712
	Task 3.7	Stimulate second well	$ 956,243
	Task 3.8	Post stimulation well testing	$ 267,846
	Task 3.9	Preliminary power plant design and engineering, transmission and interconnection design	$ 1,161,600
	Task 3.10	Update project economics and risk analysis	$ 39,737
	Task 3.11	Reporting and presentations	$ 48,704
	Go/No-Go decision point - Proceed to Phase IV		

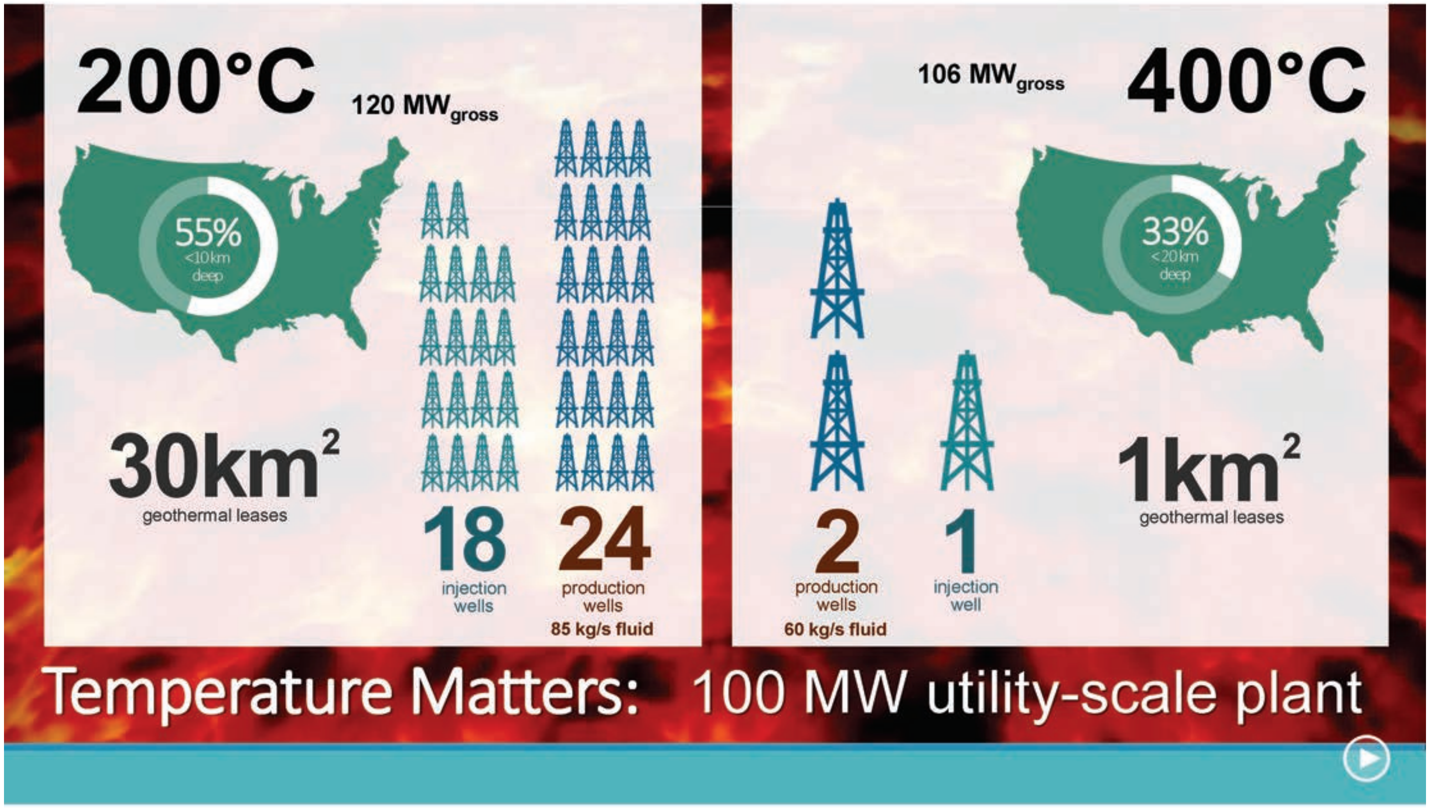
Decisions From Phase 3

Final pilot plant design with engineering and risk analysis update

Updated economics

Permitting and regulatory compliance update

Final resource assessment for utility scale power potential


200°C
120 MWgross
55%
<10km
deep
30km²
geothermal leases
18
injection wells
24
production wells
85 kg/s fluid
106 MWgross
400°C
33%
<20km
deep
2
production wells
60 kg/s fluid
1
injection well
1km²
geothermal leases
Temperature Matters: 100 MW utility-scale plant

Phase 4 – Construct Pilot Plant

eliverable: Operating pilot plant. Plan r utility scale project. Operating port.

Go/No-Go Decision: Plan for utility scale project?

Phase IV	Pilot Power Plant Construction		$	13,162,544
	Task 4.1	Project management	$	578,048
	Task 4.2	Public outreach	$	20,000
	Task 4.3	Regulatory compliance and permitting - including EFSC operating permit modification	$	69,680
	Task 4.4	Final facility layout, design & cost estimate	$	571,620
	Task 4.5	Transmission interconnection planning	$	34,256
	Task 4.6	Detailed design procurement	$	311,040
	Task 4.7	Major equipment manufacturing	$	8,603,424
	Task 4.8	Pilot plant construction and commissioning	$	2,912,512
	Task 4.9	Start-up operation	$	13,168
	Task 4.10	Financing plan for utility scale project	$	16,754
	Task 4.11	Reporting and presentations	$	32,043
	Go/No-Go decision point - Expand to utility scale project			

The Future: SuperHot EGS

- Geothermal energy today uses the natural heat of the earth to generate electricity. The low temperatures mean low energy conversion efficiencies: 8%-20%
- Extremely high flow rates of low temperature fluids are needed for economic generation
- Going to supercritical temperatures means increased enthalpy and conversion efficiency for 10x the output at the same flow rates
- Very high temperatures are accessible at depths less than 6 km in many areas of the world
- Improved drilling technology can get us to these very high temperature at depths to 20 km to supply power to 85% of the world population
- Reservoir creation using EGS methods allows us to develop a reservoir in very hot impermeable rock
- Supercritical temperature geothermal fluids can be stored directly as heat in the thermal energy storage system

Commitment to Action: Proposed Phases

Phase I – Feasibility of transitioning coal power to geothermal power (C2G)

- Feasibility study with detailed engineering analysis of technical and economic potential for transition of coal to geothermal
- Workforce transition potential including education, training and jobs assessment

Phase II – Demonstration Project-5-15 MW

- Site selection for first C2G project
- Plan C2G transition for selected site including all regulatory compliance, design engineer, workforce development and financing for full utility scale C2G transition
- Demonstration project development
  - Drilling, stimulation and testing of resource development wells
  - Power plant construction

Phase III – Utility scale C2G Project - >100 MW

- Expand demo project to scale: Permitting, financing, drilling, stimulation, testing and plant construction
- Train workers at coal plant (and mine if mine mouth plant is selected) for geothermal project development and operation

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Deep Direct-Use for Industrial Applications: Producing Chilled Water for Gas-Turbine Inlet Cooling

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[2]TAS Energy, Houston, TX

Keywords

Deep Direct-Use, DDU, industrial, absorption cooling, turbine inlet cooling

ABSTRACT

Direct use of deep, low-temperature geothermal resources is underutilized due to challenging project economics associated with developing a deep geothermal resource for what are historically small-scale, variable-demand projects. This project assesses the feasibility of geothermal energy integration in natural-gas combined cycle power stations in the Sabine Uplift and Gulf Coast regions of Texas. The low-grade geothermal resource is tapped to drive absorption chillers for production of chilled water at 5-10°C (41-50°F). This chilled water is stockpiled and dispatched to provide turbine inlet cooling (TIC) at the inlet to the compressor of a natural-gas combined cycle power plant, thereby boosting power production during periods of high temperature and high-power demand. This presentation focuses on the system design related to geothermal well-site selection (proximity vs. resource quality), absorption chiller size and location, chilled-water storage capacity, and dispatch logic to realize the maximum financial benefit.

1. Introduction

Geothermal energy use in the United States includes power generation occurring in western states such as California and Nevada that have conventional hydrothermal assets, as well as geothermal heat pumps applications throughout the county. Deployment beyond these applications will require use of engineered geothermal systems (EGS) for power generation or tapping low-temperature resources, which are more suited for direct use. The latter have found use in scattered, small-capacity systems for space heating, greenhouse heating, aquaculture, pools and spas, and district heating (see Figure 1). While such beneficial direct-use can be cost effective, the applications tend to be small and subject to "one-off" project development and design characteristics that are not conducive to regional or national deployment.

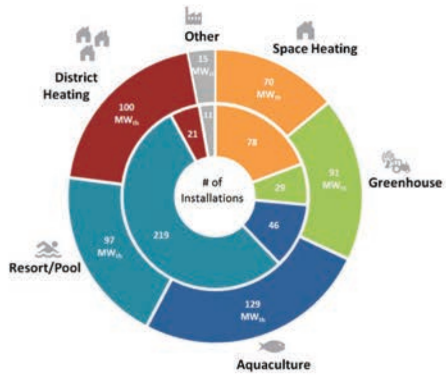

Figure 1. Current geothermal direct-use applications in the United States [Snyder et al., 2017].

When compared to these traditional direct-use applications, the possible integration of geothermal heat into thermo-electric power plants represents a large-scale opportunity with nationwide potential. For comparison, one of the largest current direct-use applications is district heating, with 21 systems and an average capacity of about 5 MW_{th} (Figure 1). A single turbine inlet cooling application for an average-size 500 MW_e combined cycle power station could be as large as 54 MW_{th}, 11-fold larger than the average district-heating system and of a scale comparable to the combined installed capacity of all geothermal district heating facilities in the United States [EPRI 2002]. With approximately 2200 thermo-electric power plants in the United States, the possibilities for significant geothermal augmentation are good, should suitable subsurface resources be nearby. The Deep Direct-Use (DDU) program with the U.S. Department of Energy's Geothermal Technologies Office seeks to identify and assess the feasibility of such DDU applications.

1.1 Low-Temperature Geothermal Resource in Texas

The study region chosen for the work aligns with known areas of low-temperature resource in Texas and western Louisiana. Southern Methodist University's Geothermal Laboratory (SMU) is a team member of the current project and has leveraged the extensive well database for the region to examine the resource potential in the region. This work is documented in prior studies as well as a complementary paper at this conference. SMU's "I-35 Corridor East" geothermal assessment completed in 2010 for the Texas State Energy Conservation Office [Blackwell et al., 2010] highlights an area of high heat flow along the Sabine Uplift in East Texas. The I-35 Corridor East project focused on temperature mapping of thousands of wells with depths of at least 7,000 feet in the eastern half of the Texas between interstate I-35 and the Texas-Louisiana border and encompassed North, East, and South Texas, including the large population centers along the Texas Gulf Coast. Temperature-at-depth maps at multiple depth intervals were created which will provide the basis for this DDU project analysis. The large region exhibits good potential for low-temperature direct-use applications with the power plants in the region (see Figure 2). A complementary paper in this conference describes the local resource in more detail [Batir et al., 2018].

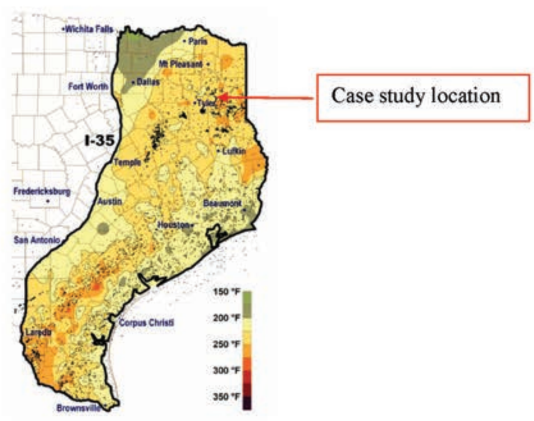

Figure 2. Texas geothermal resources at 9,000 ft depth taken from the SMU "I-35 Corridor East" Study.

1.2 Turbine Inlet Cooling (TIC)

Natural-gas combustion turbines and combined-cycle plants (combustion turbine(s) followed by a steam-cycle turbine) are becoming dominant power generators in the U.S. generation fleet. An attribute of all combustion turbines is that hot weather degrades their power capacities. The impact ranges from about 10 percent to 35 percent of the rated/nameplate output capacity, which is always rated at 59°F (15°C) as specified by the International Standards Organization. To compound matters, as ambient temperature increases, power demand and electricity prices typically increase too. Thus, turbine output decreases when it is most needed. In combined-cycle, cogeneration and combined-heat-and-power (CHP) systems, a rise in ambient temperature not only reduces the turbine power output, it also reduces the total thermal energy available in the turbine exhaust gases for the desired downstream use [Punwani & Hurlbert, 2006]. Inlet air cooling increases the gas density, allowing turbine performance to recover.

TIC can be provided by evaporative cooling of the turbine inlet air or through sensible chilling via mechanical vapor-compression or thermal absorption chillers, Figure 3. Evaporative coolers are simpler and less expensive, but these systems are limited by the local wet-bulb temperature and do not work as well in high-humidity regions. Prior studies have shown that active chilling can yield much greater benefits in terms of increased power output, especially in humid environments such as East Texas and the Gulf Coast [Punwani, 2008].

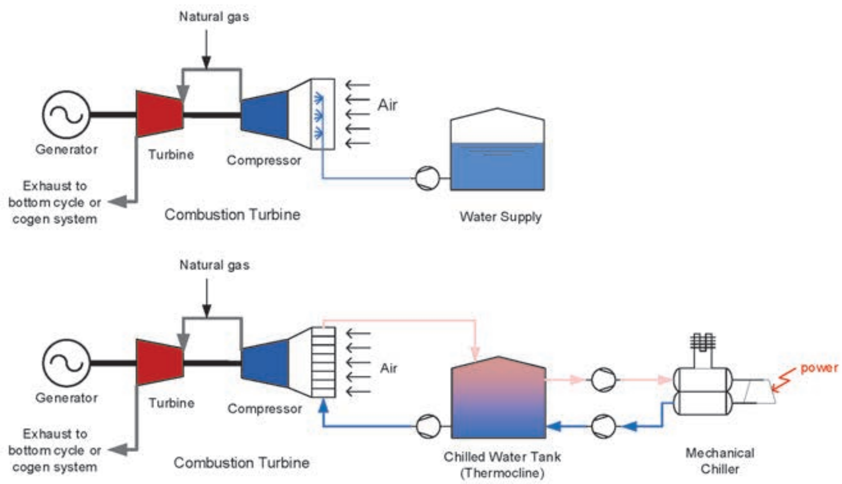

Figure 3. Typical TIC systems - evaporative cooling via spray injection (top) and chilled-water cooling with mechanical chiller (bottom).

1.3 Absorption Chillers with Thermal Storage

Although not as intuitive as direct heating, geothermal energy can be used to provide cooling through the use of commercial absorption chillers. At low pressure, water evaporates at low temperature while absorbing heat and this phenomenon can be used to produce refrigeration. A low-pressure condition is maintained in an evaporator/absorber with a salt solution that has a strong affinity for water. This salt, typically lithium bromide, absorbs water vapor that evolves from the evaporator to maintain the low-pressure condition in the chamber. The diluted salt solution is re-generated by (geothermal) heat and recycled to the absorber. A separate chilled water loop can include storage to decouple the rates of production and use of the chilled water. For example, absorption chillers can be sized to operate 24/7 on the steady geothermal heat source and supply chilled water to a holding tank. This chilled water can be dispatched to coincide with the periods of greatest power demand and/or hottest ambient temperatures to ensure the greatest economic benefit for the plant.

Prior studies that explored the use of absorption chillers for TIC identified as a limitation the need to couple heat availability from the operating power plant to the demand for chilling. Integrating geothermal energy removes this constraint, while inclusion of thermal energy storage allows for design of a small-capacity chiller that runs 24/7 off the geothermal resource to fill the storage system, which can be dispatched at a different rate as needed.

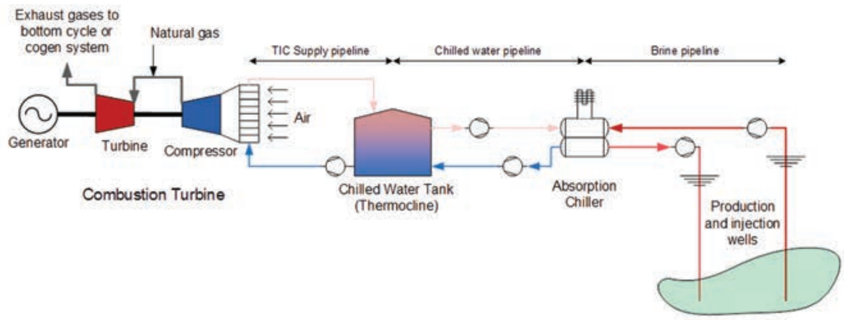

Figure 4. Turbine inlet cooling provided by geothermal-driven absorption chillers. The use of chilled-water storage allows one to decouple the geothermal use from the TIC dispatch.

2.0 Preliminary Findings

An initial assessment of project potential is made by comparing the estimated cost for accessing the geothermal resource to the estimated revenue potential from turbine inlet cooling. Geothermal energy cost is provided by examining the range of resource conditions identified by SMU Geothermal Laboratory [Batir, et al., 2018] and applying a techno-economic model for geothermal development. Application revenue is estimated as the maximum increase in revenue possible if turbine inlet cooling is applied to generate additional electric power. Power value is assessed using historic hourly wholesale price data for location in question. These initial estimates will be refined in later project work.

2.1 Geothermal Resource Costs

The development cost for the geothermal resource is estimated using a new version (v2.0) of the geothermal techno-economic simulation tool GEOPHIRES (GEOthermal energy for Production of Heat and electricity ("IR") Economically Simulated). GEOPHIRES combines reservoir, wellbore, surface plant, and economic models to estimate the capital and operation and maintenance costs, instantaneous and lifetime energy production, and overall levelized cost of energy of a geothermal plant. In addition to electricity generation, direct-use heat applications and combined heat and power or cogeneration can be modeled. GEOPHIRES v2.0 includes updated cost correlations, coupling to the external reservoir simulator TOUGH2, enhanced wellbore simulator, and has been converted the programming language to Python and made open-source. An overview of the capabilities and updates to GEOPHIRES is provided in Beckers & McCabe 2018.

For this preliminary work, GEOPHIRES' thermal drawdown model is used to estimate reservoir production over time. The key input parameters for GEOPHIRES are listed in Table 1. All other variables within GEOPHIRES are left at their default values, with the notable exception of the drilling costs. The default drilling costs within GEOPHIRES are based on hard-rock EGS wells as reported in Lowry et al. 2017 and are likely not representative for a sedimentary region such as East Texas. Furthermore, the large number of wells in the region suggest that drilling criteria are known, and cost uncertainty would be low. Accordingly, the "Intermediate 1" drilling costs from Lowry et al.—representing reduced costs due to technical advancements—are applied for this feasibility study. Future work is planned to examine the applicability of this assumption. The switch from the GEOPHIRES' default to the "Intermediate 1" case reduces the estimated drilling cost from approximately $4.3 million down to $2.5 million per well for the 2,590-ft well depth of the case study.

The tornado plot shown as Figure 5 highlights the parameters of greatest influence on capital cost: pipeline distance, gradient, and drilling depth. The results are not surprising but require context for interpretation. Figure 6 shows a similar plot for levelized cost of heat (LCOH), which considers not only the capital cost, but the geothermal energy that is produced. Gradient and drilling depth are significant parameters in both figures, which highlights the importance of drilling costs and the temperature gradient available. The injection temperature becomes a significant parameter because it represents the amount of energy that can be extracted from the geothermal brine. A typical design-point for a single-stage absorption chiller heat source is about 88 °C (190 °F) [U.S. DOE, 2017]. This becomes the limiting temperature at which heat can be extracted from the geothermal brine. Based on the SMU data, the best guess brine surface temperature is about 111 °C, thus the ΔT for enthalpy extraction is only 23 °C. Widening this range would have a significant impact on LCOH.

Table 1. Input values for GEOPHIRES showing the best guess values for the region around the Eastman Chemical plant as well as a sensitivity range of ±25%.

Variable	-25%	Best Guess	25%	Source
Drilling Depth [m]	1,943	2,590	3,238	SMU data
Gradient [deg.C/km]	28	37	46	SMU data
Drawdown Parameter [%/year]	0.38	0.50	0.63	Snyder et al., 2017
Flow Rate [kg/s]	56	75	94	Estimated from Productivity Index
Pipeline Distance [km]	4	5	6	SMU data
Productivity Index [kg/bar.s]	4.1	5.5	6.9	SMU data
Injection Temperature [deg.C]	66	88	110	Absorption Chiller Model

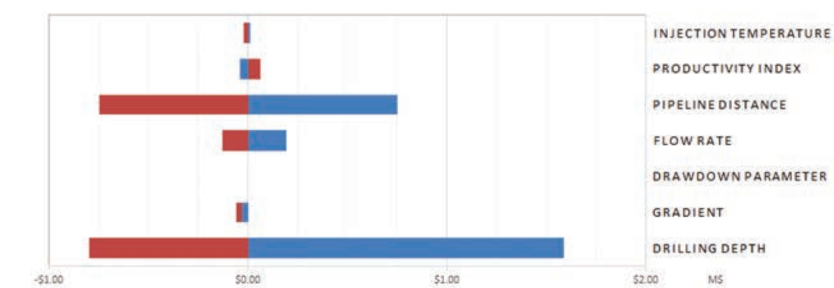

Figure 5. Sensitivity of capital cost ($ millions) to GEOPHIRES input variables listed in Table 1. The baseline-case cost is $12.7 million with a single producer/injector well pair.

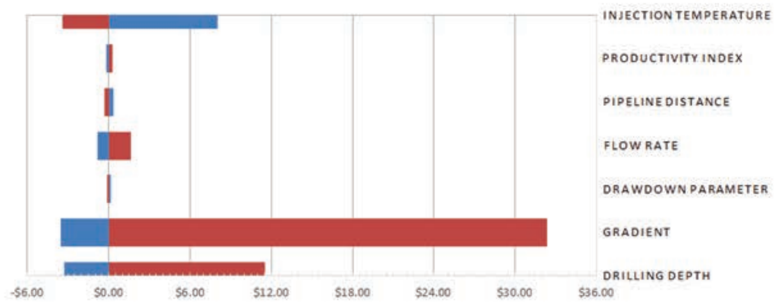

Figure 6. Sensitivity of levelized cost of heat (LCOH) to GEOPHIRES input variables listed in Table 1. The baseline-case LCOH is $7/MMBTU with an initial reservoir temperature of 116 °C.

2.2 Modeling the Power Plant

A simulation model of the combined cycle or co-generation power plant was required to assess the potential benefit of turbine inlet cooling as a function of weather and operating conditions. The model was developed using IPSEpro (SimTech 2017), which is a flow-sheeting simulation tool that calculates heat balances and predicts design and off-design performance of power-plant components and systems. The Eastman Chemical cogeneration plant consists of two General Electric PG7241(FA) gas turbines (GTs) each with a rated capacity of 171.7 MW_e. The exhaust from each turbine is used to heat steam in a Heat Recovery Steam Generator (HRSG) and combined to power a two-stage steam turbine with a rated capacity of 126.5 MW_e. A fraction of the steam is used in the chemical plant as process steam. This process steam/condensate is ultimately returned to the power block, and its remaining enthalpy is used to heat the GT fuel, and then to pre-heat the inlet water to the HRSGs. Low- and high-pressure (HP) steam is extracted for use in the chemical plant.

Design models were developed in IPSEpro using process flow diagrams and data sheets provided by Eastman Chemical. Operational data for the cogeneration plant was also provided and included cycle-property data at 15-minute intervals. Data were provided for six representative days throughout the course of 2017 and gave an overview of the operational points of the cogeneration plant and indicate the effect of ambient temperatures on the system. Off-design models of the system were developed in IPSEpro, and the operational data were used to tune the correction curves and to validate the model output.

The response of the system to variations in key parameters (such as ambient temperature and load) were investigated. Modeling the full system (GTs, steam turbines, and HRSGs) led to problems with the model convergence when the system was far from the design point. Therefore, it was decided to model the GT separately from the steam turbine. This allowed a wider range of off-design operational points to be investigated. This approach is justified because the GT cycle and steam turbine cycle are not strongly coupled to one another—that is, the exhaust gas from the GT does not directly correlate with the steam inlet flow to the steam turbine. This is a result of the variable steam demand of the chemical plant. The operational data indicated that the steam entered the steam turbine at a constant temperature and pressure. The steam flow rate did not depend directly on the steam generated in the HRSG because the quantity of steam sent to the chemical plant varied significantly. A diagram illustrating the GT model is shown in Figure 7.

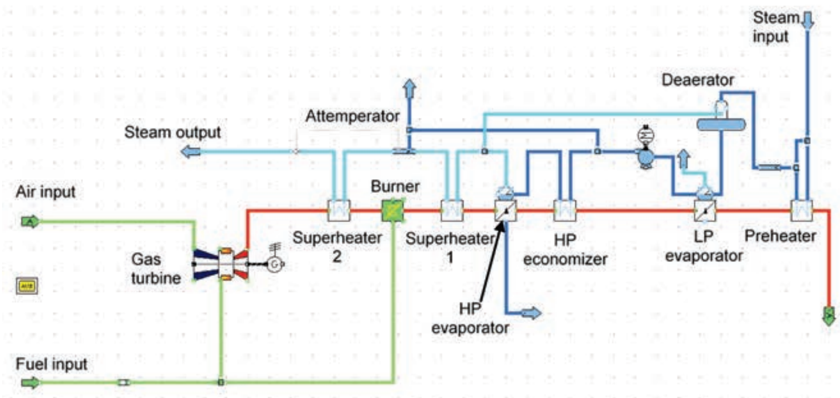

Figure 7: Screenshot of the gas turbine and heat recovery steam generator model from IPSEpro

The operational data were used to validate the off-design IPSEpro model. The normalized heat rate is plotted versus part load fraction in Figure 8. Heat rate (fuel thermal content divided by electric generation, MMBTU/kWh$_e$) is a common measure of cycle efficiency. The operational data did not exhibit any correlation between ambient temperature and power generation. This is because the Eastman plant typically runs at part-load operation with primary responsibility to the power and steam demands of the chemical plant. Since the required power is generally below the design value, the power-diminishing effect of high-ambient temperatures may be overcome by simply increasing the air and fuel flow rate through the GT. For this reason, most applications do not deploy turbine inlet cooling until the plant is operating at full load. Still, it is possible to quantify the effect of ambient temperatures on part load as well as full-load conditions, as illustrated in Figure 9. The IPSEpro simulation shown in Figure 9 shows that the relative effect of inlet temperature is the same regardless of whether the plant is at full load or 75% of full load. The curve and data points are each normalized by the respective operating power (100% or 75%) at design-point wet-bulb temperature. For a given load, higher temperatures lead to lower power outputs. The design point conditions by ISO definition are dry-bulb temperature of 15°C and relative humidity of 60% (corresponding to a wet-bulb temperature of 10.8°C).

Having validated a GT model with operational data, we consider two operational modes:

1. A cogeneration plant operating identically to the Eastman chemical plant. Hourly power data was provided for 2017 and is used to evaluate the benefit of turbine inlet cooling on the existing plant as it currently operates.
2. A merchant plant, running nominally at full load for the entire year.

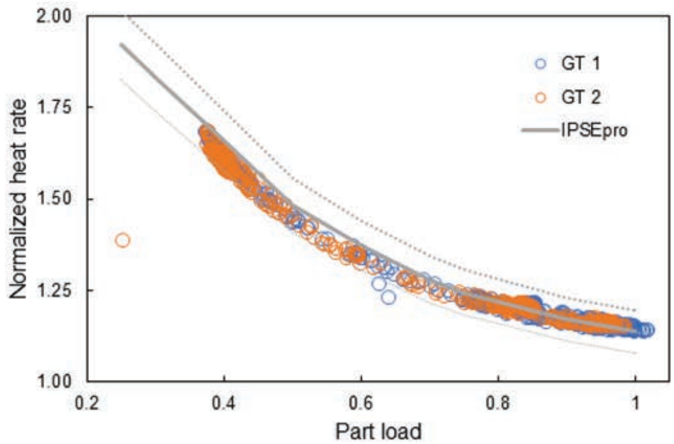

Figure 8: Variation of heat rate with part load operation for the gas turbines (GTs). This figure compares operational data and IPSEpro model output. The model heat rate ±5% is illustrated with dotted lines.

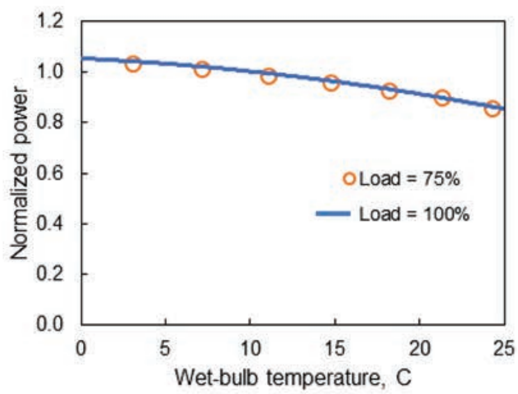

Figure 9: Effect of wet-bulb temperatures on GT power output. Power normalized by the power at ISO design point conditions (T_{db} = 15 °C, RH = 60%) at that load condition.

2.3 Annual cooling opportunity and revenue calculation

Hourly data for 2017, including power production, wet-bulb and dry-bulb temperatures (T_{wb} and T_{db}) and pressure, were obtained for the Eastman plant. For each hour, the relative humidity (RH), specific humidity and enthalpy of the incoming air were calculated. The specific cooling opportunity is given by the difference in enthalpy of air at the observed value and at the design value, unless the ambient enthalpy is below the design enthalpy, in which case the cooling opportunity is zero. The specific cooling opportunity is then multiplied by the air mass flow rate to find the required cooling power for each hour.

The turbine inlet cooling system comprises an absorption chiller and storage vessel, and the capacity of these two components determines the cooling load that may be delivered at every hour. The chiller is assumed to run at full load for the entire year (via geothermal heat), and the cold water fills the storage tank. The available cooling load at each hour is the cooling that can be supplied by the chiller, plus the cooling available from the storage tank. In the initial analysis, a simple control algorithm for dispatch of cooling is applied:

- Whenever the required cooling is less than the cooling power of the chiller, the inlet air is cooled to the design value, and excess chiller capacity continues to fill the tank. If the tank is full, the chiller is shut off or bypassed.
- If the required cooling is more than the cooling power of the chiller, then the tank level falls as water is dispatched to provide the required cooling load. If the storage tank is emptied, the turbine inlet air is not cooled down to the design temperature.

Having evaluated the temperature of the cooled inlet air, the increase in power output may be calculated by using Figure 9. Hourly real-time electricity price data for 2017 were obtained from the Southwest Power Pool (https://www.spp.org/), the grid operator for the Longview region. The increase in annual revenue may be found by multiplying the additional power by the locational marginal price (LMP) at each timestep.

Cooling one GT inlet to its design temperature at every hour of the year would lead to additional electricity generation of 80.3 GWh_e at the Eastman plant, and 128.7 GWh_e for a merchant plant. This corresponds to an additional revenue of \$2.6 million and \$3.8 million for the Eastman plant and a merchant plant respectively. These values represent the maximum revenues that may be achieved, exclusive of other practicalities. Providing cooling to both gas turbines would roughly double these values.

2.4. Sizing the chiller and thermal storage tank

Storage provides a way for the geothermal system and chiller to run at full load all year, thereby meeting a flexible cooling demand while reducing the size of these components. The optimal sizing of the chiller and storage, and the storage dispatch strategy are closely related and require careful analysis.

For example, a 12-MW_{th} chiller at the Eastman plant could provide about 80% of the annual cooling opportunity with no storage Figure 10 (top). The chiller provides more than enough cooling throughout the winter. However, summer cooling loads frequently exceed 12 MW_{th} and the chiller rarely cools the air to the design value. However, it is notable that the chiller can generate an annual total of 105.1 GWh_{th} of cooling energy, while annual cooling opportunity is only 60.3 GWh_{th}. This indicates that the chiller is large enough (perhaps too large), but that it cannot always provide cooling at the required times. Storage can provide the flexibility to deliver cooling independent of the chiller status and provide greater cooling power than the chiller can on its own.

The influence of a 5000 m^3 (1.3 million gallons) storage tank on the delivered cooling is shown in Figure 10. By filling the storage when cooling opportunities are low, it is possible to meet the cooling opportunity for much of the summer. There is a notable period in the summer where the cooling opportunity is above the chiller load for several days. As a result, the storage is not filled during this period, and the maximum cooling that can be delivered is 12 MW_{th}. Table 2 shows the annual cooling opportunity, delivered cooling, and revenue potential for several cases based on 2017 data. Addition of a 5000 m^3 tank raises annual revenue from $2.1 million to $2.4 million for the Eastman plant scenario with a 12-MW_{th} chiller.

Increasing the storage size further allows for seasonal storage of cold water, which may help to provide the required cooling load during the long period of high ambient temperatures that is observed in the summer. However, Table 2 indicates that this is unlikely to be a cost-effective solution. For instance, quadrupling the storage size to 20 000 m^3 (5.3 million gallons) only leads to a 1.6% increase in the delivered cooling, and an almost negligible increase in revenue. This size approaches the benefit of an infinite-capacity storage tank.

Table 2: Annual results for different storage tank volumes.

		Eastman plant (12-MW_{th} chiller)				Merchant plant (18-MW_{th} chiller)			
Storage volume	m^3	0	5000	20 000	Infinite	0	5000	20 000	Infinite
Max cooling capability	GWh_{th}	105.1				157.7			
Cooling opportunity	GWh_{th}	60.3				89.1			
Delivered cooling	GWh_{th}	52.2	56.5	57.4	60.3	82.0	85.1	85.7	89.1
Delivered water	m^3 (billions)	2.4	2.6	2.6	2.7	3.7	3.8	3.9	4.0
Excess water	m^3 (billions)	2.4	2.2	2.1	0.0	3.4	3.3	3.2	0.0
Additional energy	GWh_e	67.8	74.3	75.7	80.3	118.5	122.9	123.8	128.7
Additional revenue	M$	2.1	2.4	2.4	2.6	3.4	3.6	3.6	3.8

A similar pattern is observed for the merchant plant, although revenues are higher because the plant is generating more power. These results indicate that installing a modest quantity of storage is worthwhile to distribute cooling loads over the course of a day, but that seasonal storage is unlikely to be profitable.

The analysis so far uses a simple dispatch model, whereby stored cold water is delivered whenever opportunity exists. However, it is likely that a more sophisticated control strategy could make better use of the storage to take advantage of the variations in electricity prices. To illustrate the benefit that dispatch control can provide, a simple model is implemented here. Figure 11 shows the reported distribution of electricity prices for each hour of the day. It is notable that prices fluctuate more significantly during daytime hours, and that variations are minimal between 8 pm and 4 am. A better dispatch model would avoid any cooling during these low-value hours and instead fill the storage tank to be available to provide cooling during more profitable hours. Such a dispatch algorithm is presented in Table 3 for the Eastman plant and the merchant plant with a storage volume of 5000 m^3. Although this dispatch method produces less cooling energy over the course of the year, the energy is provided at higher-value times and the "additional revenue" increases as a result. This suggests that dispatch strategy needs to be optimized along with chiller capacity and storage capacity.

Results are also presented in Table 3 for smaller chillers. These smaller chillers can generate almost as much revenue as a larger chiller without the improved dispatch model. For instance, a 25% smaller chiller at the Eastman plant generates only 12% less revenue than the 12-MW_{th} chiller. The cost of the chiller *and geothermal system* will both be reduced by 25%. More sophisticated control strategies may be able to further increase revenues at reduced costs. This optimization process is part of the ongoing project.

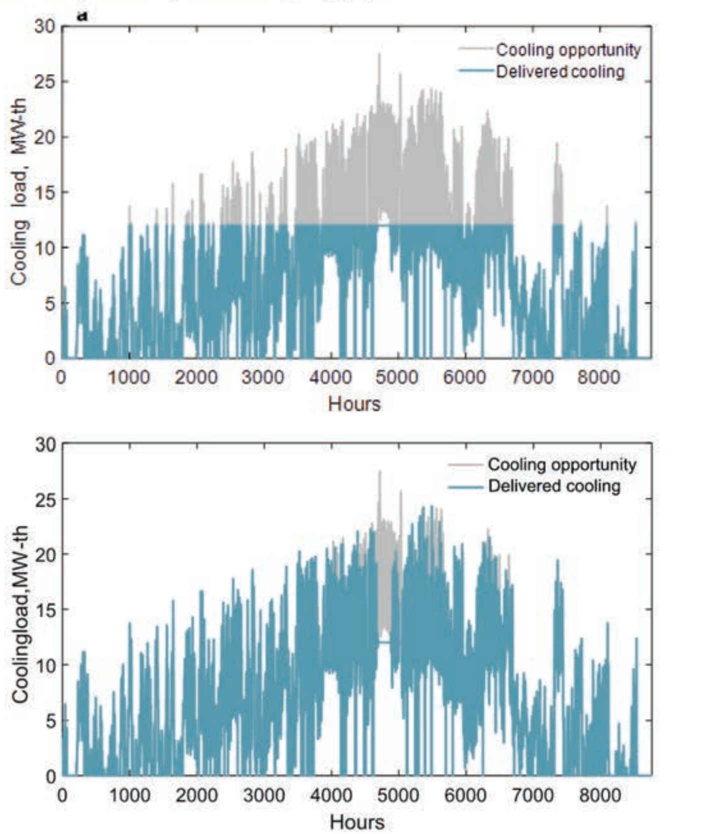

Figure 10. The hourly cooling load that is required, and the cooling load that is supplied to the Eastman co-generation plant with a 12-MW_{th} chiller: (top) No storage, (bottom) with 5000 m^3 storage.

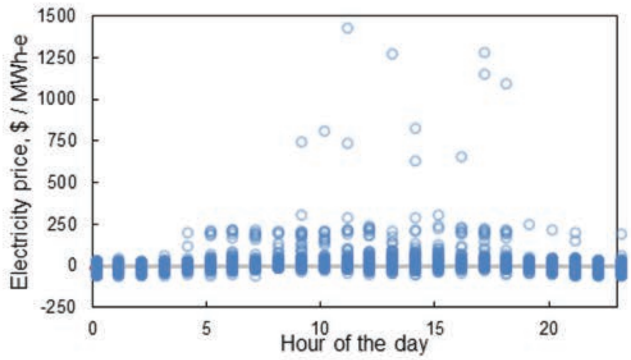

Figure 11: The distribution of electricity prices at each hour of the day for 2017 Southwest Power Pool, south hub LMP.

Table 3: Annual results for different chiller sizes and dispatch strategies. In strategy "A" cooling is dispatched whenever it is required. In strategy "B," no cooling occurs between 8 pm and 4 am, so that the storage is charged.

		Eastman plant				Merchant plant			
Chiller size	MW_{th}	9		12		13.5		18	
Dispatch strategy		A	B	A	B	A	B	A	B
Storage volume	m^3	5000	5000	5000	5000	5000	5000	5000	5000
Max cooling capability	GWh_{th}	78.8	78.8	105.1	105.1	118.3	118.3	157.7	157.7
Cooling opportunity	GWh_{th}	60.3	60.3	60.3	60.3	89.1	89.1	89.1	89.1
Delivered cooling	GWh_{th}	48.8	47.6	56.5	54.4	73.7	72.3	85.1	84.0
Delivered water	m^3 (billions)	2.2	2.1	2.6	2.5	3.3	3.3	3.8	3.8
Excess water	m^3 (billions)	1.3	1.4	2.2	2.3	2.0	2.0	3.3	3.3
Additional energy	GWh_e	62.7	63.4	74.3	72.8	106.0	104.2	122.9	121.2
Additional revenue	M$	1.9	2.2	2.4	2.5	3.1	3.3	3.6	3.7

3.0 Conclusions

This project seeks to assess the feasibility of integrating direct use of deep geothermal resources in natural-gas combined cycle power stations in the Sabine Uplift and Gulf Coast regions of Texas. A low-grade geothermal resource is tapped to drive absorption chillers for production of chilled water that is used to provide turbine inlet cooling at the compressor inlet of a natural-gas combined cycle power plant. Turbine inlet cooling is a proven commercial method of boosting power production during periods of high temperature and high prices.

The preliminary assessment of economics compares the cost of heat from the geothermal resource, as measured by levelized cost of heat (LCOH), using default values in GEOPHIRES 2, augmented by "best-guess" values based on the local geothermal resource. GEOPHIRES highlights that system capital cost is dominated by drilling costs, while geothermal energy production is dominated by thermal gradient (source temperature at depth) and injection temperature. The minimum injection temperature is controlled by the temperature required by the assumed absorption chiller. These parameters estimate a baseline-case cost of a single producer/injector well pair producing 6 MW_t at a cost of $12.7 million. This is prohibitively expensive for the application being considered, given the annual revenue from such a system is estimated at approximately $1 to 1.2 million with a 6 MW_t chiller. Several pathways are suggested for refining or improving the overall economics and will be explored in the ongoing project. These include:

- Optimize dispatch strategy simultaneously with chiller and storage capacity.
- Obtain drilling performance and cost data for East Texas (from the oil and gas sector) and compare with the drilling cost used in GEOPHIRES. The specific geology of the region may yield lower-cost drilling.
- Consider the use of abandoned oil & gas wells in the area for use in geothermal production and/or injection.
- Extend the injection-well temperature to lower temperatures to allow greater recovery of enthalpy from the brine. This requires evaluation of different absorption chiller designs and operating points.
- Explore additional uses of the geothermal heat or chilled water within the chemical plant as an additional or alternative value stream.

Lastly, system component costs will be refined through discussion with the project's industrial partners.

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REFERENCES

Batir, J., M. Richards, H. Schumann, and S. Fields, (2018) "Reservoir Review for Deep Direct Use Project in East Texas," GRC Transactions, Vol. 42.

Beckers, K.F. and K. McCabe (2018) "Introducing GEOPHIRES v2.0: Updated Geothermal Techno-Economic Simulation Tool," Proceedings, 43rd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 12-14, 2018, SGP-TR-213.

Blackwell, D., M. Richards, and P. Stepp (2010) "Texas Geothermal Assessment for the I35 Corridor East," Southern Methodist University, Final Report for Texas State Energy Conservation Office Contract CM709, March 2010.

Lowry, T.S., et al., "Reservoir Maintenance and Development Task Report for the DOE Geothermal Technologies Office GeoVision Study," Sandia National Laboratories, SAND2017-9977, September 2017.

Punwani, D.V., and C.M. Hurlbert (2006) "To Cool or Not to Cool," Power Engineering, February 2006.

Punwani, D.V. (2008) "Impact of Turbine Inlet Cooling Technologies on Capacity Augmentation and Reduction in Carbon Footprint for Power Production," presented at Electric Power 2008, Baltimore, MD, May 6-8, 2008.

SimTech. 2017. "Process Simulation Environment (IPSEpro)." Retrieved (http://www.simtechnology.com/CMS/index.php/ipsepro).

Snyder, D.M., K.F. Beckers, and K.R. Young (2017) "Update on Geothermal Direct-Use Installations in the United States", Proceedings, 42nd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 13-15, 2017, SGP-TR-2017

U.S. Department of Energy Factsheet, "Absorption Chillers for CHP Systems," DOE/EE-1608, May 2017.