UNEARTHING INNOVATION: THE FUTURE OF SUBSURFACE SCIENCE AND TECHNOLOGY IN THE UNITED STATES

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

OF THE

HOUSE OF REPRESENTATIVES

ONE HUNDRED EIGHTEENTH CONGRESS

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C O N T E N T S

July 26, 2023

UNEARTHING INNOVATION: THE FUTURE OF SUBSURFACE SCIENCE AND TECHNOLOGY IN THE UNITED STATES

WEDNESDAY, JULY 26, 2023

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

The Subcommittee met, pursuant to notice, at 2:24 p.m., in room 2318 of the Rayburn House Office Building, Hon. Frank Lucas presiding.

COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
CHAIRMAN FRANK LUCAS

SUBCOMMITTEE ON ENERGY

HEARING CHARTER

"Unearthing Innovation: The Future of Subsurface Science and Technology in the United States"

Wednesday, July 26, 2023
2:00 p.m.
2318 Rayburn House Office Building

Purpose
The purpose of this hearing is to explore the status of U.S. subsurface science and technology research including in the areas of fundamental scientific discovery, clean energy production and storage, waste management strategies, and next generation mining technologies. This hearing will specifically examine research and development activities carried out or supported by the U.S. Department of Energy (DOE) and will serve as a legislative hearing for bills that would authorize DOE's work in these areas as appropriate.

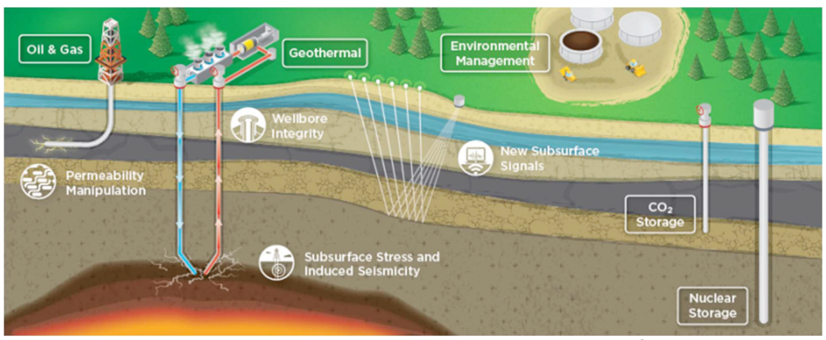
Witnesses
- **Dr. Alexandra Hakala,** Senior Fellow, Geologic and Environmental Systems, National Energy Technology Laboratory, U.S. Department of Energy
- **Mr. Ben Serrurier,** Government Affairs and Policy Manager, Fervo Energy
- **Dr. Kevin M. Rosso,** Associate Director, Physical Sciences Division, Pacific Northwest National Laboratory
- **Dr. Haruko Murakami Wainwright,** Norman C. Rasmussen Career Development Professor, Assistant Professor of Nuclear Science and Engineering, and Assistant Professor of Civil and Environmental Engineering, Massachusetts Institute of Technology
- **Ms. Allyson Book,** Chief Sustainability Officer, Baker Hughes

Overarching Questions
- What are some of the major research and development challenges associated with subsurface science and technology? What research areas need to be prioritized?
- What role do traditional subsurface energy sources play in the development of next generation ones?
- How is DOE coordinating with industry and academia to accelerate U.S innovation in subsurface science?

BACKGROUND

Subsurface energy sources are the backbone of the U.S. energy sector, responsible for meeting more than 80 percent of our nation's overall energy needs.[1] A strong understanding of subsurface systems is essential, not only for harnessing these resources, but also for expanding our clean energy portfolio, sustaining critical domestic supply chains, and securing the storage of use products like carbon dioxide and nuclear waste. Research and development into the subsurface environment and the characterization, production, and management of subsurface energy sources is critical for U.S. energy independence and national security.

For the purposes of this hearing, subsurface science and technology is a broad and multidisciplinary field of study that encompasses several important focus areas. These include fundamental research in areas like geochemistry, materials science, and computational modeling, and applied research in areas like advanced geothermal energy, carbon sequestration, mining, and waste remediation. These focus areas share a fundamental challenge: researchers in these fields are uniquely constrained by their limited ability to access, assess, and monitor the subsurface.[2]



Conceptualization of Subsurface R&D Focus Areas | U.S. Department of Energy[3]

With its network of world-leading national laboratories which steward cutting-edge research in fundamental science and diverse next generation clean energy pathways, the Department of Energy (DOE) is well positioned to lead U.S. innovation in subsurface science and technology. DOE's Subsurface Energy Innovation (SEI) Crosscut leverages expertise from across the Department through various offices, including its Office of Science, Office of Energy Efficiency and Renewable Energy (EERE), and Office of Fossil Energy and Carbon Management (FECM), among others.

To address some of the hardest challenges in this space, DOE researchers work together with industry and academic partners to support subsurface data collection, management, and standardization; create and validate complex models of geophysical and geochemical processes; develop advanced

[1] "What Is Energy?" Sources of Energy - U.S. Energy Information Administration (EIA), www.eia.gov/energyexplained/what-is-energy/sources-of-energy.php. Accessed 21 July 2023.
[2] DOE Briefing to SST Staff, 07.13.23
[3] "Subsurface Science, Technology, Engineering, and R&D Crosscut (Subter)." Energy.Gov, 9 Jan. 2014, www.energy.gov/subsurface-science-technology-engineering-and-rd-crosscut-subter.

sensor technologies durable under extreme pressures and temperatures; and facilitate technology transfer from the oil and gas industry.[4]

Fundamental Research in Subsurface Science

Through several of its core programs, DOE's Office of Science carries out significant fundamental research in subsurface science and technology.

The Basic Energy Sciences (BES) program supports advanced research in geochemistry and geophysics to improve our understanding the physical properties of the subsurface in varying environments and conditions.[5] In addition, BES supports advanced materials research to provide industry partners with better tools to operate under extreme pressures and temperatures. BES is also home to the Energy Frontier Research Centers which support a broad range of disciplines relevant to subsurface science.[6]

The Advanced Scientific Computing Research (ASCR) program supports broad subsurface science activities by maintaining advance computing capabilities and expertise and developing complex modeling techniques to predict subsurface behavior. These can be used for characterizing reservoir behavior for oil and gas activities and monitoring the movement of potentially hazardous materials underground. ASCR's leadership computing facilities are also an important resource for the subsurface science community. Models developed to replicate subsurface behavior can be incredibly complex and many researchers require supercomputers to run them effectively.[7]

The Biological and Environmental Research (BER) program supports DOE subsurface research activities through environmental system science initiatives. These initiatives focus on improving our understanding of the behavior of subsurface features within larger environmental systems, encompassing microbial, biogeochemical, hydrological, and physical processes. BER research can help subsurface scientists predict and better understand various scales of subsurface interactions. Much of this work is carried out through the Environmental Molecular Sciences Laboratory (EMSL) at Pacific Northwest National Laboratory.[8]

Enacted in 2022, the CHIPS and Science Act included a comprehensive authorization of the DOE Office of Science and specific language related to BES and BER subsurface science activities. For example, BES received updated guidance on the need for a Carbon Sequestration Research and Geologic Computational Science Initiative. This plan would leverage resources from FECM, as well as the United States Geological Survey (USGS) to make advancements in the modeling of subsurface geology for the purpose of carbon sequestration.[9]

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[4] DOE Briefing to SST Staff 07.13.23

[5] Office of Science. "CSGB Geosciences: U.S. Doe Office of Science (SC)." CSGB Geosciences | U.S. DOE Office of Science (SC), 13 July 2023, science.osti.gov/bes/csgb/Research-Areas/Geosciences.)

[6] Office of Science. "Centers." EFRC Centers | U.S. DOE Office of Science (SC), 6 Feb. 2023, science.osti.gov/bes/efrc/Centers.

[7] Science, Office of Science. "New Geometric Model Improves Predictions of Fluid Flow in Rock." ASCR New Geometric Model Improve... | U.S. DOE Office of Science(SC), 9 Dec. 2019, science.osti.gov/ascr/Highlights/2019/ASCR-2019-06-f.

[8] EMSL Strategic Plan (pnl.gov)

[9] "Text - H.R.4346 - 117th Congress (2021-2022): Chips and Science Act." Congress.gov, Library of Congress, 9 August 2022, https://www.congress.gov/bill/117th-congress/house-bill/4346/text.

Applied Research in Subsurface Science

Geothermal Energy

Geothermal energy is an abundant and renewable energy source that generates electricity from the earth's heat. Using advanced drilling techniques, geothermal energy can provide reliable baseload power along with heat for the industrial sector. However, today geothermal power plants account for just 0.4% of the total U.S. utility scale electricity generation.[10]

Within EERE, DOE's Geothermal Technologies Office (GTO) accelerates the deployment of geothermal energy through research, development, and demonstration activities. GTO focuses on four key program areas: enhanced geothermal systems, hydrothermal resources, low temperature & coproduced resources, and data, modeling, and analysis.[11] In 2018, DOE selected Milford, Utah to be home to GTO's Frontier Observations for Research in Geothermal Energy (FORGE) program. FORGE is an enhanced geothermal system facility and dedicated laboratory, which advances research and development of drilling techniques, reservoir simulation, and flow testing efforts. In 2021, DOE awarded 17 projects to receive $46 million to collaborate with FORGE. Recently, a participant of the FORGE program, Fervo Energy, announced that over a 30-day period, it successfully attained a flow rate of 63 liters per second at high temperatures and an electric power output of 3.5 MW.[12] This is a record for a commercial pilot enhanced geothermal system site. Later this year, DOE will announce up to $44 million for 17 projects to build off FORGE's existing work.

The Energy Act of 2020 included a comprehensive reauthorization of GTO's activities including demonstration projects, milestone-based demonstration projects, research for heat pumps and direct use, expansion of FORGE, and the utilization of DOE's computing and modeling capabilities. The Infrastructure, Investment, & Jobs Act (IIJA) appropriated $84 million for enhanced geothermal systems demonstrations. DOE received full applications in June of 2023 and will announce selections by October of this year.

Fossil Energy and Carbon Management

Fossil energy sources, like natural gas, coal, and petroleum, provide reliable, low cost, baseload power. Innovation has allowed the U.S. to become a major player in the export of petroleum-based products and liquified natural gas. Thanks to advancements in horizontal drilling, 3D seismic imaging, and micro-seismic fracturing mapping, these sources account for 60% of the United States electricity generation.[13]

Through FECM, DOE supports applied research, development, demonstration, and commercialization of technologies related to fossil energy sources. DOE's National Energy Technology Laboratory (NETL) leads this cross-cutting research in areas including carbon capture, carbon transport and storage, and carbon dioxide conversion. NETL is also instrumental in the

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[10] "Geothermal Explained ." Use of Geothermal Energy - U.S. Energy Information Administration (EIA), 20 Apr. 2023, www.eia.gov/energyexplained/geothermal/use-of-geothermal-energy.php.
[11] "About." Energy.Gov, 26 Jan. 2023, www.energy.gov/eere/geothermal/about.
[12] "Fervo Energy Announces Technology Breakthrough in Next-Generation Geothermal." Fervo Energy, 18 July 2023, fervoenergy.com/fervo-energy-announces-technology-breakthrough-in-next-generation-geothermal/.
[13] "Frequently Asked Questions (Faqs) - U.S. Energy Information Administration (EIA)." Frequently Asked Questions (FAQs) , 2 Mar. 2023, www.eia.gov/tools/faqs/faq.php?id=427&t=3.

development of next-generation mining technologies to support their critical materials program. This program was put in place to create new domestic sources for minerals and materials that are crucial to national security.[14] Through these efforts, NETL is developing additional methods to extract rare earth elements from coal and coal-by-products to further increase the domestic supply and to decrease dependencies internationally.

The Energy Act of 2020 enacted wide-ranging reauthorizations of DOE's FECM activities including the carbon storage validation and testing, carbon utilization, and intra-agency coordination between the FECM and the National Laboratories. In addition, it established the carbon capture technology program, which will use CCUS technology to reduce the cost and emissions from coal, natural gas, and industrial facilities through demonstration projects. The IIJA appropriated significant funds for these activities, including $2.54 billion for the Carbon Demonstration Projects program and $937 billion for Carbon Capture Large-Scale Pilot Projects.

Environmental Management

DOE's Office of Environmental Management (EM) is responsible for remediating environments impacted by the Department's nuclear activities, decommissioning contaminated facilities, and disposing of toxic waste. This important aspect of DOE's mission relies on the advancement of subsurface science and technology. Many EM sites, like DOE's Hanford Site, must have their subsurface constantly monitored. This subsurface observation requires advanced sensors and modeling software to ensure that the contaminated areas are adequately isolated.[15] In addition, in locations where nuclear waste material is being stored it is important to understand how the containers will interact with the surrounding soil on a molecular level. This helps understand the corrosion risks with the containers as well as possible safety concerns in the event of a leak into the subsurface.[16] Leading these efforts, DOE's Savannah River National Laboratory (SRNL) conducts cross-cutting research and development in areas including environmental remediation, hazardous material stabilization, processing and disposal, and nuclear processing and disposition. Innovations in these areas inform and direct future cleanup efforts across the country.[17]

While EM is not a formal participant in the DOE SEI Crosscut, its role in DOE's subsurface R&D activities is essential. In 2021, the Government Accountability Office (GAO) released a report titled, "Nuclear Waste Cleanup: DOE Needs to Better Coordinate and Prioritize Its Research and Development Efforts." In this report, GAO made several recommendations, including that DOE develop a system to collect relevant R&D information across the Department, and develop a comprehensive approach to prioritizing R&D across the EM complex.[18]

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[14] "Critical Minerals and Materials Program." Netl.Doe.Gov, 2022, www.netl.doe.gov/resource-sustainability/minerals-and-materials/program-overview/background.
[15] United States, Department of Energy, Pacific Northwest National Laboratory. "Environmental Remediation." June 2021, https://www.pnnl.gov/sites/default/files/media/file/PNNL_EM_EnvironmentalRemediation_brochure.pdf
[16] United States, Department of Energy, Pacific Northwest National Laboratory. "Environmental Remediation." June 2021, https://www.pnnl.gov/sites/default/files/media/file/PNNL_EM_EnvironmentalRemediation_brochure.pdf
[17] United States, Department of Energy, Office of Environmental Management. "EM Strategic Vision: 2023-2033." May 2023, https://www.energy.gov/sites/default/files/2023-05/DOE%20EM%20Strategic%20Vision%202023%20%282%29.pdf
[18] U.S. Government Accountability Office. "Nuclear Waste Cleanup: Doe Needs to Better Coordinate and Prioritize Its Research and Development Efforts." Nuclear Waste Cleanup: DOE Needs to Better Coordinate and Prioritize Its Research and Development Efforts | U.S. GAO, 28 Oct. 2021, www.gao.gov/products/gao-22-104490.

Chairman LUCAS. The Committee on Energy will come to order. Without objection, the Chair is authorized to declare recess of the Subcommittee at any time.

Welcome to today's hearing entitled "Unearthing Innovation: The Future of Subsurface Science and Technology in the United States." And before I recognize myself for five minutes in an opening statement, I would simply note that our Subcommittee Chairman, Mr. Williams, is under the weather, and I and other Members on the Republican side will be tag-teaming presiding today over this hearing. And we expect him to be back very promptly.

That said, today, the Energy Subcommittee will explore the status of U.S. subsurface science and technology research, a field of study that's highly relevant for Americans all around the country, including those in my home State of Oklahoma. Our country has significant subsurface energy resources, and, if harnessed correctly, these resources have the capacity to provide all Americans with clean, baseload power and secure energy storage for generations to come.

Subsurface science encompasses a broad range of technologies and energy sources, ranging from next-generation mining and mineral extraction to advanced geothermal energy and carbon sequestration. A strong understanding of subsurface systems is essential not only for harnessing today's resources, but for expanding our clean energy portfolio, sustaining critical domestic energy supplies, and ensuring that the long-term storage of carbon dioxide and nuclear waste.

Despite significant advances in recent years, the fundamental and applied research in these fields faces unique challenges associated with accessing the subsurface. That's why robust support for subsurface R&D (research and development) is critical for U.S. energy independence and national security. On the Science Committee, we prioritize the fundamental and early stage research that leads to groundbreaking technologies, and subsurface science is truly one of these areas, a multidisciplinary field of study that maximizes return on investment by advancing several clean energy pathways at once. This is an important segment of our all-of-the-above clean energy strategy.

While I look forward to hearing from our subsurface experts here today, I'm particularly pleased to see representation from the U.S. geothermal industry. Advanced geothermal technologies have the potential to transform the U.S. energy sector. Geothermal is a source of clean and renewable energy that is always on. Yet, although the United States leads the world in geothermal power production, geothermal still contributes less than one percent of the total utility scale U.S. electricity generation. While I've seen the value of geothermal energy in my district with Oklahoma's 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. federally funded research programs at the Department of Energy (DOE) have a history of paving the way for industry innovation. It is critically important to our clean energy future that we have the support they need to pursue research that industry cannot undertake. That's why, three years ago, the Science Committee worked to get my bill, the *Advanced Geothermal Research and De-*

velopment Act, signed into law as a part of the bipartisan *Energy Act of 2020.* This legislation provided DOE with a comprehensive reauthorization of its geothermal technologies R&D activities, including its Frontier Observatory for Research in Geothermal Energy, FORGE as some of us call it, program, directing DOE to partner with industry and academia to improve the next generation of geothermal energy systems.

Just last week, a participant in the FORGE program, Fervo Energy here with us today—you can correct me on that—announced a record advanced achievement of an enhanced geothermal system (EGS) site. I hope that this afternoon we can get a clearer picture of the outcome of some of these kinds of investments and recommendations for appropriate next steps. I also look forward to our larger discussions that will improve our understanding of the subsurface environment that both DOE and U.S. industry are advancing groundbreaking activities to meet our present and future energy resource needs.

Recently, I was fortunate enough to visit Baker Hughes' research facilities in Oklahoma and saw firsthand the potential for industry collaboration and technology transfer between subsurface energy sectors and applications. If we want to ensure a diverse portfolio of clean energy technologies now and in the future, we in Congress should prioritize this kind of important fundamental research and partnership.

I want to thank our witnesses for the testimony, and I look forward to a very productive discussion.

[The prepared statement of Chairman Lucas follows:]

Good afternoon. Today, the Energy Subcommittee will explore the status of U.S. subsurface science and technology research, a field of study that is highly relevant for Americans around the country, including in my home state of Oklahoma.

Our country has significant subsurface energy resources, and, if harnessed correctly, these resources have the capability to provide all Americans with clean baseload power and secure energy storage for generations to come.

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

I want to thank our witnesses for their testimony and I look forward to a productive discussion.

Chairman LUCAS. And with that, I now recognize the Ranking Member, the gentleman from New York, for his opening statement.

Mr. BOWMAN. Thank you so much, Mr. Chairman, for convening us here today. And thank you to our panel of expert witnesses for appearing before this Committee to talk about a topic that is relevant to several technologies that we must use to enable our clean energy future.

Understanding the natural processes of the Earth and how we can sustainably harness its resources is essential to human wellbeing, and a lot of our unanswered questions lay in the rock and soil beneath our feet in the subsurface of the Earth. There too can be found one of our most promising technologies for building a climate-safe future. Geothermal energy technology allows us to utilize the warmth naturally captured in the subsurface of the Earth to produce clean energy. We can even use that heat directly to enable industrial processes that need high temperatures to heat our homes.

Many communities in my district are pursuing the creation of thermal energy networks to efficiently bring geothermal power to clusters of public buildings and affordable housing, which is very exciting. I am pleased to see President Biden's Administration embrace geothermal energy, and I'm proud to have joined with my colleagues here on the Science Committee to support efforts to advance the technology.

I also understand that there has been a recent breakthrough in geothermal technology development that one of our witnesses here today can talk extensively about, and I greatly look forward to that discussion.

Historically, a lot of the subsurface technology R&D supported by the Department of Energy has focused on extracting fossil fuels from the ground. We have learned a great deal on how to harness resources in the subsurface, which can thankfully now be applied to clean energy, as with geothermal. This body of knowledge can

also help us assess if and how carbon can be safely stored in the underground.

But as we work to transition to a new clean energy system, we must build in principles of equity and justice at every step of the process. And I'm happy to see the President focusing on exactly that through his Justice40 Initiative, which ensures that 40 percent of the benefits from our Federal investments, including science R&D, flow to the communities that have been historically hit hardest by fossil fuel pollution.

The Department of Energy has also stewarded decades of subsurface research related to understanding natural terrestrial processes, such as the carbon and water cycles and on applying the science to help understand how Manhattan Project experiments impacted the environment. This emphasis on biogeochemistry and material science not only helps us to understand our responsibility to manage legacy contaminants, but also helps us further the Earth sciences in general and their application to climate action. This research that the Department supports is part of a global effort to understand and reduce the damage humans are causing to the Earth. It is critical that we continue to fund these Federal investments in climate science.

With that, I want to say thank you again to the Chair and to our panel of distinguished witnesses for putting on this hearing today, and I yield back.

[The prepared statement of Mr. Bowman follows:]

Thank you, Chairman Williams, for convening this hearing today. And thank you to our panel of expert witnesses for appearing before the Committee to talk about a topic that is relevant to several technologies that we must use to enable our clean energy future. Understanding the natural processes of the earth and how we can sustainably harness its resources is essential to human well-being. And a lot of our unanswered questions lay in the rock and soil beneath our feet, in the subsurface of the earth.

There, too, can be found one of our most promising technologies for building a climate-safe future. Geothermal technology allows us to utilize the warmth naturally captured in the subsurface of the earth to produce clean energy. We can even use that heat directly to enable industrial processes that need high temperatures, or to heat our homes. Many communities in my district are pursuing the creation of thermal energy networks to efficiently bring geothermal power to clusters of public buildings and affordable housing. I am pleased to see PresidentBiden's administration embrace geothermal energy and am proud to have joined with my colleagues here on the Science Committee to support efforts to advance the technology. I also understand that there has been a recent breakthrough in geothermal technology development that one of our witnesses here today can talk extensively about, and I greatly look forward to that discussion.

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Mrs. BICE [presiding]. Thank you, Ranking Member Bowman.

[The prepared statement of Ms. Lofgren follows:]

Thank you, Chairman Williams, for holding today's hearing, and I would also like to welcome our distinguished panel of witnesses for being here to discuss this important topic.

Climate change causes real and present threats to our constituents and communities. As the country strives to reach our goal of net-zero emissions as quickly as possible, we must broaden and accelerate our approach to advancing new technologies that will get us there. Just last month, this Committee held a hearing about the revolutionary potential that fusion energy has as a clean energy source—as we see every day in that giant fusion reactor in the sky called the sun. And today we are turning to subsurface science and examining our ability to unlock the immense geothermal energy resource that resides well below our feet.

With help from the Bipartisan Infrastructure Law, the Department of Energy is conducting important efforts to position the U.S. to use our subsurface resources effectively. But we all need to recognize that this is going to require a long-term effort to adequately improve our ability to assess, monitor, and access critical subsurface resources.

While a lot of progress has been made in the past few years, we need to double down on this work now—and this Committee has the opportunity to help make that happen. A better understanding of the subsurface would not only pave the way to incorporating more geothermal energy into our electric grid, but also enable advancements in geologic carbon and hydrogen storage. All of these technologies are expected to play a substantial role in our clean energy future, so we really don't have time to waste.

In addition, we will be discussing the importance of subsurface science in accelerating nuclear waste cleanup projects at legacy waste sites across the country, some of which date back to the Manhattan Project. The communities around these sites deserve safe and healthy environments, and we should be doing everything in our power to ensure that that's exactly what they have.

For all of these reasons, I think this hearing is good step forward in improving our national capability for subsurface science for a broad range of important applications. I look forward to today's conversation, and thank the witnesses again for being here today.

Mrs. BICE. And at this time, let me introduce our witnesses. Our first witness today is Dr. Alexandra Hakala, a Senior Fellow for Geologic and Environmental Systems at the National Energy Technology Laboratory (NETL). Our next witness is Mr. Ben Serrurier, the Government Affairs and Policy Manager for Fervo Energy. Our third witness, with a much easier-to-pronounce name, is Dr. Kevin Rosso, the Associate Director of Physical Sciences Division for Geochemistry at Pacific Northwest National Laboratory (PNNL). Next is Dr. Haruko Murakami Wainwright, the Norman C. Rasmussen Career Development Professor, Assistant Professor of Nuclear Science and Engineering, and Assistant Professor of Civil and Environmental Engineering at MIT (Massachusetts Institute of Technology). And the last witness is Ms. Allyson Book, Chief Sustainability Officer for Baker Hughes.

I now recognize Dr. Hakala for five minutes to present her testimony.

TESTIMONY OF DR. ALEXANDRA HAKALA, SENIOR FELLOW, GEOLOGIC AND ENVIRONMENTAL SYSTEMS, NATIONAL ENERGY TECHNOLOGY LABORATORY, U.S. DEPARTMENT OF ENERGY

Dr. HAKALA. Thank you, Congresswoman Bice, Ranking Member Bowman, and Members of the Subcommittee. Thank you for this opportunity to testify on subsurface science and its vital role in understanding and harnessing the vast resources beneath our feet.

I'm Dr. Alexandra Hakala, a Senior Research Physical Scientist and Acting Senior Fellow for Geologic and Environmental Systems, representing the National Energy Technology Laboratory, or NETL, within the U.S. Department of Energy.

DOE plays an essential role in advancing subsurface R&D to secure America's energy future. Bringing together experts across scientific fields, DOE is focused on better understanding subsurface systems and optimizing their use to ensure clean and reliable energy sources for the Nation. Collaboration between DOE and the National Laboratories is essential to drive this progress in subsurface science.

The DOE Science and Energy Innovation, or SEI, crosscut, funds research, development, demonstration, and deployment so we can assess, access, and monitor the subsurface more quickly and accurately. These advancements will allow key technologies in geothermal energy, geologic carbon storage, geologic hydrogen storage, sustainable critical mineral extraction, and geologic hydrogen sourcing to become market-competitive, scalable, and permanent clean energy solutions.

The Office of Science's Advanced Scientific Computing Research (ASCR) and Basic Energy Sciences programs are supporting the fundamental research advancing our knowledge of the subsurface. Meanwhile, the Office of Fossil Energy and Carbon Management, or FECM, Carbon Transport and Storage Program has supported projects like the Regional Carbon Sequestration Partnerships, which conducted field tests to safely store more than 11 million metric tons of CO_2 and laid the foundation for regional initiative and commercial-scale projects supported by the Carbon Storage Assurance Facility Enterprise known as the CarbonSAFE Initiative.

Funded by the Bipartisan Infrastructure Law, CarbonSAFE pairs with the Carbon Basin Assessment and Storage Evaluation, or CarbonBASE, and Carbon Storage Technology Operations and Research, CarbonSTORE Initiatives, designed to advance each stage of carbon storage resources and projects as the CCS (carbon capture and storage) industry is implemented over time.

The Carbon Transport and Storage Program also invests in small-scale CO_2 injection and research on storage through mineralization. It's currently assessing potential storage resources and surface and subsurface locations nationwide. Proof-of-concept studies are being conducted in volcanic basins and offshore basalts, exploring unconventional storage resources to support regional decarbonization goals. Two multi-lab initiatives, the National Risk Assessment Partnership, or NRAP, and the Science-informed Machine Learning for Accelerating Real-Time Decisions initiative, or SMART, are working to reduce the uncertainty associated with geologic carbon sequestration.

Meanwhile, the Energy Data eXchange, or EDX, maintains all data from the Carbon Transport and Storage Program, including NRAP and SMART tools, and enables users to find and apply relevant data for carbon storage analyses. EDX works with other agency data bases to provide comprehensive access to subsurface data. These resources support site selection, risk analysis, and decisionmaking processes.

Finally, I want to emphasize the significance of our critical minerals and materials R&D and their potential to advance sustainable mining practices. The subsurface holds significant reserves of critical minerals, often inaccessible due to depth or mining limitations. Many of these un-mineable mineral resources can be unlocked using advanced subsurface imaging, detection, drilling, and fluid-handling technologies. The mines of the future will harness these advanced technologies, allowing for the extraction of mineral wealth with minimal surface and environmental impacts. As FECM's National Laboratory, NETL's R&D efforts align with this vision of a sustainable and environmentally responsible mineral extraction industry, strengthening America's position in critical minerals production.

At the same time, the Office of Science, primarily through the Basic Energy Sciences, is supporting fundamental experimental and theoretical research to understand the basic properties of critical minerals and materials. This enables the development of enhanced extraction, separation, and processing methods, as well as discovery of substitutes for critical materials that will perform equally well or better in the technology applications we rely on.

So thank you very much, Committee, for this opportunity to speak. And I'd like to highlight that through the collaboration between the DOE offices and the National Laboratories on these and other efforts, we are at the forefront of developing sustainable and efficient solutions for subsurface resource utilization and contributing to the Nation's energy security, environmental stewardship, and technological leadership.

Thank you again for the opportunity to discuss these cutting-edge innovations, and I'm happy to answer any questions.

[The prepared statement of Dr. Hakala follows:]

TESTIMONY OF DR. ALEXANDRA HAKALA

SENIOR RESEARCH PHYSICAL SCIENTIST

OF THE NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON ENERGY

U.S. HOUSE OF REPRESENTATIVES

UNEARTHING INNOVATION: THE FUTURE OF SUBSURFACE SCIENCE AND TECHNOLOGY IN THE UNITED STATES

JULY 26, 2023

Chairman Williams, Ranking Member Bowman, and honored members of the House Committee on Science, Space, and Technology, I am Dr. Alexandra Hakala, a senior research physical scientist and acting Senior Fellow for Geologic and Environmental Systems representing the National Energy Technology Laboratory (NETL) within the U.S. Department of Energy (DOE). Thank you for the opportunity to testify today on the crucial subject of subsurface science and its vital role in understanding and harnessing the vast resources beneath our feet.

Importance of Subsurface Science Research and Development (R&D)

The DOE plays a vital role in advancing subsurface science R&D in new application areas relating to the Nation's energy future. By bringing together experts from various scientific fields, DOE focuses on enhancing our understanding of subsurface systems and optimizing their utilization for geologic CO_2 storage, hydrogen storage, geothermal energy, and other applications. Collaboration between DOE and the National Laboratories is instrumental in driving progress in subsurface science. These partnerships foster knowledge exchange, leverage expertise, and facilitate the translation of research into tangible solutions.

In my testimony, I will highlight the vital research and achievements of DOE Offices and the National Laboratories in the field of subsurface science and technology development. I will also emphasize the importance of fundamental-to-applied R&D in subsurface science and technology and the significance of DOE offices working together to accelerate knowledge and technology advancement. These initiatives are integral to shedding light on the role subsurface science plays in mitigating climate change, exploring innovative energy production and storage solutions,

ensuring the environmentally prudent development of subsurface resources, and addressing the nation's legacy of nuclear weapons development. By focusing on these areas of research, DOE can advance subsurface science to enable responsible energy development and minimize environmental impact.

Subsurface R&D at DOE

DOE Subsurface Energy Innovation (SEI) Crosscut

The DOE SEI Crosscut funds research, development, demonstration, and deployment (RDD&D) to improve the accuracy, precision, and speed with which subsurface resources can be assessed, accessed, and monitored. Such advancements will allow the technologies listed below to become market- competitive, scalable, and permanent clean energy solutions, and create tens of thousands of good-paying jobs:

- Geothermal energy, which requires dramatic cost reductions in Enhanced Geothermal System (EGS) capability to increase its footprint beyond 0.5 percent of U.S. electricity generation;
- Geologic carbon storage, currently happening at 0.1 percent of the rate necessary to meet climate goals;
- Geologic hydrogen storage, currently only feasible in unique and rare geologic features;
- Sustainable critical mineral (CM) extraction, necessary to reduce high American import reliance; and
- Geologic hydrogen sourcing, a new and potentially cost-effective, zero-emission source of hydrogen.

SEI Crosscut activities reduce the uncertainty and cost burden facing these technologies through the production and application of tools, data products, and workstreams that improves observational, decision-making, and operational capabilities. Such activities require advancements across fundamental science, and applied RDD&D, which is why the SEI Crosscut membership spans the Offices of Science, Fossil Energy and Carbon Management, Energy Efficiency and Renewable Energy, and Clean Energy Demonstrations, as well as ARPA-E. The SEI Crosscut leverages the integration of state-of-the-art High-Performance Computing (HPC) resources, Artificial Intelligence (AI), Machine Learning (ML), and simulation capabilities with applied technology workstreams necessary to build subsurface simulation and interpretation visualization, prediction, and decision-making tools.

Enhanced Geothermal Shot

A major focus in key crosscutting efforts is the execution of DOE's Energy Earthshots Initiative™. The Initiative sets cost and performance targets on a decadal timescale and drives forward breakthrough RD&D across the Department. Each ambitious, yet achievable, Energy Earthshot target represents a major innovation goal that we know we must achieve to solve the climate crisis, reach our 2050 net-zero emissions goals, and create the jobs of the new clean energy economy.

Subsurface innovation can advance progress for Carbon Negative Shot™, but perhaps most of all for the subsurface-focused Energy Earthshot is DOE's Enhanced Geothermal Shot™, which aims to bring geothermal energy – the vast energy resource beneath our feet – to Americans nationwide by driving down the cost of enhanced geothermal systems (EGS) by 90% to $45/MWH between now and 2035. These cost reductions would unlock 90 gigawatts-electric (GWe) of clean, firm, and flexible energy, enough to power 65 million American homes. Achieving the Energy Earthshot target could also create a geothermal industry that supports more than 250,000 jobs, including jobs that leverage existing skillsets from the oil and gas sector to ensure an equitable transition for those workers.

Office of Fossil Energy and Carbon Management (FECM)

Within the DOE's FECM, significant efforts have been devoted to advancing subsurface science R&D to address the pressing challenges of mitigating climate change, exploring innovative energy solutions, and ensuring responsible subsurface resource utilization. Through collaborative efforts, cutting-edge research, and systems analysis capabilities, NETL strengthens the ability of FECM to deliver innovative approaches for advanced energy systems. Subsurface science priorities include:

- **Foundational work for Carbon Transport and Storage Program (CTS)**: This program has supported R&D projects for over two decades, validating geologic carbon storage as a viable climate mitigation solution. It has leveraged the Regional Carbon Sequestration Partnerships (RCSP), which conducted field tests to safely store more than 11 million metric tons of CO_2. The RCSPs have transitioned to the Regional Initiative projects and now provide regional technical assistance to carbon storage stakeholders. This is a time of unprecedented development of carbon storage projects. Globally, projects in operation capture and store more than 40 million metric tons annually (MTpa) with more than 200 additional MTpa planned. The findings from the RCSP have laid the foundation for commercial-scale projects supported by the Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative.
- **Three interfacing initiatives to realize basin-scale deployment of commercial-scale storage:** The CTS program has developed an integrated approach with three interfacing initiatives to ensure safe and secure geologic storage of captured CO_2. The Bipartisan Infrastructure Law (BIL)-funded CarbonSAFE Initiative pairs with the new Carbon Basin Assessment and Storage Evaluation (CarbonBASE) and Carbon Storage Technology Operations & Research (CarbonSTORE) initiatives. These three efforts are designed to be executed in coordination to enable sustained and responsible stewardship of carbon storage resources and projects as the CCS industry is implemented over time.
  - → **Commercial-scale storage**: The BIL-funded CarbonSAFE initiative aims to develop commercial-scale geologic storage facilities and associated transport infrastructure. The goal is to provide future access to billions of metric tons of secure geologic storage capacity. These facilities, expected to range from 20 to 40 facilities, will enable the injection of up to 100 million metric tons of CO_2 per year by 2030. Future facilities developed post BIL will further enable decarbonization from point sources to meet the decarbonization goals of greater than one billion metric tons per year by midcentury.

→ **Basin-scale storage resource data gaps, efficiency, impacts, and management**: As individual and hub-scale storage projects come online, managing basin-wide storage resources becomes crucial for efficient, safe, and secure geologic storage of captured CO_2. To address this challenge, the CTS base program will invest in the CarbonBASE initiative. This initiative will collect geologic data, develop basin-scale management tools, and deploy basin-wide monitoring systems to assess the efficiency and security of storage resources.

→ **At-scale technology validation and performance testing**: The CarbonSTORE initiative funded by the CTS base program focuses on accelerating the development of enabling technologies for carbon storage. CarbonSTORE facilities are intended to belong-term field laboratories that will test, validate, and demonstrate emerging technologies in different geological settings. This includes monitoring and control systems, characterization tools, storage efficiency methods, and risk avoidance and mitigation technologies.

- **Technical assistance**: The Regional Initiative program, now expanded to a more place-based technical assistance framework, provides specific assistance to support development of large-scale storage facilities and regional carbon management hubs. The objectives are to fill knowledge gaps, provide crucial information to operators, and develop community engagement strategies.
- **Risk assessment and management**: The CTS program has been focused on reducing uncertainty associated with geologic carbon sequestration through the National Risk Assessment Partnership (NRAP). NRAP, a multi-laboratory initiative led by NETL and including Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), Pacific Northwest National Laboratory (PNNL), and Lawrence Berkeley National Laboratory (LBNL), has developed open-source tools for assessing and quantifying risks throughout the lifecycle of a storage project. NRAP is also expanding its scope to manage risks associated with the deployment of multiple commercial-scale storage projects in a region.
- **CO_2 mineralization storage resources**: The CTS program invests in small-scale CO_2 injection and research on storage via mineralization. It is currently assessing potential storage resources in subsurface and surface locations throughout the nation. Proof-of-concept studies are being conducted in volcanic basins and offshore basalts, exploring unconventional storage resources to support regional decarbonization goals.
- **AI/ML enabled technologies**: The CTS program is advancing storage technologies, such as sensors, telemetry, and power sources, to streamline characterization and monitoring capabilities. These technologies, integrated into the Science-informed Machine Learning for Accelerating Real-Time (SMART) Decisions initiative, aim to improve the efficiency and effectiveness of field-scale carbon storage through real-time visualization, forecasting, and virtual learning to revolutionize decision-making in subsurface applications. SMART focuses on developing ML-based tools that consolidate technical knowledge, optimize carbon storage reservoirs, and improve understanding of subsurface behavior during carbon storage operations.

- **Transport systems**: FECM is investing in multi-modal front-end engineering design (FEED) and Pre-FEED studies and the development of analysis tools for evaluating CO_2 transport systems. This includes pipeline, rail, truck, and marine modes. Applied research in CO_2 transport priority areas includes the impact of impurities on transport modes, leak detection protocols, repurposing existing infrastructure, and intermodal hubs.
- **Energy Data Xchange (EDX)**: The CTS program and the development of EDX as a data curation and collaboration platform includes both public and private data sharing capabilities, entire life cycle of data, data discovery, transformation, and integration. EDX maintains all data from the CTS program, including NRAP and SMART tools. A multi-cloud DisCO2very platform combines mapping, tools, models, machine learning, and advanced data discovery to enable users to find and apply relevant data for carbon storage analyses. EDX is federated with other agency databases, providing comprehensive access to subsurface data. These resources support site selection, risk analysis, and decision-making processes, democratizing access to models and data for improved resource management and decision support.
- **Terrestrial carbon sequestration**: DOE's terrestrial carbon sequestration work began with FECM investments in the early 2000s. It involved a coordinated approach across forest management, agriculture, and woody crops. The focus was on technology development, economic modeling, and stakeholder engagement. Collaborative efforts assessed carbon sequestration at various scales and deepened our understanding of capture mechanisms and carbon fluxes. FECM is currently partnering with DOE's Office of Technology Transitions to commercialize measurement, reporting, and verification technologies. Further efforts are needed to understand, assess, monitor, and implement commercial terrestrial carbon sequestration, including analytical work and technology development.
- **Offshore subsurface:** FECM's offshore subsurface research focuses on enhancing subsurface characterization, improving subsurface property prediction in data-scarce areas, and unlocking the energy extraction and storage potential of our Nation's subsurface. This research provides valuable insights into offshore infrastructure performance, identifies potential hazards, and explores opportunities to repurpose existing offshore energy infrastructure for accelerated offshore CCUS projects.
- **Critical minerals**: FECM has funded efforts to characterize the mineral deposits found in secondary and unconventional feedstocks, such as coal, under burden and overburden layers, recycled resources, and shale. These efforts include the assessment of different potential ore minerals (e.g., monazite for rare earth elements (REE)) that are found within the original subsurface formations and how that contributes to ease of extraction of the metals of interest. Data is being collected in a number of basins across the U.S. in the CORE-CM Initiative for the assessment of REE and other CM content and is curated via the Energy Data Xchange. Data analysis, including machine learning tools, have been developed and used to help better predict the locations of formations higher in critical minerals.
- **Underground hydrogen storage:** In 2021, FECM initiated the SHASTA (Subsurface Hydrogen Storage Assessment and Technology Acceleration) project, a collaborative effort between NETL, PNNL, LLNL, and Sandia National Laboratories (SNL). The project aims to assess the feasibility, safety, and reliability of storing pure hydrogen or hydrogen natural gas blends in subsurface environments. Key challenges addressed by the SHASTA team include evaluating the efficacy of different underground systems, such as depleted hydrocarbon

reservoirs, saline aquifers, and salt caverns, for hydrogen storage. Additionally, the project investigates hydrogen loss due to biogeochemical reactions, containment risks through caprock, faults, fractures, or leaky wells, and the development of real-time monitoring technologies for assessing gas migration, potential leakage, microbial activity, and well integrity.

- **Sustainable mining:** Even with unconventional and recycled sources, many new mines will be required to meet clean energy and climate change goals. The IEA[1] estimates that 4-6 times the current amount of critical minerals and metals will be needed by 2040 compared to what is used today to meet stated clean energy goals. The subsurface of the Nation holds significant reserves of critical minerals, often inaccessible due to depth or mining limitations. These "unmineable" mineral resources may be unlocked by leveraging advanced subsurface imaging, detection, drilling, and fluid handling technologies. The mines of the future will harness these advanced technologies, allowing for the extraction of mineral wealth with minimal environmental impact. By employing closed systems for leaching, extracting, and processing, these future mines will ensure minimal surface impacts while tapping into vast untapped mineral resources. As FECM's national laboratory, NETL R&D efforts align with the vision of a sustainable and environmentally responsible mineral extraction industry, strengthening America's position in critical minerals production.
- **Orphaned wells R&D:** The number of orphaned wells across the U.S. is estimated to approach 1 million[2,4]. Of these wells, between 90,000 and 130,000[3] are referred to as documented orphaned wells that have known locations and ownership. A second category of orphaned wells, referred to as "undocumented" orphaned wells, are wells for which no permits, records, location, nor ownership exist, and range between 210,000 and 746,000[3]. FECM initiated the Undocumented Orphaned Wells Program (UOWP) in 2022. This program is focused on developing technology, methodologies, and guidelines for identifying and characterizing undocumented orphaned wells. UOWP leverages the expertise of several national labs to support active stakeholders, such as the Interstate Oil and Gas Compact Commission, States, Tribes, and the Department of the Interior. NETL is working to bridge the knowledge gap and develop cost-effective methods for locating undocumented orphaned oil and gas wells, quantifying their emissions in order to prioritize their management for plugging. For example, since 2005, NETL has developed rapid airborne methods for locating undocumented orphaned wells through the development and field validation of advanced electromagnetic hardware and machine learning software.
- **Unconventional Field Laboratories:** The DOE has established a suite of 17 Field Laboratories across various basins in collaboration with industry, academia, and national laboratories. These Field Laboratories serve as platforms for collaborative research and aim to accelerate the development and application of new technologies, tools, and processes in unconventional field-based settings. The overarching objectives of these laboratories are to optimize operational efficiency, improve reservoir characterization, enhance recovery

[1] IEA World Energy Outlook Special Report. 2021. "The Role of Critical Minerals in Clean Energy Transitions. The Role of Critical Minerals in Clean Energy Transitions (windows.net)

[2] Management of Abandoned and Orphaned Oil and Gas Wells, The American Association for the Advancement of Science

[3] Idle and orphan oil and gas wells—State and provincial regulatory strategies 2021, IOGCC, December 2021, https://iogcc.ok.gov/idle-and-orphan-oil-and-gas-wells-2021

[4] Wright, B., Hide and Seek: The Orphan Well Problem in America, Journal of Petroleum Technology, August 2021

efficiency, promote environmental sustainability by improving water use and preserving air/water quality, and explore future energy storage opportunities such as expanded CO_2 enhanced oil recovery (EOR), carbon storage, and hydrogen storage. The knowledge gained from these Field Laboratories will not only contribute to the understanding of subsurface dynamics in producing basins but also have practical applications in geologic CO_2 storage, hydrogen storage, and the development of mines of the future. Furthermore, future Field Laboratories are planned to expand the research scope, focusing on simultaneous CO_2-EOR with CO_2 storage, leveraging the knowledge gained from existing projects to support the deployment of commercially viable CO_2 injection for EOR and geologically storing CO_2.

Office of Science

The Office of Science (SC) provides fundamental knowledge and state-of-the-art capabilities, supporting discovery science and energy-use-inspired research to establish the foundations for the advancement of energy technologies. SC supports theoretical, computational, and experimental science across various topics to enhance our understanding of nature and promote national security. Research supported by SC is conducted at DOE's National Laboratories and institutions of higher education, including underrepresented and emerging research institutions, located across the U.S. SC operates user facilities such as x-ray and neutron sources, nanoscience facilities, genome sequencing facilities, and high-performance computing and network facilities that contribute to research in subsurface science and related areas like geothermal energy, carbon sequestration, energy storage, and environmental management.

- **Subsurface/Geothermal**: SC conducts computational, theoretical, and experimental research to advance subsurface energy technologies by understanding geo-mechanical/chemical, hydrological, and interfacial chemistry, and materials behavior. Predicting the coupled effects of rock stresses, fluid pressure, and reactive fluid transport is crucial for implementing subsurface technology. Basic research is needed to improve predictability and enable heat mining for geothermal energy, subsurface storage of carbon and hydrogen, and underground storage for environmental remediation. Challenges include developing theoretical models to understand fracture system behavior and connecting signals to subsurface processes using data science and machine learning methods.

  Two SC program offices, Advanced Scientific Computing Research (ASCR) and Basic Energy Sciences (BES), actively participate in the multi-office DOE SEI Crosscut. Other participating offices are EERE-GTO, FECM, ARPA-E, and NNSA. ASCR supports fundamental research to enable higher precision in subsurface characterization and monitoring by exascale simulation, data analysis, and basic research in AI/ML through ASCR's exascale computing project, core research program, and SC Energy Earthshots Initiative. ASCR also invested in basic research in edge computing, novel computational tools for data collection at various scales, verification and validation of field data, uncertainty quantification, and integration of massive heterogenous data using AI/ML techniques. BES also supports fundamental geosciences research through experimental and computational user facilities, single principal investigator and small team science through the BES Geosciences core program and SC Energy Earthshots Initiative, and larger multi-disciplinary, multi-institutional centers such as Energy Frontier and Energy Earthshot Research Centers.

The core program is distinct in its support for research combining geochemistry and geophysics, and its coordination with other research efforts across the BES portfolio and scientific user facilities. Taken together, this research contributes crosscutting knowledge to enable control of processes in extreme geological environments, large-scale subsurface storage of CO_2 via mineralization, and understanding geochemical and geophysical processes at larger scales.

- **Carbon Management**: SC supports theoretical and experimental research relevant to carbon capture, utilization, and storage. BES conducts fundamental research in materials and chemistry to advance carbon management technologies, including CO_2 removal and direct air capture. Workshops and roundtables have identified priority research opportunities to address scientific barriers in CO_2 removal technologies and carbon capture. ASCR funds exascale simulation projects to provide higher resolution characterization of geological sequestration and design and optimization of large-scale commercial systems. Research areas include energy transfer mechanisms, novel materials and chemical systems for efficient carbon capture, functionality of 2D materials, control of mineral dissolution and formation rates, and catalytic and enzymatic approaches for carbon concentration or conversion.
- **Critical Materials**: SC, primarily through BES, supports fundamental experimental and theoretical research to understand the basic properties of critical materials. This research is enabling the development of enhanced extraction, separation, processing methods, as well as the discovery of substitutes for critical materials that maintain or improve technology performance. Fundamental research in critical materials, including both rare earth and platinum group elements that play critical roles in clean energy technologies, is advancing our understanding of the physics and chemistry of critical materials and the dynamic geochemistry and properties of fracture systems and hydrothermal fluids. These advances are necessary for realizing innovations that reduce or eliminate critical mineral use and advancing new approaches for extraction and recovery from complex and dilute mixtures, respectively.
- **Biological and Environmental Research (BER) Environmental Studies**: The BER program invests in experimental and modeling research on the transformation of organic and inorganic compounds in the environment. Long-term studies in various watersheds, including those near Oak Ridge National Laboratory (ORNL), PNNL, and the East River of the upper Colorado River, focus on surface and groundwater interactions and the influence of physical and biogeochemical processes on environmental predictions.
- **Research related to Radiation and Environmental Management**: BES supports research that advances understanding of the effects of radiation on materials and chemical processes for heavy elements and ionizing radiation. This includes understanding defect evolution in irradiated materials and radiation chemistry in nuclear reactors and waste processing. Through support for research on the molecular-level chemistry of ores and legacy waste contaminants, BES is contributing to the development of new strategies for mining and remediation. Multiple SC programs, including BES, have collaborated with EM to define priority research directions that will advance the scientific foundations for future

environmental management technologies and support cleanup efforts at sites like the Hanford Site.

Office of Energy Efficiency and Renewable Energy

Geothermal energy is a clean, renewable resource that can play a significant role in electricity generation, heating, and cooling. By harnessing geothermal power, the United States can create jobs, support impacted communities, and leverage the expertise of the oil and gas sector. Furthermore, geothermal energy offers opportunities for extracting critical materials from geothermal brines, developing a domestic supply of minerals like lithium, and enabling efficient processes such as direct-air capture and hydrogen production. Promising cutting-edge geothermal technologies include:

- **Enhanced geothermal systems (EGS):** Injecting water into hot rock underground to create reservoirs for electricity generation.
- **Supercritical geothermal energy**: Producing energy by heating water to a temperature and pressure that causes it to become a supercritical fluid.
- **Closed-loop geothermal**: Injecting fluid into interconnected wells in the subsurface, preventing fluid from contacting the rock.

The United States is home to vast heat subsurface resources, but a substantial amount of that heat is not accessible with current technology. Research and innovation to advance EGS and other cutting-edge geothermal technologies can unlock those resources and put new, clean, firm, and flexible electricity on the grid and open the possibility for geothermal energy nationwide.

Office of Environmental Management (EM)

The achievements and ongoing efforts within the DOE's EM deserve recognition as they exemplify the government's commitment to addressing the environmental legacy of national defense programs. EM has successfully completed cleanup operations at 92 out of 107 sites, showcasing significant progress over its 34-year tenure. Some notable accomplishments include:

- Safe demolition of the Hanford Site's Plutonium Finishing Plant, responsible for two-thirds of the nation's Cold War-era plutonium production.
- Construction and operation initiation of depleted uranium hexafluoride conversion plants at the Portsmouth and Paducah sites.
- Management of one of the world's largest groundwater and soil remediation efforts, treating billions of gallons of contaminated groundwater at sites like Hanford, Los Alamos, Moab, and Savannah River.
- Completion of waste vitrification activities and subsequent demolition of the Vitrification Facility at the West Valley Demonstration Project in New York.
- Full demolition of all Department of Energy-owned buildings at the Energy Technology Engineering Center in California.
- Establishment of the world's only deep geological repository, the Waste Isolation Pilot Project in New Mexico, dedicated to transuranic waste from atomic energy defense activities.

- Completion of the entire tank waste treatment system at the Savannah River Site, addressing one of the Department's significant environmental and financial liabilities.
- Commencement of large-scale treatment of radioactive liquid waste from underground tanks using the Tank-Side Cesium Removal System at the Hanford Site and the Integrated Waste Treatment Unit at the Idaho National Lab Site.

Conclusion

The DOE offices and the National Laboratories collaborate closely to develop crosscutting technologies for the subsurface. By combining expertise and capabilities, they drive innovation and advancements in subsurface science and technology. These crosscut collaborations allow the DOE to tackle complex challenges, such as carbon capture and storage, hydrogen storage, geothermal energy extraction, critical materials exploration, environmental management, and more. Through joint efforts, the DOE is at the forefront of developing sustainable and efficient solutions for subsurface resource utilization, contributing to the nation's energy security, environmental stewardship, and technological leadership.

In conclusion, my testimony has highlighted DOE's extensive expertise in subsurface science and the collaborative approach taken in R&D. The examples presented illustrate the DOE's commitment to advancing subsurface technologies and responsible resource management. Thank you for the opportunity to discuss some of these cutting-edge innovations, which have applications within – and beyond – the energy sector. I look forward to the opportunity to further discuss these crucial topics and respond to any questions you may have.

J. Alexandra Hakala, Ph.D.

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NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

Dr. Hakala is a geochemist and leader of multidisciplinary geoscience and engineering research teams executing R&D focused on ensuring prudent development of natural resources for energy extraction, water management, and climate change mitigation. She has fifteen years of experience in applied geoscience and engineering research at the National Energy Technology Laboratory (2008 – present), earned her Ph.D. in Earth Sciences (Geochemistry focus) from The Ohio State University (2008) where she was a U.S. Environmental Protection Agency Science to Achieve Results Graduate Fellow, and earned her Bachelor of Arts Cum Laude in Geosciences with a Certificate (minor) in Environmental Studies from Princeton University (2003).

She actively engages in strategic planning and initiative development across the National Energy Technology Laboratory and Fossil Energy Carbon Management Headquarters, and with external industrial, academic, and Federal lab stakeholders on multidisciplinary and multi-organizational geologic and environmental R&D. Dr. Hakala is NETL's representative on the Network of National Laboratories for Environmental Management and Stewardship (via DOE-Environmental Management and DOE-Legacy Management) and is active in geothermal R&D via DOE-Energy Efficiency and Renewable Energy's Geothermal Technologies Office. She is the author of 60+ technical publications focused on multiple energy geoscience topics, including geologic CO2 storage, unconventional oil and gas development, geothermal resources, produced water management, and environmental geochemistry, and has mentored 30+ students and/or postdocs. Dr. Hakala is a recipient of the Presidential Early Career Award for Scientists and Engineers (2017) and is an Oppenheimer Science and Energy Leadership Program Fellow (2023).

Mrs. BICE. Thank you, Dr. Hakala.

Next up, I recognize Mr. Serrurier for five minutes for his testimony.

TESTIMONY OF MR. BEN SERRURIER, GOVERNMENT AFFAIRS AND POLICY MANAGER, FERVO ENERGY

Mr. SERRURIER. Thank you, Representative Bice, Ranking Member Bowman, and Members of this Committee for the opportunity to be here today. My name is Ben Serrurier. I'm the Government Affairs and Policy Manager at Fervo Energy. We are developing enhanced geothermal systems to deliver 24/7 clean electricity. Our approach to EGS leverages drilling advances from the natural gas industry to increase production, reduce risk, and produce cost-competitive power from hot dry rock.

Harnessing domestic resources, literally the heat beneath our feet, with American-made equipment and a homegrown workforce that pulls directly from America's world leading oil and gas industry, geothermal is a complete energy security solution that has a major role to play in the future electric grid.

This hearing is taking place at an opportune moment. Last week, Fervo announced a major technological breakthrough, proving that enhanced geothermal is commercially viable and ready to scale. In removing the remaining technical barriers to expanding geothermal, America is in position to dominate the global market for this high-potential clean energy resource. This breakthrough reflects the important technological progress that has carried geothermal to this stage and shows the way forward toward realizing its huge potential.

Enhanced geothermal today is in a similar place to the natural gas industry roughly 15 years ago on the cusp of the shale revolution. EGS benefits from the technology, experience, and skilled workforce of pure subsurface industries, and it will also benefit from following their commercialization pathway. Following the shale playbook, the next phase of innovation in geothermal will come from project standardization and modular development, driving down costs through learning and deployment. Fervo has demonstrated the effectiveness of EGS technology, and we now have the opportunity to perfect it.

The Department of Energy and its national labs have been instrumental in pioneering the technologies and techniques that enabled first the shale gas boom and now breakthroughs in EGS. Expanding these research and deployment investments in geothermal is critical to meeting clean energy goals, while safeguarding grid reliability, strengthening domestic energy security, and creating high-paying jobs in manufacturing and subsurface development.

In May, Fervo's commercial scale pilot project in northern Nevada produced 3.5 megawatts of geothermal energy and established itself as the first EGS project to achieve commercial viability. This breakthrough signifies the official commencement of what is likely to be yet another American-led energy revolution.

Now, the key in tapping geothermal's potential is through optimizing our subsurface approach in the same way natural gas development utilizes standardized well designed to reduce drilling time and increase production. Fervo has already finished drilling its first

well at a new field in southwest Utah for a plant that will total over 400 megawatts and come online before the end of the decade. And we're already seeing this learning curve in action. Across our four drilled wells, we've accomplished an 18 percent improvement in drilling performance. This indicates that greater cost reduction is yet still achievable.

Federal support for early stage R&D has been instrumental in reaching this milestone, and Federal support for demonstration and deployment will be just as important in sustaining progress. Historically, funding for geothermal has lagged other clean firm energy technologies, despite its recent progress and large benefits per invested dollar. To that end, we are eager for the DOE Geothermal Technologies Office to invest its allocated funding from Fiscal Year 2023 appropriations for EGS demonstration projects.

While America is well-positioned to lead the geothermal revolution, other countries are catching up. A single $100 million grant from the European Union to a project in Germany is by itself $16 million more than the Bipartisan Infrastructure Law provided to divide across all U.S. projects. And China's most recent five-year plan on renewable energy development includes a prominent role for Chinese geothermal development and generation. The U.S. must capitalize on its comparative advantage in subsurface technology, advanced manufacturing, and project development. And by increasing investment in EGS research and deployment will catalyze a wave of American-built geothermal across the globe.

The shale gas revolution has shown us what is possible when the government agencies, national labs, and universities work together with industry to invest in subsurface exploration. That journey of technological innovation, commercial entrepreneurship, economic abundance, and energy security is now continuing in geothermal. Now that EGS has proven optimizing this technology through standardization and modularity will deliver affordable and reliable clean energy and jumpstart a globally significant American industry.

Thank you again for the opportunity to speak with you today, and I look forward to your questions.

[The prepared statement of Mr. Serrurier follows:]

Testimony of Ben Serrurier
Government Affairs and Policy Manager
Fervo Energy

U.S. House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Energy
Hearing on "*Unearthing Innovation: The Future of Subsurface Science and Technology in the United States*"

July 26, 2023

Thank you Chairman Williams, Ranking Member Bowman, and the Members of this Committee for the opportunity to be here today. My name is Ben Serrurier and I am the Government Affairs and Policy Manager at Fervo Energy, the leader in next-generation geothermal energy technology. We are developing enhanced geothermal (EGS) projects to deliver 24/7 clean electricity that leverages the drilling advances achieved in the natural gas industry over the last decade. Geothermal has a major role to play in the future electric grid by providing clean and reliable energy, and our key advancements in drilling and subsurface analytics bring a full suite of modern technology to make geothermal cost competitive.

New Technological Breakthrough: We Can Deploy Next-Generation Geothermal Today

The convening of this hearing happens at an opportune moment: last week, Fervo Energy announced a major technological breakthrough in next-generation geothermal energy development, proving that next generation geothermal energy is commercially viable and ready to scale.[1] Removing the remaining technical barriers to expanding geothermal puts America in the position to dominate the global market for this high potential clean energy resource.

Fervo is applying the techniques and technologies that were key to unlocking the American shale gas revolution, but have never before been applied to geothermal reservoirs. In May, Fervo completed a 30-day test of our commercial scale pilot project, called "Project Red," in northern Nevada. This successful well test confirms our system, the most productive enhanced geothermal system in history, is commercially ready. This breakthrough signifies the official commencement of what is likely to be yet another American-led energy revolution.

Geothermal energy is not novel: in both the United States and abroad, geothermal energy has been a source of reliable electricity for over half a century and used for heating and cooling for

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[1]https://www.bloomberg.com/news/articles/2023-07-18/fervo-energy-says-it-has-achieved-geothermal-energy-tech-breakthrough

even longer. However, until now, its potential has been limited by our ability to find and tap only specific geologic formations. Despite significant advancements in reservoir characterization, subsurface monitoring and simulation, drilling, and well production – the fundamental drivers of geothermal cost and productivity – the approach to commercial geothermal power development has barely advanced at all.

Fervo's project data demonstrates that we have removed this limitation and opened up a new era in geothermal potential.

The important metrics for a successful geothermal project come down to flow rate and temperature. In other words, how much water you can produce from the well, and how much energy that water holds. Greater flowrates and higher temperatures result in greater power production.

Over 30 days, we flowed water through our reservoir as part of a standard geothermal exercise called a flow test. Through this test we achieved a flowrate of 63 liters per second at a temperature of 375°F, enabling 3.5 MW of electric production.[2] All of these data points set new records for output from an enhanced geothermal system, and are solidly within the expected range for successful commercial production.

We achieved this outcome by drilling a horizontal well pair and performing a multi-stage completion, and we installed fiber optic cables to monitor well performance and inform future optimization plans. Our horizontal well pair, the first and second horizontal wells to ever be drilled in a geothermal reservoir, reached a vertical depth of 7,700 ft before turning ninety degrees and extending another 3,250 feet each.

Our multi-stage well completion process was the second multi-stage high pressure completion with proppant to be pumped in a geothermal reservoir – the first was a pilot test Fervo ran in 2020 in an existing highly deviated well in the same field. All operations were accomplished safely and without incident.

While successful, this project is just a start. Data collected through the course of the pilot will enable rapid advancement in geothermal technology, and Fervo has already finished drilling its first well at a new field in southwest Utah. Now complete, this well is Fervo's fourth well drilled overall and the first on a project that will ultimately total over 400 MW and come online before the end of the decade.

[2] Norbeck, Jack; Latimer, Tim (2023): Commercial Scale Demonstration of a First of a Kind Enhanced Geothermal System. EarthArXiv. https://doi.org/10.31223/X52X0B

Over the course of drilling just four wells, we have seen an 18% performance improvement, demonstrating the powerful cost reduction achieved through deployment learning curves (see Figure 1). Late last year, the Department of Energy (DOE) launched the enhanced geothermal EarthShot with the goal of cutting the cost of EGS by 90% to $45 per megawatt hour (MWh) by 2035.[3] Fervo's RD&D roadmap includes reducing drilling time, reducing the complexity of completions, enhancing supply chain efficiency, and increasing reservoir optimization - our roadmap has already paved a clear path to achieving the EarthShot's goal ahead of schedule.

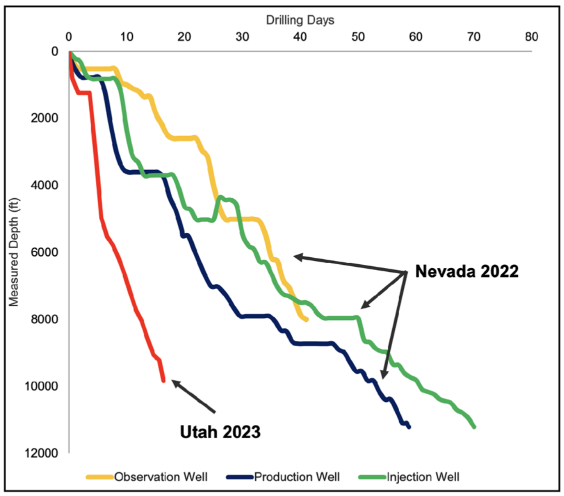

Figure 1: Fervo drilling productivity, demonstrating learning curve reduction in drilling days.

Our results from Project Red support the findings of the DOE Enhanced Geothermal EarthShot – that EGS is ready to scale and can supply over 20% of U.S. power needs as a critical piece of a reliable, fully decarbonized power grid. American-led innovation has removed the last remaining technological barriers to geothermal deployment, and we are charging ahead to achieve another step change growth in clean energy from the subsurface.

Federal Research, Development, Demonstration & Deployment (RDD&D) Investments in Next-Generation Geothermal Will Help Lower Costs Further

The breakthrough success of Project Red is the result of many years of reservoir modeling, pilot testing, and field construction; innumerable partnerships with universities, DOE and its National

[3] https://www.energy.gov/eere/geothermal/enhanced-geothermal-shot

Labs, and service companies; and the determined ingenuity of the Fervo team. Fervo's approach is adapted from technological developments from the shale gas revolution, one of the great technological innovation stories of the past few decades. Following the path blazed by the natural gas industry can point the way forward for the U.S. to become the global leader in geothermal.

America's abundant natural gas supply is the result of decades of dedicated research funding, strategic innovation programs and public-private partnerships spearheaded by DOE and other government agencies.[4] Together with industry partners, public investment in subsurface R&D developed the data, tools, techniques, and technologies necessary to access natural gas in shale formations. The critical components enabling the growth of the shale industry, including but not limited to reservoir simulation, well stimulation techniques, polycrystalline diamond compact drill bits, microseismic imaging, and directional drilling, were all developed by federal researchers, or with their close collaboration. Our ability to successfully develop enhanced geothermal projects follows directly from this long history of successful public investment in subsurface science and technology.

Innovation in the shale industry did not stop at simply proving the feasibility of these new technologies but continued through their demonstration and deployment. Over the past decade, America has completed hundreds of thousands of wells across a wide range of geologies. Each of these projects contributes to our collective understanding of shale formation behavior and drilling tools and techniques. Learning from this experience, the shale industry has optimized a manufacturing approach to well development – resulting in shorter drilling times, more efficient completion, and greater production per well. Like the natural gas industry a decade ago, geothermal is at a critical inflection point: Fervo has demonstrated the effectiveness of EGS technology, and we now have the opportunity to perfect it.

Fervo has worked closely with DOE and its National Labs to reach this point. Our co-founders were accepted into the Cyclotron Road fellowship program at Lawrence Berkeley National Lab to develop the initial idea for Fervo's approach to EGS and set up a Series A funding round led by some of the largest names in clean energy venture investing. In 2019, Fervo received a $1 million development grant from DOE, followed closely by a $1.2 million ARPA-E development grant, which helped us demonstrate the use of advanced fiber optic sensing and complete the first ever multi-stage well stimulation in a geothermal well. As our projects and company grew, we also increased our partnership with DOE; we received a $1.5 million exploration grant from DOE in 2020 and a $7 million development grant with DOE's Frontier Observatory for Research in Geothermal Energy (FORGE) in 2021. An ARPA-E OPEN award of $4.5 million in 2022 is providing critical backing to advance long duration in-reservoir energy storage capabilities to

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[4] https://thebreakthrough.org/issues/energy/where-the-shale-gas-revolution-came-from

allow for load-following geothermal production.[5] The partnership between Fervo and DOE has helped push forward the science of geothermal energy while demonstrating the commercial importance of those new discoveries.

Revenue and learnings from Fervo's Nevada project will go toward the development of other projects in new geographies. This summer, Fervo broke ground on its first greenfield development in southwest Utah, adjacent to DOE's FORGE site. Following the subsurface breakthroughs that enabled shale, Fervo's Utah project will utilize a modular approach with standardized well design to increase drilling speed, reduce development costs, and bring EGS to scale.

Federal support for early-stage R&D has been critical to reaching this milestone, and federal support for demonstration and deployment will be just as important to sustaining progress. Historically, funding for geothermal has trailed far behind other clean firm energy technologies, despite its recent progress and large benefits per invested dollar (see Figure 2). To that end, we are eager for the DOE Geothermal Technologies Office (GTO) to invest its allocated funding from Fiscal Year 2023 appropriations for enhanced geothermal systems demonstration projects.

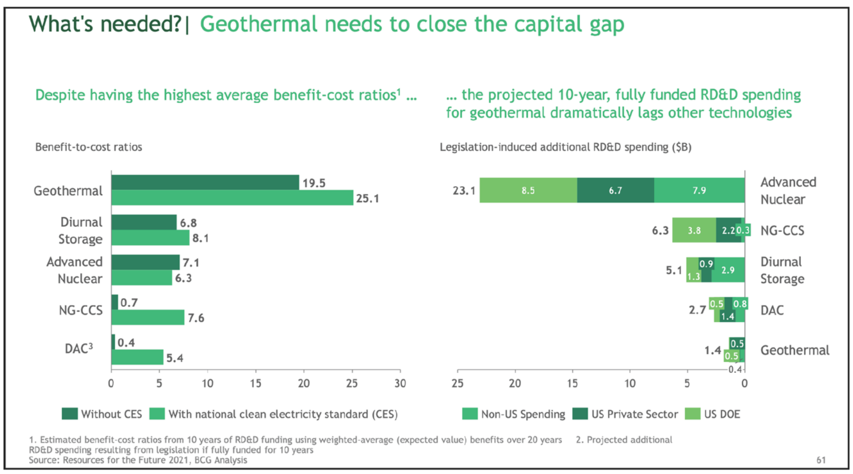

Figure 2: Energy technology spending and benefit-to-cost ratios (BCG 2023).

[5] Latimer, T., Ricks, W., & Jenkins, J. (2022). The value of in-reservoir energy storage for flexible dispatch of geothermal power. *Applied Energy*, *313*, 118807. https://doi.org/10.1016/j.apenergy.2022.118807

Next-Generation Geothermal Energy Provides 24/7 Clean Electricity, Enhances U.S. Energy Security, and Creates Jobs

The technical breakthrough in EGS comes at a critical time for the U.S. energy landscape. Capitalizing on the now-proven technical capabilities of EGS is necessary for the United States to meet its clean energy goals while safeguarding grid reliability, strengthening domestic energy security, and creating high-paying jobs in manufacturing and subsurface development.

As part of the ongoing energy transition, the United States will need more 24/7 clean electricity to meet growing demand from advanced computing and the electrification of vehicles, buildings, and industrial processes. The North American Electric Reliability Corporation (NERC) warns that large portions of the grid are at a "high risk" of capacity shortfalls through 2027, even under normal seasonal peak conditions.[6] At the same time, states, utilities and major corporations are increasing their calls for clean energy. EGS is the only next-generation clean, firm generation resource that has proven production under fully commercial conditions and can deploy today to meet tomorrow's challenges.

Geothermal energy is American energy. Utilizing domestic resources – literally the 'heat beneath our feet' – with American-made equipment and a homegrown workforce that pulls directly from America's world-leading oil and gas industry, geothermal energy is a complete energy security solution. America's steel mills are equipped to produce the advanced metals needed to withstand the harsh downhole conditions and our experienced drilling workers are ready to set new records for geothermal well execution.

While conventional geothermal resources are relatively limited, the subsurface heat resources that can be tapped with an EGS approach is inexhaustible. Analysis by DOE and the U.S. National Renewable Energy Laboratory (NREL) estimated that geothermal energy generation capacity could exceed 230 GW by 2050 and also found that the available geothermal resource is potentially orders of magnitude greater than that.[7] The successful EGS results from both Fervo and FORGE projects indicate that these prior studies are conservative. America's geothermal industry draws upon a resilient domestic supply chain and ready-skilled workforce to build a strong foundation of uninterruptible power.

While America is well-positioned to lead this geothermal revolution, other countries are catching up. In early 2023, the European Union announced a nearly $100 million grant to demonstrate a

[6] https://www.utilitydive.com/news/nerc-grid-resource-adequacy-shortfall-reliability-assessment/638949/
[7] Augustine, Chad, Sarah Fisher, Jonathan Ho, Ian Warren, and Erik Witter. 2023. Enhanced Geothermal Shot Analysis for the Geothermal Technologies Office. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-84822. https://www.nrel.gov/docs/fy23osti/84822.pdf.

next-generation geothermal project in Germany.[8] This single grant was $16 million more than the total investment the Bipartisan Infrastructure Law provided to divide across four U.S. geothermal projects. China's most recent Five Year Plan on Renewable Energy Development includes a prominent role for Chinese geothermal development and generation. A Chinese research team recently broke ground on a new deep-drilling project seeking to develop more advanced subsurface capabilities.[9]

The Boston Consulting Group estimates that globally, geothermal represents a $1.5 trillion market.[10] To capture the lion's share of this economic opportunity, America should consolidate its comparative advantages in subsurface technology, advanced manufacturing, and project development. Increasing investment in American EGS innovation and deployment will catalyze a wave of American-built geothermal across the globe.

Conclusion

The shale gas revolution has shown what is possible when the U.S. Federal government works with industry to invest in subsurface exploration. That journey of technological innovation, commercial entrepreneurship, economic abundance and energy security, is now continuing in geothermal. Enhanced Geothermal Systems are now proven. Optimizing this technology through standardization and modularity will deliver affordable and reliable clean energy, tens of thousands of high-paying jobs, and a globally significant American industry.

Thank you again for the opportunity to highlight our technological breakthroughs and share our experience on how important it is for the public and private sectors to work together to advance subsurface technology.

[8]https://www.bloomberg.com/press-releases/2023-03-09/eavor-s-next-generation-geothermal-project-awarded-91-6-million-grant-from-the-european-innovation-fund
[9]https://www.bloomberg.com/news/articles/2023-07-21/china-is-drilling-another-10-000-meter-hole-this-one-for-gas
[10] Karan Mistry, Nico deLuna, Tina Zuzek-Arden and Thomas Baker, "Two Paths to US Competitiveness in Clean Technologies," Boston Consulting Group. March, 2023: https://thirdway.imgix.net/pdfs/override/Two-Paths-to-US-Competitiveness-in-Clean-Technologies-Report.pdf

Ben Serrurier

Ben Serrurier leads the Government Affairs & Policy team at Fervo Energy, a leading advance geothermal energy developer. Prior to joining Fervo, Ben was a Manager with RMI's Carbon-Free Electricity Practice focused on federal policy and wholesale power markets. He has previously held positions at LevelTen Energy, Cypress Creek Renewables and NextGen Climate.

Ben holds a Masters of Environmental Management from Yale University and a Bachelor of Arts from Whitman College.

EXPERIENCE

Fervo Energy, San Francisco, CA, January 2023 - Present
Government Affairs and Policy Manager

Rocky Mountain Institute, San Francisco, CA, July 2020 - December 2022
Manager, Carbon-Free Electricity

LevelTen Energy, San Francisco, CA, June 2019 - July 2020
Senior Manager, Origination

Cypress Creek Renewables, San Francisco, CA, August 2017 - June 2019
Senior Manager, Market Development

Climate Solutions, Seattle, WA, November 2012 - July 2015
Policy Specialist

EDUCATION

Yale University, School of Forestry & Environmental Studies New Haven, CT
Master of Environmental Management, 2017
- *Concentration:* Political economy of power markets and energy transition

Whitman College Walla Walla, WA
BA with honors, Politics – Environmental Studies, 2011
- Honors Thesis: "From Models to Markets: Climate Science and the Rise of Carbon Markets"

RECOGNITION

Clean Energy Leadership Institute Fellow, 2018
NextGen Climate America Policy Fellow, 2016
Yale COP Fellow, 2015 & 2016
Young Climate Leaders Fellow, 2014

Mrs. BICE. Thank you, Mr. Serrurier.

And at this time, I recognize Dr. Kevin Russo—Rosso, excuse me—for five minutes for his testimony. Mr. Rosso, you're recognized.

TESTIMONY OF DR. KEVIN M. ROSSO, ASSOCIATE DIRECTOR, PHYSICAL SCIENCES DIVISION, PACIFIC NORTHWEST NATIONAL LABORATORY

Dr. ROSSO. Thank you. Thank you very much, Congresswoman Bice, Ranking Member Bowman, and Members of the Subcommittee. Thanks for the opportunity to testify today. I'm Dr. Kevin Rosso, Associate Director of the Physical Sciences Division for Geochemistry at the DOE's PNNL, Pacific Northwest National Laboratory. I lead a team of about 35 researchers on a range of topics like predicting rates of CO_2 mineralization in the subsurface for storage, the chemical transformations of nuclear waste for processing, and the transport of hazardous materials in the subsurface. We focus on understanding the reaction mechanisms at their core to help make more reliable predictive models.

I'll make two main points today. The first is that environments below ground are complex, and it's difficult for us to see everything that we need to see to be able to readily bring new energy systems online. But the good news is that areas where we need technical innovations are clear. The second is that to truly enable success at large scales will undoubtedly require a sustained multidisciplinary effort between national labs, universities, and industry, the kind that we just heard about. Enabling meaningful partnerships is important.

So let me summarize why. First, it goes without saying that subsurface has so far been meeting most of our essential needs as a clean source of energy—as a source of energy, clean water, raw materials for construction, and critical elements. And we're really quite good at finding and unearthing these resources with relative ease. But we now hope to tap its abundant heat for clean geothermal energy. We also want to use it for energy storage from intermittent sources such as wind and solar, and for disposal of hazardous materials like excess CO_2 and radioactive waste. To do these things at large scale safely, efficiently, and with minimal environmental impact brings new challenges.

Pilot projects demonstrating promise had been exciting to watch unfold. This includes PNNL's Wallula CO_2 injection pilot in Washington, showing rapid carbon mineralization in the salt, below ground, and just recently, Fervo Energy's successful well test that we just heard about, which is fantastic.

The subsurface is structurally and chemically complex, and we have limited ability to see important features or predict their physical and chemical responses to change. To create an enhanced geothermal system, for example, requires that we accurately drill deep into hard rock and there creates an interconnected and permeable fracture network between wells through which fluid can easily be circulated that brings up sufficient heat sustainably for years. All the while we've got to avoid triggering earthquakes, losing fluid, flow, or heat transfer over time. It is the need for predictive control and long-term reliability that makes it a new ballgame.

Mastering this at the national scale requires that we learn how to overcome the many uncertainties involved in subsurface engineering, going beyond what industry can achieve alone. The DOE has been proactive in cultivating and supporting research to help fill critical gaps. Examples included SubTER initiative launched in 2014 that identified adaptive control of subsurface fractures and fluid flow as the core objective. A year later, the geosciences program at the Office of Basic Energy Sciences lead the report "Controlling Subsurface Fractures and Fluid Flow: A Basic Research Agenda," to define the fundamental research needed to actually achieve this goal. But to be honest, we are now—we are just now getting underway with the R&D effort.

Some of these research priorities were recently featured in funding opportunities from DOE's energy Earthshot Initiative, to which PNNL responded with a multi-institutional team to develop novel signal detection methods that could enable real-time monitoring of the state of stress between boreholes for enhanced geothermal. But this is just one small piece of the larger team science effort truly needed to ultimately get us from explorers to masters.

As research continues to onramp, I'd also like to emphasize the importance of keeping our R&D infrastructure at the bleeding edge. Key to this effect is ensuring that new and advanced experimental and computational capabilities continue at our national labs, universities, and DOE national user facilities. This will help keep us at the forefront and help us attract and retain top talent.

To conclude, though largely overlooked, the subsurface provides most of the critical resources sustaining our present way of life, and it's now poised for the foundation—to be the foundation for our future. But our ambition to use it in new ways is a grand challenge, requiring a lasting commitment to basic and applied research.

Thank you for the opportunity to provide the Committee with information on this topic. I'd be happy to answer any questions you may have.

[The prepared statement of Dr. Rosso follows:]

Testimony of Dr. Kevin Rosso
Associate Director, Physical Sciences Division
Pacific Northwest National Laboratory
Before the
United States House of Representatives
Committee on Science, Space, and Technology
Energy Subcommittee

July 26, 2023

Good afternoon, Chairman Williams, Ranking Member Bowman, and Members of the Subcommittee. Thank you for the opportunity to testify today on the future of subsurface science and technology in the United States.

My name is Dr. Kevin Rosso and I am an Associate Director of the Physical Sciences Division at the Department of Energy's (DOE) Pacific Northwest National Laboratory (PNNL). I have worked at PNNL for 25 years, and lead a group of about 35 geochemists in topics such as predicting carbon dioxide (CO_2) mineralization rates for geological storage, chemical transformations of nuclear waste for processing, and transport of hazardous materials in the subsurface. The work is fundamental in nature, in that we seek to develop the basic knowledge needed for transformational advances. We also work closely with colleagues in the applied sciences to help translate discoveries into practical solutions.

Today I would like to focus my testimony on two main concepts:

1. The subsurface is complex, and the challenges facing new energy system development below ground are substantial. But thankfully, key areas where technical innovations are needed are largely understood by the scientific community.
2. Success requires a sustained, concerted multi-disciplinary research and development (R&D) effort between national labs, universities, and industry. Facilitating the formation of robust and meaningful partnerships will accelerate advances.

Resources in the subsurface have been meeting most of our essential needs, including for energy, clean water, raw materials for construction, and critical elements, to name a few. For many years we have been prolific masters of finding and unearthing these resources, with relative ease.

But we now look to the subsurface for entirely new purposes, purposes that come with unique challenges. We seek to tap its abundant heat for clean geothermal energy. We also seek to use it for storage of energy from intermittent sources such as wind and solar, and for disposal of hazardous materials including excess CO_2 and radioactive waste. And we need to be able to do these things safely, efficiently, at large scales, and with minimal environmental impact. Exciting examples demonstrating promise are emerging both at home and abroad, including PNNL's Wallula CO_2 injection pilot in Washington which showed rapid carbon mineralization in basalt, and Fervo Energy's enhanced geothermal energy pilot in Nevada which just completed a successful month-long well test. But, to be clear, we are still just explorers, facing new unknowns.

Subsurface environments are structurally and chemically complex and we have limited ability to see important features deep below or predict their physical and chemical responses to change. Nonetheless, to create an enhanced geothermal system, for example, requires that we accurately drill deep into hard rock, create an interconnected and permeable fracture network, and circulate fluid that brings up sufficient heat sustainably for years. All the while, we must avoid triggering earthquakes, or loss of fluids, flow, or heat transfer over time. It is this need for predictive control and long-term reliability that makes it a new ballgame.

Mastering this at the national scale requires that we learn how to overcome the many uncertainties involved in subsurface engineering. We need to go beyond what industrial R&D can achieve alone. Recognizing this, the DOE has been proactive in cultivating and supporting relevant fundamental and applied subsurface R&D to help fill the most critical gaps. Examples include its 2014 Subsurface Science, Technology, Engineering Research and Development (SubTER) initiative, which identified "adaptive control of subsurface fractures and fluid flow" as its core objective. In 2015 DOE's Office of Basic Energy Sciences, Geosciences program led the report *Controlling Subsurface Fractures and Fluid Flow: A Basic Research Agenda,* to define the basic research needed to achieve this goal.

Many of the resulting research priorities were recently featured in funding opportunity announcements from DOE's Energy Earthshot Initiative, to which PNNL responded with a multi-institutional team to develop novel signal detection methods to enable real-time monitoring of the state of stress between boreholes. Success of such efforts could provide breakthroughs for predicting the evolution of fracture flow and heat transfer over the long-term for enhanced geothermal reservoirs. But this is just one piece of the larger R&D landscape required to take us from explorers to masters.

As the nation's R&D community continues to rally and drill deep into these key subsurface science challenges, it feels timely in this venue to emphasize the importance of keeping our nation's R&D infrastructure at the bleeding edge. Key to this effect is ensuring new and advanced experimental and computational capabilities continue at our national labs and universities, including ongoing and future upgrades at DOE national user facilities. This will help keep the nation at the forefront, in particular by maintaining our ability to attract and retain top talent from the competitive, international environment in which we now operate.

In conclusion, largely overlooked, the subsurface provides most of the critical resources sustaining our way of life. It is also the foundation for our future. Our ambition to use it in new ways, for new sources of energy and for safe storage, is a vital but grand challenge that requires all our attention and commitment to a national team-science R&D effort.

Thank you for the opportunity to provide the Committee with information on this topic. I would be happy to answer any questions that you may have.

Kevin M. Rosso

Lab Fellow, Chemist
Physical Sciences

Biography

Kevin Rosso is a Laboratory Fellow and the Associate Director of the Physical Sciences Division for Geochemistry. He received his B.S. degree in geological sciences from Cal Poly at Pomona, California, in 1992, and his M.S. and Ph.D. degrees in Geochemistry from Virginia Tech in 1994 and 1998. His career to date has been at PNNL where, after starting as an entry-level research scientist in 1998, he was promoted to its highest rank by 2010 and now leads a research group of approximately 35 PhD students, postdoctoral fellows, and staff scientists. Dr. Rosso has published over 400 papers and book chapters, a body of work with an H-index of 74 and over 22,000 citations. He is a regularly invited speaker, with over 100 distinguished lectures delivered at university colloquia, workshops, and conferences internationally.

Dr. Rosso is best known for his pioneering research on electron transfer reactions between aqueous ions, mineral surfaces, and bacterial enzymes. Beginning with topics such as metal sulfide oxidation, bacterial reduction of metal oxides, contaminant interactions with clay minerals, and mechanisms of crystal growth and dissolution, his research expanded into geologic carbon sequestration, stress corrosion cracking in alloys, performance optimization of lithium battery materials, and the design of semiconductor materials for solar photocatalysis. Dr. Rosso is well recognized as being at the center of the field of molecular geochemistry, a field he helped create with the inception of advanced tools such as scanning probe microscopy, quantum mechanical molecular simulations, and massively parallel supercomputers.

Dr. Rosso won the Mineralogical Society of America Award in 2004, the Mineralogical Society's Hallimond Lectureship in 2016, and the European Association of Geochemistry's Stumm Medal in 2020. He is a Life Fellow of the Mineralogical Society of America, the Geochemical Society, and the European Association of Geochemistry. He has held honorary professorship appointments at the University of Manchester, U.K., the University of New South Wales, Australia, the University of Grenoble, France, and was recently a visiting Distinguished Scholar at Durham University, U.K. Dr. Rosso was an Associate Editor for *American Mineralogist* from 2004 to 2006, for *Geochimica et Cosmochimica Acta* from 2008 to 2011, and currently serves on the Editorial Boards of *ACS Earth and Space Chemistry*, *Applied Geochemistry*, and *Geo-Bio Interfaces*. He leads the U.S. Department of Energy's major fundamental geochemistry program at PNNL.

Mrs. BICE. Thank you, Dr. Rosso.

And at this time, I recognize Dr. Haruko Murakami Wainwright for your testimony. You are recognized for five minutes. Thank you.

TESTIMONY OF DR. HARUKO MURAKAMI WAINWRIGHT, NORMAN C. RASMUSSEN CAREER DEVELOPMENT PROFESSOR, ASSISTANT PROFESSOR OF NUCLEAR SCIENCE AND ENGINEERING, AND ASSISTANT PROFESSOR OF CIVIL AND ENVIRONMENTAL ENGINEERING, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. WAINWRIGHT. Representative Bice, Ranking Member Bowman, and the Members of the Committee, thank you for the opportunity to speak with you today. As a researcher at MIT and previously at the Lawrence Berkeley National Laboratory and University of California Berkeley, I have been involved in DOE's subsurface science-related programs for the past 15 years. I have conducted interdisciplinary research on such topics as water resource, soil and groundwater remediation, carbon dioxide storage, permafrost science, and nuclear waste disposal.

The subsurface plays a critical role in our society. It provides much of our energy, as well as critical minerals needed for many parts of our economy. Groundwater is an important source of water for drinking and for industrial and agricultural use. The subsurface also provides spaces for isolated storage of nuclear waste, carbon dioxide, and others. My research has been focused on developing and applying statistical methods and artificial intelligence (AI) to improve the characterization, monitoring, and prediction of dynamic subsurface processes.

The DOE Office of Science has a long history of supporting the development of subsurface modeling and simulation capabilities, taking advantage of the latest generation of high-performance computers and software libraries, which were developed through the Advanced Scientific Computing Research program. As a result, today, scientists can simulate thermal, hydrological, mechanical, chemical, and biological processes and their interactions within a detailed model of the subsurface.

DOE's user facilities and observational sites are also essential resources for subsurface research. The user facilities have been used to discover vast and novel microbial communities in the subsurface and to visualize flow processes and chemical reactions in rock pore structures. The observational sites have enabled us to rapidly develop and test subsurface sensors and imaging technologies. Scientists can now map rock properties several hundred meters deep over an entire watershed and rapidly detect subsurface anomalies.

The capabilities developed by DOE's basic research programs in subsurface science are proving their value across the agency. The Office of Environmental Management (EM) is using the sensor and simulation tools developed by the Office of Science to improve long-term groundwater monitoring at DOE's legacy sites, ensuring the stability of remediation systems while lowering their costs. Long-term subsurface simulation capabilities also support the spent nuclear fuel disposal program under the Office of Nuclear Energy, which requires waste isolation for longer than 10,000 years.

The Office of Science is increasing its investment in the use of artificial intelligence in subsurface research. This rapidly evolving field has already made it possible to find patterns in very large datasets and has accelerated simulations. In 2021, I co-organized the Artificial Intelligence for Earth Systems Predictability Workshop, which explored how AI should be incorporated across the Earth systems modeling program. I believe that DOE can make a unique contribution in this topic, having great strengths in both computing and observation capabilities.

Another promising new area of research is the use of local subsurface sensors to improve environmental monitoring in regions where mining waste disposal or storage or other commercial subsurface activities are underway or under consideration. These are often in rural places that are far from scientific centers. STEM (science, technology, engineering, and mathematics) education and community science programs could be built around these datasets from sensor networks, empowering local communities to monitor and protect their own environment.

In summary, DOE programs support work at the national labs and in academia and play an essential role in advanced subsurface science and technologies for various applications. They are improving our ability to take advantage of subsurface resources and to minimize and remediate any environmental impacts.

Thank you again. I welcome any questions you may have. Thank you.

[The prepared statement of Dr. Wainwright follows:]

Testimony of

Dr. Haruko Murakami Wainwright
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Assistant Professor of Civil and Environmental Engineering
Massachusetts Institute of Technology

Before the

Subcommittee on Energy
Committee on Science, Space and Technology
United States House of Representatives

Unearthing Innovation: The Future of Subsurface Science

July 26, 2023

Chairman Williams, Ranking Member Bowman, Chairman Lucas, Ranking Member Lofgren, and members of the committee,

Thank you for this opportunity to testify today on the importance of the Department of Energy's subsurface science programs.

As a researcher at MIT, and previously at the Lawrence Berkeley National Laboratory and University of California, Berkeley, I have been involved in DOE's subsurface science-related programs for 15 years. My research has been focused on developing and applying statistical methods and artificial intelligence (AI) technologies to improve the characterization, monitoring and prediction of dynamic subsurface processes for various applications. I have worked on many interdisciplinary projects, on such topics as water resources, soil and groundwater remediation, carbon dioxide storage, permafrost science, and nuclear waste disposal.

The subsurface provides much of our energy, as well as critical minerals needed for many parts of our economy. Groundwater is an important source of water for drinking and for industrial and agricultural use. The subsurface also provides spaces for isolated storage of nuclear waste, carbon dioxide and other waste products.

DOE's Scientific Computing and Observation Capabilities

The DOE Office of Science (OS) has a long history of supporting the development of subsurface modeling and simulation capabilities. By taking advantage of the latest generation of high-performance computing (HPC) systems and software libraries developed through the Advanced Scientific Computing Research (ASCR) program, we can now simulate coupled thermal, hydrological, mechanical, chemical, and biological processes that interact within complex three-dimensional environments, and their responses to various perturbations. Two new geoscience codes have been developed to utilize the exascale Frontier supercomputer recently installed at Oak Ridge National Laboratory -- one for simulating coupled thermal-hydrological-mechanical-chemical (THMC) processes in the subsurface, and the other for predicting large-scale earthquakes from the initiation of fault rupture to surface ground motions (www.exascaleproject.org). Computational tools like these are a valuable and unique resource DOE provides to subsurface scientists.

The Office of Science's user facilities and observational sites are also essential resources for subsurface research. The OS facilities have been used to study vast and novel microbial communities in the subsurface, and to visualize flow processes and chemical reactions in rock pore structures. DOE's Joint Genome Institute, for example, provides high-throughput genomic sequencing to research communities, which enabled DOE funded researchers to discover the subsurface microbial communities and their functions and significantly expand the tree of life (Hug et al., 2016). In parallel, DOE observation sites have enabled us to quantify subsurface properties and dynamics at site and regional scales, and to rapidly develop and test new subsurface sensors and imaging technologies. In LBNL's Watershed Science Focus Area project (watershed.lbl.gov), for example, a machine learning technique was applied to integrate

remote sensing and airborne geophysics data for mapping rock properties over an entire watershed and improving groundwater flow simulations (Uhlemann et al. 2022; Wainwright et al., 2022). In addition, fiber optic sensor technologies have advanced rapidly under the DOE programs. They can be used to monitor various properties such as seismic signals, temperature and pressure changes, making it possible to rapidly detect subsurface anomalies in an extended area (e.g., Daley et al., 2013).

Applications to Offices of Environmental Management and Nuclear Energy

The capabilities developed by DOE's basic research programs in subsurface science are proving their value across the agency. The Office of Environmental Management is using the subsurface sensor, imaging and simulation tools to improve long-term groundwater monitoring for supporting the DOE's stewardship responsibility at legacy sites. The Advanced Long-term Environmental Monitoring (ALTEMIS) project (altemis.lbl.gov), led by Savannah River National Laboratory and MIT, aims to establish a new paradigm for groundwater contamination monitoring through the integration of these tools. The integrated system can be used to continuously confirm the stability and effectiveness of remediation systems and to detect any anomalies that occur in real-time, while reducing the overall costs (Schmidt et al., 2018; Denham et al., 2022). ALTEMIS heavily leverages groundwater flow and transport simulation capabilities and sensor technologies developed under the Biological and Environmental Research program.

Long-term subsurface simulation capabilities also support the spent nuclear fuel disposal program under the Office of Nuclear Energy, which requires that nuclear waste remains isolated for much longer than 10,000 years. The THMC models and simulations developed by ASCR are particularly important for assessing the performance of disposal systems, and for quantifying the long-term integrity of the engineered barrier system (EBS) surrounding the emplaced waste (e.g., Zheng et al., 2017) as well as the thermal impact on host rock, such as potential fracture generations (e.g., Sasaki and Rutqvist, 2022). Recent research in this domain often utilizes AI techniques; for example, surrogate modeling approaches enable us to accelerate complex simulations (e.g., Mariner et al., 2017; Lu et al., 2021). They are also used to synthesize community datasets (such as geochemical experiments) from multiple literature sources and institutions for improving uncertainty quantifications (e.g., Zavarin et al., 2022).

New Opportunities for Subsurface Research

The Office of Science is increasing its investment in the uses of artificial intelligence in subsurface research. This rapidly evolving field has already improved modeling and observation research by making it possible to find patterns in very large datasets and accelerate simulations. In 2021, I co-organized the *Artificial Intelligence for Earth Systems Prediction* workshop, which explored how AI should be incorporated across DOE's earth systems modeling program (www.ai4esp.org). The workshop identified a range of opportunities as well as significant challenges that can be tackled using AI, such as scaling and heterogeneity, AI-guided data acquisition, and the representation of extreme events.

The integration of AI and simulations within scientific computing – often called *simulation intelligence* – is a particularly exciting area where many new developments are happening to synthesize large datasets and physically-based numerical models (Lavin et al., 2021). I believe that DOE can make a unique contribution in this topic, with its strength in both computing and observational science. In particular, an iterative model-experiment (ModEx) approach, developed by the Biological and Environmental Research (BER) program, is an effective framework to rapidly integrate data into predictive models, and then to use modeling results to inform future observations and experiments. Tight integration of modeling and measurements is critical to address difficult but important challenges such as quantifying flow dynamics and reactions in fractured rocks (Viswanathan et al., 2022)

The use of AI to inform data acquisition and observation is an emerging field as well. ASCR's Center for Advanced Mathematics for Energy Research Applications (CAMERA) has been developing autonomous data acquisition and experimentation frameworks for various science domains (Noack et al., 2021). Along with advances in high-resolution subsurface sensors and imaging technologies, this approach has the potential to transform subsurface observation protocols, such as sensor optimization, autonomous data acquisitions and self-driving field labs (Wu et al., 2018). Dedicated observational facilities and sites are critical for integrating interdisciplinary components effectively, and rapid prototyping and testing.

Another promising new area of research is the use of low-cost subsurface sensors to improve environmental monitoring in rural regions far from scientific centers, where mining, waste disposal or storage, and other commercial subsurface activities are underway or seeking approval (e.g., Schmidt et al., 2018; Wielandt et al., 2023). Coupled with innovative STEM education approaches such as the Teaching Through Technology program (t3alliance.org), community science programs could be built around these sensor datasets, empowering local communities to monitor and protect their own environment.

Next-generation Workforce Development

Access to DOE's leading-edge resources has been essential to my career and research. During my PhD research, for example, I ran thousands of groundwater flow simulations for assessing soil and groundwater remediation strategies at the DOE's Hanford Site. This would not have been possible without access to HPCs at the National Energy Research Scientific Computing Center (NERSC). In addition, I have also benefited tremendously from the team science approach that the National Labs have pioneered. I have seen firsthand how new discoveries and innovations happen at the interface between different fields, as well as how effectively modelers and experimentalists can work together to develop new ideas and technologies. Now as a member of an academic institution, I believe it is important that we train more students and scientists to work in interdisciplinary teams. In particular, the AI4ESP workshop identified the need for developing next-generation researchers who know both Earth science and AI well. Strong continuing collaboration between the National Labs and academia is extremely important in developing that kind of workforce.

Closing Remarks

In summary, DOE programs support work at the national labs and in academia that plays an essential role in advancing subsurface science and technologies for various applications. The tools and understanding from these programs improve our ability to take advantage of subsurface resources, and to minimize and remediate any environmental impacts.

Thank you for this opportunity to share my thoughts with the subcommittee. I welcome any questions you may have.

References:

Daley, T. M., Freifeld, B. M., Ajo-Franklin, J., Dou, S., Pevzner, R., Shulakova, V., ... & Lueth, S. (2013). Field testing of fiber-optic distributed acoustic sensing (DAS) for subsurface seismic monitoring. The Leading Edge, 32(6), 699-706.

Denham, M. E., Amidon, M. B., Wainwright, H. M., Dafflon, B., Ajo-Franklin, J., & Eddy-Dilek, C. A. (2020). Improving long-term monitoring of contaminated groundwater at sites where attenuation-based remedies are deployed. Environmental Management, 66, 1142-1161.

Hug, L. A. et al., (2016). A new view of the tree of life. Nature microbiology, 1(5), 1-6.

Lavin, A., Krakauer, D., Zenil, H., Gottschlich, J., Mattson, T., Brehmer, J., ... & Pfeffer, A. (2021). Simulation intelligence: Towards a new generation of scientific methods. arXiv preprint arXiv:2112.03235.

Lu, H., Ermakova, D., Wainwright, H. M., Zheng, L., & Tartakovsky, D. M. (2021). Data-informed emulators for multi-physics simulations. Journal of Machine Learning for Modeling and Computing, 2(2).

Mariner, P. E., Berg, T. M., Chang, K. W., Debusschere, B. J., Leone, R. C., & Seidl, D. T. (2020). Surrogate Model Development of Spent Fuel Degradation for Repository Performance Assessment (No. SAND-2020-10797R). Sandia National Lab.(SNL-NM), Albuquerque, NM (United States); Sandia National Lab.(SNL-CA), Livermore, CA (United States).

Noack, M. M., Zwart, P. H., Ushizima, D. M., Fukuto, M., Yager, K. G., Elbert, K. C., ... & Sethian, J. A. (2021). Gaussian processes for autonomous data acquisition at large-scale synchrotron and neutron facilities. Nature Reviews Physics, 3(10), 685-697.

Sasaki, T., & Rutqvist, J. (2022). Effects of time-dependent deformation of shale on the integrity of a geological nuclear waste repository. International Journal of Rock Mechanics and Mining Sciences, 158, 105206.

Schmidt, F., Wainwright, H. M., Faybishenko, B., Denham, M., & Eddy-Dilek, C. (2018). In situ monitoring of groundwater contamination using the Kalman filter. Environmental science & technology, 52(13), 7418-7425.

Uhlemann, S., Dafflon, B., Wainwright, H. M., Williams, K. H., Minsley, B., Zamudio, K., ... & Hubbard, S. (2022). Surface parameters and bedrock properties covary across a mountainous watershed: Insights from machine learning and geophysics. Science advances, 8(12), eabj2479.

Viswanathan, H. S., Ajo-Franklin, J., Birkholzer, J. T., Carey, J. W., Guglielmi, Y., Hyman, J. D., ... & Tartakovsky, D. M. (2022). From fluid flow to coupled processes in fractured rock: Recent advances and new frontiers. *Reviews of Geophysics*, *60*(1), e2021RG000744.

Wainwright, H. M., Uhlemann, S., Franklin, M., Falco, N., Bouskill, N. J., Newcomer, M. E., ... & Hubbard, S. S. (2022). Watershed zonation through hillslope clustering for tractably quantifying above-and below-ground watershed heterogeneity and functions. Hydrology and Earth System Sciences, 26(2), 429-444.

Wielandt, S., Uhlemann, S., Fiolleau, S. and Dafflon, B. (2023) TDD LoRa and Delta Encoding in Low-Power Networks of Environmental Sensor Arrays for Temperature and Deformation Monitoring. Journal of Signal Processing Systems, 1-13.

Wu et al. (2018), ECOSENSE, Vision for an Integrated Suite of Sensing and Data Capabilities to Quantify Soil-Microbe-Plant Interactions Across Scales,

Zavarin, M., Chang, E., Wainwright, H., Parham, N., Kaukuntla, R., Zouabe, J., ... & Brendler, V. (2022). Community data mining approach for surface complexation database development. Environmental Science & Technology, 56(4), 2827-2838.

Zheng, L., Rutqvist, J., Xu, H., & Birkholzer, J. T. (2017). Coupled THMC models for bentonite in an argillite repository for nuclear waste: Illitization and its effect on swelling stress under high temperature. Engineering geology, 230, 118-129.

Haruko Wainwright is the Norman C. Rasmussen Career Development Professor in the Department of Nuclear Science and Engineering, and the Department of Civil and Environmental Engineering at Massachusetts Institute of Technology. She received her BEng in Engineering Physics from Kyoto University, Japan in 2003; her MS in nuclear engineering in 2006, MA in statistics in 2010 and PhD in nuclear engineering in 2010 from University of California, Berkeley. Before joining MIT, she was a Staff Scientist in the Earth and Environmental Sciences Area at Lawrence Berkeley National Laboratory. Her research focuses on environmental modeling and monitoring technologies with a particular focus on nuclear waste, and nuclear contamination.

Mrs. BICE. Thank you, Dr. Murakami Wainwright.

And finally, we have Dr.—I'm sorry, Ms. Allyson Book, who is recognized for five minutes for her testimony.

TESTIMONY OF MS. ALLYSON BOOK, CHIEF SUSTAINABILITY OFFICER, BAKER HUGHES

Ms. BOOK. Thank you to each of the Members of the Committee for the opportunity to address you all today and for your efforts to highlight the importance of subsurface sciences. My name is Allyson Anderson Book, and I'm the Chief Sustainability Officer for Baker Hughes. I'm also a trained geoscientist. I oversee our corporate sustainability program and drive the company's energy transition. My team supports our growth areas that include carbon capture and storage, hydrogen, and geothermal. Through focused research, development, and demonstration activities, we work to identify public partnerships, consortia, and other opportunities for enabling the scale up of our technology and services.

Subsurface science and technology is used today to characterize subsurface for energy production and natural resource extraction to determine the best sites for waste disposals—many people here have said—and numerous other applications. federally funded R&D programs have supported real innovation in each of these areas and remain essential today.

We see three key areas where we need subsurface R&D—and it remains critical—that is CCS hydrogen storage and, not surprising, geothermal, as we've heard on the Committee today. CCS is a critical energy of research as it's essential for reducing emissions within the energy, steel, cement, and petrochem sectors. We're active throughout the entire CCS value chain from project design to post-combustion capture, compressions, subsurface storage, and long-term integrity and monitoring of a reservoir.

Hydrogen storage is an emerging area of focus thanks to new funding from hydrogen hubs and the section 45V tax credit. Important work remains to understand how to safely control and monitor geologic hydrogen storage, as well as robust and reliable sensors are needed for the subsurface monitoring.

Additional geothermal R&D is needed to further develop the enhanced and advanced geothermal systems, as well as production of geothermal energy from oil and gas wells. Last year, we helped to launch the Wells2Watts consortium to repurpose oil and gas wells at the end of their productive life for geothermal energy. We're using test wells at our Energy Innovation Center co-located at the Hamm Institute for American Energy in Oklahoma City. This is where we simulate high-temperature subsurface environments for testing closed-loop systems for many different kinds of well configurations. We validate engineering performance models and provide scale for field pilot efforts.

The Department of Energy and its various programs provide an essential function for facilitating American technology development, and we have long history of collaboration together. Our key R&D areas have included enhanced geothermal tech, novel additive manufacturing approaches, and gas and flow sensors and monitoring technologies. We're also involved with the CarbonSAFE program projects at the Office of Fossil Energy, and that collaboration

is instrumental to our long-term CCS strategy, particularly in the subsurface.

I'd like to underscore three challenges for your consideration here today as you look to buildupon American leadership in the space. First is the need to sustain if not expand support for each of these programs. A stable private—or, excuse me, a stable Federal program produces stronger broad-based partnerships with the private sector and accelerates innovative scientific progress that would be difficult to achieve in isolation. Additional funding is most needed related to high-temperature downhole sensors and drilling technology for geothermal wells. Funding for geothermal at similar magnitude, as enjoyed by the CCS program under CarbonSAFE, as well as DOE's hydrogen hubs, would enable the industry to bring crucial new technologies to scale.

Second, I respectfully ask you to consider whether policies around intellectual property (IP) should be adjusted to reflect the difference between early stage R&D and later commercial demonstration projects. Current policies establish government rights to subject inventions that occur pursuant to grants. And this reasonable when the government directly funds the R&D leading to the subject invention. The intention of demonstration projects, however, is not to develop new inventions, but rather to scale up existing technology, so it's a different purpose. These technologies may include prototypes that are modified during the course of construction and testing but were developed entirely by the private sector. Negotiating to overcome a department's rights in this context can create challenges for equipment manufacturers who would otherwise own the IP.

So my last point, as the clock winds down, we understand this lies—this last point—beyond the Committee's jurisdiction, but I wanted to raise section 174 of the tax code, which, since 1954, has allowed companies to deduct their R&D expenses in the same year in which they were incurred as an incentive to encourage investment in domestic R&D. As of January 2022, companies must now amortize these expenses over at least five years or more if it's international, making it more expensive to invest in R&D in tighter market conditions like the ones that we see today. So we urge you to pass legislation to reinstate the immediate deductibility of R&D expenses.

Thanks again for the opportunity to present this testimony and share our views here today. Thank you.

[The prepared statement of Ms. Book follows:]

Allyson Anderson Book
Chief Sustainability Officer
Baker Hughes Company
Before the
Subcommittee on Energy
Committee on Science, Space, and Technology
U.S. House of Representatives
"Unearthing Innovation: The Future of Subsurface Science and Technology in the United States"
July 26, 2023

Good afternoon, Chairman Williams, Ranking Member Bowman, and Members of the Committee. Thank you for the opportunity to address you today and for your efforts to highlight the importance of subsurface science. My name is Allyson Anderson Book, and I am the Chief Sustainability Officer for Baker Hughes and a trained geologist. Baker Hughes is a leading energy technology company that provides solutions for energy and industrial customers worldwide. From the first rotary drill bit to the world's most extensive portfolio of compressors and gas turbines, for more than a century our inventions have helped take energy forward – making it safer, cleaner, and more efficient for people and the planet. Our headquarters are in Houston, Texas, and we have approximately 55,000 employees worldwide conducting business in over 120 countries.

My role at Baker Hughes is to oversee our Sustainability program and drive the company's energy transition. As part of my remit, I work to support several of our core growth areas, carbon capture and storage (CCS), hydrogen, and geothermal, through focused research, development and demonstration activities and partnerships. My team works to identify opportunities for public partnerships, consortia, and other opportunities for enabling the scale up of our technology and services.

Subsurface science and technology is as important today as it was when pioneering scientists began to image the inside of the Earth from the outside for early seismological efforts. Today, we rely on subsurface science and technology to help us characterize the subsurface for energy

production, extract natural resources in the form of oil, gas, and mineral resources, and determine the best sites for waste disposal and numerous other applications. Federally funded research and development programs have supported real innovation for subsurface science and engineering and continue to be essential in driving innovation to meet societal needs.

The energy transition is also accelerating the demand for subsurface science and technology. Baker Hughes is re-engineering the same technologies and services that have helped make the U.S. oil and gas sector a world leader, to meet the challenge of delivering lower-carbon energy. For example, carbon capture and storage, or CCS, is a critical area of research for Baker Hughes because it is an essential solution to reduce emissions within the energy sector and in strategic, hard-to-abate sectors like steel, cement, and petrochemicals. Baker Hughes is active across the entire CCS value chain, beginning with project design to post-combustion capture, compression, subsurface storage, and long-term integrity and monitoring of the reservoir.

However, the importance of subsurface technology does not end with CCS. Hydrogen storage is an emerging area of focus thanks to funding provided in the Infrastructure Investment and Jobs Act to build hydrogen hubs and the Section 45V tax credit contained in the Inflation Reduction Act. Important work remains to understand how to stimulate, control, and monitor geologic hydrogen to ensure it is conducted safely. Robust and reliable sensors for sub-surface monitoring and transportation for such geological applications remain a key challenge for the energy sector. Geological hydrogen production from mineral deposits is one example where the expertise and experience of legacy oil and gas workforce in resource identification and stimulation could be easily transferrable towards realizing this abundant, carbon-free energy alternative.

The last area of great interest to us are geothermal applications, including enhanced and advanced geothermal systems. Enhanced systems involve drilling deep underground, including lateral segments, and injecting a fluid to create fractures in the rock. This same horizontal drilling and stimulation technology was used to open the vast shale gas resources of the U.S. Advanced, closed-loop systems can produce heat for power generation and direct use. Last year we helped launch the “Wells2Watts” consortium with several industry partners to repurpose oil and gas wells at the end of their productive life for geothermal energy and renewable electricity

production using closed-loop geothermal technology developed by GreenFire Energy. Technologies like GreenFire are already being tested in existing geothermal fields in the U.S., which leads the world in geothermal production at 3.8 GW. We are presently using test wells at the Baker Hughes Energy Innovation Center located at the Hamm Institute for American Energy in Oklahoma City to simulate high temperature subsurface environments to test the closed-loop system for many well configurations, validate engineering performance models, and provide scale for field pilot efforts.

The Department of Energy and its various programs provide an essential function in facilitating American technology from its initial development through deployment stages. Baker Hughes has a long history of collaborating with the Department, and our partners include the Office of Hydrogen and Fuel Cell Technologies, Office of Fossil Energy and Carbon Management, Advanced Manufacturing Office, Office of Geothermal Technologies, and Industrial Efficiency and Decarbonization Office. Our key subjects of interest include enhanced geothermal technologies, novel additive manufacturing approaches, and gas flow sensors and monitoring technologies.

I want to highlight the Office of Fossil Energy and Carbon Management as playing a critical role in supporting subsurface research and technological development, including its CarbonSAFE Program. We are involved with several of these projects and see collaboration with DOE as instrumental to our long-term CCS strategy and are looking to increase our participation in its programs, especially CO_2 storage.

I would like to underscore three challenges for your consideration as you look to build on American leadership in subsurface science. First, is the need to sustain—if not expand–support for the programs I have highlighted. A stable federal program produces stronger, broad-based partnerships with the private sector and accelerates scientific progress. This partnership helps identify and address key gaps in research that would be more difficult to address in isolation. Among the areas of subsurface science where additional funding is most needed include downhole sensors and high temperature technology for drilling geothermal wells. Funding for geothermal at a similar magnitude enjoyed by CCS under CarbonSAFE and hydrogen under the

Office of Clean Energy Demonstrations would enable the industry to bring crucial new technologies to scale.

Given the substantial increase in demonstration project funding in recent years, another aspect this Committee might consider is looking at whether or not departmental policies around intellectual property should be adjusted to reflect the difference between early-stage R&D and demonstration projects. Current policies establish government rights to subject inventions that occur pursuant to grants, which is entirely reasonable when the government directly funds the research leading to the subject invention. The intent of demonstration projects, however, is not to develop new inventions but rather scale up existing technology. Technologies involved in demonstration projects may include prototypes that are modified during the course of construction and testing, but were developed entirely by the private sector. Negotiating to overcome a department's rights to subject inventions in this context can, in our experience, create challenges for equipment manufacturers that otherwise own the remaining IP. We would be pleased to work with you and the DOE to ensure such policies do not discourage participation in the hubs.

Finally, while we understand that the issue lies beyond the scope of this hearing and the committee's jurisdiction, I would be remiss if I failed to raise Section 174 of the Internal Revenue Code, which since 1954 has allowed companies to deduct their R&D expenses in the same year in which they were incurred as an incentive to encourage investment in R&D in the U.S. However, due to changes implemented as part of the 2017 Tax Cuts & Jobs Act, as of January 2022, companies must now amortize those expenses over five years for domestic expenses and fifteen years for international expenses. This change to an almost 70-year-old policy in the tax code makes it more expensive for companies to invest in R&D for new innovations and technologies, like those we are discussing today, disincentivizing investment in R&D in the U.S. To encourage companies to continue to invest in these crucial new technologies, we urge Congress to pass a legislative fix to reinstate the immediate deductibility of R&D expenses.

Thank you again for the opportunity to share our views on this important topic. I look forward to your questions.

Allyson Anderson Book

Chief Sustainability Officer

Allyson Anderson Book is the Chief Sustainability Officer at Baker Hughes. In this role she oversees Baker Hughes' energy transition strategy by driving sustainable operations, supporting commercial energy transition solutions for customers, and ensuring market creation of these solutions via stakeholder engagement and policy development.

In 2021 alone, she was recognized by Petroleum Economist as among Top 10 Women Leading Energy Transition in Sustainability, by Oil & Gas Investor as among 25 Influential Women in Energy, and by Hart Energy for its ESG Champion of Year Award. Under her leadership, Baker Hughes has been consistently recognized for sustainability, including being an 'industry mover' in S&P's Sustainability Yearbook 2023, Most Trustworthy Companies 2023 and Most Responsible Companies 2023 lists by Newsweek, among others.

Before joining Baker Hughes, she served as the executive director of the American Geosciences Institute, which represents more than 250,000 geoscientists and focuses on increasing public awareness of the role geosciences play in society's use of resources. Prior to that, she held several academic, policy and senior government positions, including teaching at Georgetown University, working for the U.S. Senate Energy and Natural Resources Committee, and serving as the associate director of strategic engagement of the Bureau of Safety and Environmental Enforcement (BSEE) at the U.S. Department of the Interior. She began her career as a geoscientist for ExxonMobil.

She holds bachelor's degrees in geology and music from the University of Northern Iowa, and a master's degree in geology from Indiana University-Purdue University Indianapolis.

Mrs. BICE. Thank you, Ms. Book. And I would just add I appreciate you mentioning the Hamm Institute for American Energy, which is located in Congressional District 5, mine, so thank you for that.

At this time, I thank all the witnesses for their testimony, and I recognize myself now for five minutes for questions.

Both the University of Oklahoma and Oklahoma State University have been heavily engaged in research, partnering with the Department of Energy to better model potential geothermal sites, assess how the utilization of abandoned oil and gas wells can lower costs for geothermal energy producers, as well as improving fluid hydraulics and enhanced geothermal systems. These types of research have had the potential to make Oklahoma a global leader in geothermal production, while exporting these technologies around the globe.

Dr. Hakala, if I could start with you, how does the DOE's—how does the DOE plan on further supporting academic partnerships in these areas?

Dr. HAKALA. Well, the Department of Energy has a huge focus with the Subsurface Energy Innovations crosscut, and so part of that is making sure we can leverage knowledge and understanding across all of the different offices within the Department of Energy. That also involves working with the National Laboratories and academic partnerships as part of that effort. Part of the Energy Earthshot Initiative includes government-academic partnership opportunities moving forward, so there—the expectation is that there will be opportunities in the future to look at that.

Mrs. BICE. Dr. Rosso, do you have any sort of comment on that as well, those partnerships?

Dr. ROSSO. I'd have to say that on the topic of the project in Oklahoma that was referenced I can't speak to, but the partnerships are incredibly important, particularly between national labs and universities. And the initiative that Dr. Hakala mentioned is—you know, it's got its roots, I believe, in the SubTER initiative of DOE and is continuing on in this new life, this revived form today. And it's great. It's exactly what we need, maybe more writ large, I would say, but it's—yes, it's a very good topic.

Mrs. BICE. Thank you.

Mr. Serrurier, you have highlighted the potential for enhanced geothermal systems moving forward and the great breakthrough that your company has recently made. How have partnerships with academic institutions made these types of innovations possible?

Mr. SERRURIER. Thank you. It's a great question. And it's—our company is made possible because of partnerships between industry, national labs, DOE, and academia. Our co-founders met in different programs at Stanford University, and so it really was born out of an academic institution. And so when we look to do research that's applied, we're often partnering with a whole bunch of technical schools. When we apply for funding from DOE for grants, a lot of that is joint between, you know, School of Mines. University of Oklahoma obviously has huge opportunities here. Oklahoma State has the Center for Excellence. So there's a lot of different schools, UT (University of Texas) Austin, the list goes on, but it's that they bring a lot of experience and knowledge. We bring a

whole bunch of sort of entrepreneurial perspective on what's going to be commercially important. And that combination pushes science forward that then allows it to be applied and grow in the marketplace as well.

Mrs. BICE. Do you think that in some ways we have to be careful about sort of fragmenting all of this research across so many institutions that it kind of—it may have sort of a negative impact in that it's—it—the focus is lost in some ways?

Mr. SERRURIER. I can understand the concern, but I would say coming from the—the geothermal industry, frankly, has been historically fairly small and funded at a fairly low level, and being spread thin is potentially a concern, but more is always better. And so when we can bring more, you know, different genetic diversity, so to speak, in an intellectual sense to the problem, it can only lead to good things across—especially across the many cross-sectoral applications that we can see for geothermal. So I'd say it's a "yes, and" situation with R&D and deployment in geothermal right now.

Mrs. BICE. Perfect, thank you for that.

Another research effort at Oklahoma State, funding was awarded for the university to work with both the Oak Ridge National Labs (ORNL) and in the Pacific Northwest National Lab to expand the deployment of geothermal heating and cooling tech. Dr. Rosso, you sort of alluded to this briefly, but the—you know, the role of academics, I think, specifically for your NTCs has a significant role. Would you agree with that?

Dr. ROSSO. Nominally, I would, but to be honest, I'd be guessing. My side of the house at PNNL is very fundamental basic research. There's an applied research section that I believe has the connection that you're talking about with Oklahoma. So just to be—you know, full disclosure, I can't really elaborate on this particular topic. But just a general yes of enthusiasm about the collaborations that have already been, you know, the focus of your question really.

Mrs. BICE. Perfect.

Dr. ROSSO. Yes.

Mrs. BICE. I appreciate that.

And at this time, I will yield my time and now recognize the Ranking Member, Mr. Bowman, for questions for five minutes.

Mr. BOWMAN. Thank you so much, Madam Chair.

My first question goes to Mr. Serrurier. Congratulations on Fervo's recent breakthrough. In your testimony, you cited work completed by DOE and the National Renewable Energy Laboratory on the prevalence of geothermal resources in the United States. There has been much success in the Western States with current geothermal techniques and technologies, including your company's recent groundbreaking success in Nevada. However, there are numerous geological differences between the rock formations under our feet in Washington, D.C., today, and those under Western wells like your company's Project Red. What needs to be done in terms of technological advancements to ensure that eligible geothermal resources here in the Eastern portions of the United States can be tapped?

Mr. SERRURIER. Thank you for the question, Ranking Member Bowman. This the exciting thing that we're super, you know, excited about at Fervo, which is that with this advancement that

we've shown in northern Nevada, the ultimate goal is geothermal everywhere. And what needs to happen is we need to learn how to do it better because we know it works. But now we need to do it cheaper, we need to do it faster, and we need to do it at scale. And so the deployment of geothermal energy technologies will bring the cost down, and that allows us to go into new geologies and to do them cost-effectively. It's not dissimilar from what—the growth pattern we saw in oil and gas, which started at the low-hanging fruit. And then, as the technology matured, we saw new resources. We brought those new technologies to bear in new areas and discover new opportunities for economic production. The same opportunity exists in geothermal. And ultimately, our goal is to commercialize where that low-hanging fruit exists. It's true, the West does have an abundant shallow heat resource. But the East Coast, you dig down, you find heat, right? And so now it's about getting those drilling costs down, finding the technology to optimize the subsurface reservoir that allows us to do it in every possible geologic foundation.

Mr. BOWMAN. What should DOE be considering to speed up the demonstration and deployment of these enhanced geothermal systems?

Mr. SERRURIER. It's a great question. There's a lot of opportunities here. So one thing that we're particularly excited about is the funding that can be—that has been appropriated that could be spent on actually funding demonstration projects that are actually, you know, putting drill bits in the ground and seeing how these projects work in practice, but also thinking about ways that we can optimize those types of formations. We brought up—FORGE was mentioned. The FORGE project is a great project. We partner with them on a lot of opportunities, and seeing how they are pushing the boundaries on what these reservoirs look like, how they can be operated in more flexible ways for electric generation or for a whole bunch of multiple uses, applying that research in the ground because we're at the stage where we're ready to deploy, and we need to learn how to do that deployment faster.

Mr. BOWMAN. Got it. My next question is for Dr. Hakala. One of the most energy-intensive actions a building can do is heat its air and water tanks, and enhanced geothermal systems become more commercially—as, excuse me, enhanced geothermal systems become more commercially viable, there is great potential to use these technologies to provide heat to large buildings and individual households. Many communities in my district in Westchester County in the Bronx in New York are looking at the systems, as I mentioned in my opening statement. So how can enhance geothermal systems be used to lower energy costs and decarbonize the building sector?

Dr. HAKALA. Thank you very much for your question. Unfortunately, that's outside of my area of familiarity, so we can get back to you with an answer on that. We do have colleagues across NETL and FECM who have——

Mr. BOWMAN. Got it.

Dr. HAKALA [continuing]. Information on that topic.

Mr. BOWMAN. Can I go to Ms. Book, then, next? Thank you.

Ms. BOOK. Sure. I was ready for this.

Mr. BOWMAN. All right.

Ms. BOOK. So actually, you know, I don't want to get the stat wrong, but we—in the United States, residential and commercial sector accounts for about 17 percent of U.S. greenhouse gas emissions. OK. I focus on that since I work in the energy transition. And building heating is a really big share of that, right? So the focus on that is appropriate, and a lot more can be done.

To answer your question, one thing that we've done at Baker Hughes is we have partnered with a company called ExerGo, and this a company—it's a clean tech startup, so it's a little bit earlier. It's—I would make a comparison that where Fervo is gone and it's going big, ExerGo is looking at this with CO_2 as the heat recovery fluid, OK? And so this means you're able to use excess CO_2 and so get an emissions reduction at the same time that you can have a low temperature fluid loop for geothermal, which is really exciting and very cutting edge. And so this an area we'll want to see a little bit more investment in so that—so we can see that investment take off. But that's a really great application where you get emissions reduction and some really excellent sustainable heating and cooling.

Mr. BOWMAN. Thank you. I yield back.

Mrs. BICE. Thank you, Ranking Member.

And it is my great pleasure to recognize the Chairman of the Full Committee on Science, Space, and Technology, my colleague from Oklahoma, Mr. Lucas, for five minutes.

Chairman LUCAS. Thank you, Madam Chair.

Ms. Book, in your testimony, you highlight how Baker Hughes, alongside industry and academic partners like Oklahoma State University, is using technology originally developed for the oil and gas industry for emerging technologies in geothermal and carbon capture and storage. Can you go into more detail on how the investments made by the oil and gas industry are vital to the development of other subsurface energy technologies?

Ms. BOOK. Yes, so a lot has been done in the subsurface and sort of the tech and the service side. And so just as we've heard from the gentleman from Fervo, a lot of that technology piece is well-baked in the oil and gas side, OK? And a lot of it directly transfers. So a lot of what we're doing on—in geothermal today is directly—same kind of equipment that you might use. Now, the frontier space needs technology that can go hotter and hotter, OK, as well as—lower temperature is little easier. That's a direct translation. I'd also say it's the same as you start to look at CCS in terms of the storage side for CO_2. And a lot of the drilling techniques, same idea, controlling the wells the same. And so it's—what's great about this is a direct translation of both the tools and the skills that people have into this different frontier.

Chairman LUCAS. Do you think we would have seen the rapid development in these technologies without the contributions made by industry?

Ms. BOOK. I don't. I mean, a lot of the innovation comes from there, but also in this public-private partnership, right? And so you've seen companies like ours in partnership with the U.S. Government and the labs working over time—like I think it was Sandia who came up with the first PDC bit many years ago, in

partnership with the private sector, OK, because they have the application space where they're really advancing that.

Chairman LUCAS. Mr. Serrurier, in your testimony, you describe the partnership between Fervo and DOE's Frontier Observatory for Research in Geothermal Energy and the role it played in the advancement of enhanced geothermal technologies. Within this partnership, what were the benefits to Fervo?

Mr. SERRURIER. Thank you, Mr. Lucas. It's a great question. FORGE has been a great partner of ours, and the benefits that we saw—first of all, we had a great view into the rock because of their experience drilling in southwest Utah, but also to have a community of researchers who are dealing with the same challenges of taking oil and gas technology and applying it in a new geologic formation. There were a lot of unknowns, and to have the FORGE success story—and they also have had some recent breakthroughs in their own project. To have their experience translate into our ability to raise capital, our ability to apply that capital to a new development, and to start pushing the boundaries on, you know, taking—they can take some risks with their project, which, frankly, is harder to do when you have the private backing that we do.

Chairman LUCAS. And by the same token, in all fairness, what do—what would you describe as the benefits of this to DOE?

Mr. SERRURIER. The benefits to DOE is helping the American grid decarbonize, create a ton of new jobs, and pioneer a whole application of subsurface development and technology that wouldn't be feasible without these sorts of partnerships.

Chairman LUCAS. One last question, what specific recommendations, if any, do you have for FORGE moving forward?

Mr. SERRURIER. My recommendations for FORGE is to stay close to their phone because we love to call them. But also, it's to look at the—you know, when you think about where this industry is going and the application of EGS, to think about—we're applying these at large scale. FORGE has a couple great wells. We're looking to do a 400 megawatt project nearby, and to think about the application challenges that the private industry will be facing as we scale up from an industry that is nascent but, as I mentioned, on the cusp of very rapid growth. And so there's scaling challenges. There's application challenges. There's a new world of scientific inquiry, and I look forward to working with them to help solve some of those challenges.

Chairman LUCAS. Thank you very much.

And with that, I yield back, Madam Chair.

Mrs. BICE. Thank you, Mr. Chairman.

At this time, I recognize Ms. Lee for questions for five minutes.

Ms. LEE. Thank you, Madam Chair and Ranking Member Bowman, and to our panel of witnesses today for your time and your testimony.

Western Pennsylvania, where I represent, has been home to mining operations for over 200 years. And of course, that's not been without consequence. Black lung, an incurable respiratory disease, has become more prevalent and is impacting younger workers earlier across the postindustrial Appalachian communities. While I'm a strong advocate and supporter for a clean energy future that does not rely on fossil energy, I'm also obligated as a representative of

my people to ensure that every individual is carried along as part of our energy transition.

Every Member of this Committee represents families who are concerned or affected by the changes they see and feel in their environment. It's vital that we continue to push for new technologies and strategies, not just for energy security, but for better welfare and living standards for our constituents.

The continued extraction of energy resources from the Earth creates numerous spheres within the communities that I represent. Millions of structures in the Commonwealth of Pennsylvania stand on top of old and abandoned underground mines. In fact, my constituents are often advised to purchase subsidence insurance in case their homes ever cave in. There are an estimated 230,000 homes in my district at risk of sinking into the ground from mine subsidence. Powering our homes and industry should not and must not mean that parents go to sleep worrying that their home may literally be swallowed by the ground.

So this why I'm proud that Rep. Bice and I have been able to work together to introduce the *Abandoned Well Remediation Research and Development Act,* which will further support research and development into the subsurface environment and help reduce methane emissions from abandoned mines across the country.

So not to sound like a radio hit on repeat, but some of the worst air quality in the country is found in my district. It means a lot to me that I sit in this seat to affect change to my community and communities I represent. Legislation like this is one step in the right direction toward cleaner air in PA.

I'm also intrigued by the opportunities that advanced computing and complex modeling will create in mapping abandoned mines and wells to better plan and protect our communities from harmful emissions and geological abnormalities. It's important to me that research and development into how we interact with subsurface energy sources caters to the safety and well-being of our fellow human beings on the surface, along with remembering that we share this planet with all the flora and fauna, and we are obligated to protect such as well.

With that said, Ms. Book, how are researchers at organizations like your own utilizing their research to create technologies and devices that protects our family—or, excuse me, our frontline workers from occupational diseases like black lung?

Ms. BOOK. Well, typically, that's not associated with our part of the energy sector, right, and so—but we're—we have a really big focus on safety. And so I actually sit on top of all of the statistics for our company's performance in that area, and in terms of the people, planet, and principles, it's a part of our sustainability reporting and accountability to the communities we operate in. And so we take that very serious. In fact, we measure perfect health safety days to ensure that our frontline workers are protected. And so I can assure you and point you to the things that we do in more detail offline because there's quite a bit that that we do——

Ms. LEE. Thank you.

Ms. BOOK [continuing]. And we partner with communities.

Ms. LEE. Certainly, I appreciate that.

Similarly, many communities in my district struggle with domestic wastewater treatment due to the leaching of metals from abandoned mines into watersheds. If anyone knows, how is research and development helping create cost-effective solutions for municipalities, such as improved detection or prevention of contaminants from abandoned subsurface infrastructure? I'll give that to you, but if others have input.

Ms. BOOK. I don't have an answer, so——

Ms. LEE. Yes. Dr. Hakala?

Dr. HAKALA. Thank you so much, Representative Lee, and thank you for representing Allegheny County. That's where—I'm up at the Pittsburgh, Pennsylvania, NETL site. So I can say that some of the research that's being performed at NETL and across the Department of Energy has focused on taking what they call unconventional feedstocks, and so that would be something similar to some of these wastewaters from abandoned mines and figuring out how to clean them up and then also how do we extract valuable minerals from those resources? And so that type of work expands from the basic R&D stage all the way out to some technology deployments that are being tested in some other regions but that would be applicable to our region, as appropriate.

Ms. LEE. Yes, thank you, Dr. Hakala. And really quickly, one more. You know how DOE R&D is working to incorporate public feedback and community engagement to adequately address air quality and public health concerns in our communities?

Dr. HAKALA. Well, DOE is—as part of all of these larger projects that are funded to look at carbon storage and direct air capture and things, as part of those external opportunity announcements, there is an opportunity—or there is a request for the teams responding to those to include a community engagement plan. And so that can include outreach, education, and any type of involvement with the community as appropriate.

Ms. LEE. Thank you so much. I yield back.

Mrs. BICE. Thank you, Ms. Lee.

And at this time, I recognize the gentleman from New Jersey, Mr. Kean, for five minutes.

Mr. KEAN. Thank you, Madam Chair. And thank you to our witnesses for being here today.

Dr. Wainwright, MIT collaborates with Savannah River National Laboratory on the Advanced Long-Term Environmental Monitoring (ALTEMIS) project. How has this partnership informed future remediation of contaminated groundwater? What other insights has come from this project?

Dr. WAINWRIGHT. Yes, so one of the biggest challenges for DOE is the long-term stewardship of these sites. And there are so many technologies available, including new sensors, AI, artificial intelligence, for example, but it has not—they have not been integrated into the DOE's remediation program. So in the ALTEMIS project, we are trying to integrate these technologies to improve the long-term monitoring, such as, for example, rapid anomaly detection at the site, ensuring the stability of the system, and also really sort of providing the communities with the assurance that the sites are safe. That's the ultimate goal.

Mr. KEAN. OK. In what ways does the collaboration further development of the next-generation workforce?

Dr. WAINWRIGHT. Yes, in our project there are many students from different universities, more than five universities. Many of them are from minority-serving institutions. For example, we are teaching them how to do machine learning, AI, and groundwater flow simulation. I believe that we are developing the next generation workforce for EM and beyond; for general environmental industries.

Mr. KEAN. And then I've got a broader question to any member on the panel that thinks it's appropriate to answer. When considering the importance of having multiple energy sources to help the United States move toward energy independence, what potential regulatory barriers or other barriers are there that might hinder the growth of enhanced geothermal energy production and utilization?

Mr. SERRURIER. I'll be happy to take that first. Thank you, Mr. Kean. One area is public lands management, honestly. There is—90 percent or so of America's geothermal resource as currently recognized sits on federally owned land. And so the permitting process, the lease sales, and the in-house expertise at the various permitting agencies is a critical component of our ability to expand the technology as fast as the market is demanding it.

Dr. ROSSO. I'll jump in on that one. Yes. I'm all for the enthusiasm and learning-by-doing approach to things like enhanced geothermal, and we have some very good success stories that have been featured even in this discussion. But if I bring it back to the question about safety and the need to kind of drive carefully through this, you know, there's cautionary tales here. The fundamental R&D that is needed to sort of ensure safety, to ensure that we know what we're doing as we establish these pilot plants, is ultimately very critical to actually keeping the whole industry from actually undermining itself with accidents such as induced seismicity or, you know, creating a reputation of not-in-my-backyard would ultimately be something that would be an inertial drag on the entire enterprise.

So the point I'm trying to make is that there's a complementation to all of this with fundamental R&D on the subsurface complexity that I refer to in my testimony. There's things that we still don't know. When you're drilling into deep, hard rock or trying to do things that are really challenging, like enhanced geothermal, you don't know how stressed those rocks are that you're drilling into. You really don't know at the very beginning what's going to happen.

And so the research that is needed really at the fundamental level is things like new sensing technologies, things that are being developed like to try and understand reactive transport of fluids through stressed rock and fractures. These are really fundamental, challenging questions that require an incredible collaborative team of multidisciplinary folks to wrap their heads around these problems and help produce predictive tools, so I just want to make sure that's clear.

Mr. KEAN. That's very helpful.

Anybody else on the panel?

Dr. HAKALA. I'd just like to highlight that a lot of the lessons learned from other industries is—can also be very important, and also extending it to figuring out how—you know what are areas that we already know about versus what are areas that require some more of this focused investigation.

Mr. KEAN. That's great. Thank you, and I yield back.

Mrs. BICE. Thank you.

And at this time, I'd like to recognize the gentlelady from North Carolina, Ms. Ross, for five minutes for questions.

Ms. ROSS. Thank you very much. And thank you to the Chair and the Ranking Member for holding this hearing, and thank you to all the panelists for joining us today.

One of the most important societal issues we face today is a shift to a carbon-free renewable energy distribution system and really harnessing what we've got in nature to do just that. And this is essential to limiting climate change. And obviously, subsurface resources provide a patchwork of solutions for this energy transition, including enormous amounts of pore space to permanently absorb carbon dioxide and renewable energy from geothermal sources.

Last summer, I had the great pleasure and privilege of going with a bipartisan delegation to Iceland to see how they use geothermal energy and to see some innovative carbon capture technology, some of which was being done between Iceland and the United States. I'd like to know—because nobody's talked about Iceland here. I mean, obviously, we don't have, you know, volcanoes like they do. But how much of what you do is based on the amazing success that they've had in Iceland? And I think we'll—we should start with Dr. Hakala and move on from there.

Dr. HAKALA. Great, thank you very much for this excellent question. And what this points toward for me is I'm trying to understand how can we both recover geothermal energy and also trap CO_2 in a mineralized form? And so the U.S. Department of Energy is looking at mineralization R&D across a variety of scenarios, both looking at above-ground and in situ or within the geologic reservoir, and how do we trap the CO_2 as an immobile phase? And so there is still some fundamental R&D required in that space, especially depending on the formation and depending on specific flow pathways and properties. However, being able to understand what's happening in currently deployed field settings where things are—where CO_2 is being injected and then coupling that with the fundamental R&D—is critical to figuring that out.

Ms. ROSS. Does anybody have anything to add?

Mr. SERRURIER. Yes, I would just like to add quickly, thank you for the question. And direct air capture is something that we're very interested in at Fervo, and Climeworks, one of the direct air capture firms I believe it is in Iceland that pairs with geothermal, it works really well because you have the need for high heat for direct air capture, as well as the need for low-cost, steady, clean electricity. We produce both of those things. And so we're looking at what those partnerships could look like if we integrate an EGS system with a direct air capture system. And a lot of that's modeled off stuff that's being pioneered right now in Iceland, so it's great to have that working model for us.

Ms. ROSS. Great. And—oh, did you—Dr. Rosso, did you——

Dr. ROSSO. That's OK. I was just quickly going to add, there's exciting things going on similar to what's going on in Iceland, but in the Salton Sea in California where basically you've got geothermal so you've got the heat at the surface, but you can also extract metals. You can extract lithium. Lots of other important critical elements are coming out. It's just fantastic advances in R&D going on at sites like that. So in certain ways, I'd say we're trying to keep up with what's going on internationally.

Ms. ROSS. Great. And the—my next question is really about our energy grid for energy distribution. And so we've seen that with solar and wind, we're going to have to make some upgrades to our grid to deal with either—particularly with offshore wind, an entirely new way of getting that energy to shore, into our homes, into our businesses. And then we've seen this unbelievable queue in solar where we haven't been able to tap into this amazing resource that we have because we simply don't have the distribution system. What do we need to do to our energy grid to be able to get geothermal energy on it in an efficient way and not have the grid be the thing that stands in the way?

Mr. SERRURIER. Thank you. It's a huge question. And I think transmission is going to be a huge piece of that. We're developing projects in places—we have some flexibility in siting, but geothermal to date has been a relatively small share of our energy grid, and so there isn't necessarily the same amount of installed transmission capacity to the areas where we see the most exciting development opportunities.

But, in addition to that, I'll note that geothermal, because it is a 24/7, clean, firm resource enables the development of a whole slew of variable renewable resources, so you have that really cheap solar and wind power coming online, but you're also adding flexible baseload power in geothermal that can play a critical role in keeping the lights on and keeping everything affordable. So the portfolio, but the transmission access is going to be important.

Ms. ROSS. OK. With 4 seconds to go, does DOE have anything to add to that?

Dr. HAKALA. Yes, we have—I have many colleagues who are looking at this question across the Department of Energy. I can get some additional information from them. Unfortunately, it's not my area of expertise.

Ms. ROSS. OK. Thank you, and I yield back.

Mr. KEAN [presiding]. Thank you. The Chair now recognizes Mr. Baird from Indiana for five minutes.

Mr. BAIRD. Thank you, Mr. Chairman, Ranking Member. And I always appreciate you witnesses taking the time to share your expertise with this Committee.

You know, ag is my—kind of my background, and earlier this week, I introduced H.R. 4824, the *Carbon Sequestration Calibration Act*—there's a name for you—but anyway, a bill that authorizes the Department of Energy to carry out terrestrial carbon sequestration research and development, which we've referred to here, in collaboration with key Federal agencies like the U.S. Department of Agriculture and the Department of Interior.

So, Dr. Rosso, in your opinion and based on your decades of experience working in DOE Office of Science lab, what role does basic

research in biology or environmental systems science play in DOE's other subsurface science activities specifically related to carbon sequestration?

Dr. ROSSO. Thank you, Chairman Baird. It's an excellent question. I'll try and respond on two fronts. One is terrestrial carbon sequestration. There, you're basically trying to enhance the amount of carbon that soils can take up. And one concept there that should be evaluated is how can we take advantage of biology and the entire ecosystem of soils basically to drive carbon deeper into the—just basically for longer-term storage. And that's something that I think the Office of BER, I believe, Biological and Environmental Research has an interest in.

On the flip side, back to the other point, carbon sequestration below ground, deep below ground, in other words, taking CO_2 and injecting it safely below ground, this an important area that can't be overlooked. It's been mentioned by Dr. Hakala, and this something that still needs a lot of research. We need to understand how we can safely keep it underground. And one of the things we do at PNNL very well because we're sitting out there on a mile of basalt is to try and take advantage of the fact that there's reactive minerals in basalt that will react with CO_2 and convert it into stable solid phases. And so this an area that we should really continue to keep on the forefront because, you know, a large part of the country has got a lot of storage capacity for permanent sequestration of CO_2.

Mr. BAIRD. You know, you mentioned one thing that I think's important in this—because of agriculture and what they've done over the years in conservation, you know, the carbon adds another activity to the soil and improves soil health. And so the more that we could capture in the soil, the better off we would be.

But, Dr. Hakala, can you—I want to go to you next if you'd like to comment about this.

Dr. HAKALA. Sure. I—thank you very much. And I agree with Dr. Rosso's response. There is some fundamental research that does happen across the DOE labs, and what's really important also is the—leveraging the knowledge that we gain in different program areas and applying it toward a specific application. And so with this question of what do we need to understand about enabling terrestrial sequestration, well, is there—are there fundamental advances in geomicrobiology that we can leverage to further enhance carbon sequestration in the soils and in other types of reservoirs like the deep subsurface?

Mr. BAIRD. Would any of the other witnesses—yes.

Dr. WAINWRIGHT. So I have worked in many projects under BER, the Office of Science Biological and Environmental Research (BER) program. BER supports research, for example, developing mathematical models computational tools, to simulate and predict the carbon cycling in terrestrial systems. Those capabilities can be directly applied to carbon sequestration in soil. Also, they support research to map soil heterogeneity over a large area, and they also support carbon cycling experiments. Those types of research in BER can be directly applied to agriculture setting for carbon sequestration in soil.

Mr. BAIRD. Thank you. Anyone else care to—yes.

Ms. BOOK. Yes, I'd like to put on a hat from a former life. The—as the token geoscientist sitting here, I'd be remiss if I didn't mention that the USGS (United States Geological Survey) and the U.S. Biological Survey are a powerhouse in this area as well, OK? And so let's just remember as you work on—and I haven't looked at your bill yet, but now I'm going to, OK, because they have a lot to offer, and they've done great work in the last decade on assessing the capabilities and where we can have some of the strongest terrestrial sequestration across the United States.

Mr. BAIRD. I thank all of you. And with that, I'm out of time and yield back.

Mr. KEAN. Thank you. The gentleman yields back.

I now recognize Mr. Sorsen, Sorensen from Illinois for five minutes.

Mr. SORENSEN. Thank you, Chairman and Ranking Member Bowman, for convening this hearing and our witnesses for appearing before us.

In Illinois, 54 percent of the energy that we use to power our State is nuclear-generated electricity. Illinois is the leader in nuclear energy production. This a clean and reliable source of energy that has worked so well for my State. However, nuclear power does create waste. And currently, we do not have a central location for the country's nuclear waste to be stored and disposed of. The solution we have gone with is simply storing the waste at temporary storage sites at or near the generating reactor. This not a long-term solution and generates environmental contamination concerns. Sites where nuclear waste is stored must be monitored very carefully, activities which rely heavily on the expertise derived from subsurface research and technology development.

One of Illinois' nuclear reactors is just outside the Quad Cities, a community that I represent. Drs. Wainwright and Rosso, are there new developments in subsurface science that we can better protect our communities that live near these facilities?

Dr. WAINWRIGHT. I go first. So I teach nuclear waste management at MIT. I was hired last year to teach this subject. And nuclear waste, I would say, is one of the best-managed wastes in human history. It's protected by a highly engineered barrier system. And also, there are many regulations to protect the environment.

I would say there can be many technologies transferred from the EM domain in a sense that EM—DOE Office of Environmental Management have so much experience moving defense-related waste and monitoring these wastes. I manage a project developing monitoring technologies. There are so many new sensor technologies and artificial intelligence, for example, to do anomaly detection. So these technologies, and new technologies, monitoring particularly, can be transferred to secure nuclear waste at commercial facilities as well.

Dr. ROSSO. Yes, it's a great question, Congressman Sorensen. PNNL is parked right next to the Hanford Site. And we—you know, we deal with a lot of contamination just upstream from us on the Columbia River. It's an area that EM has taken over in terms of—let me back up. They actually are responsible for cleanup of that site with its thousand or so plumes of contamination slowly

making its way down. But the R&D effort is largely there as well. And it used to be something that was a focal area of the Office of Science, but it's—to be honest, it's actually waning a little bit. And it's hard to explain why. It's above my paygrade why exactly—and maybe it's political, largely. But the point is that there's a lot of left-off questions that haven't been addressed in terms of trying to understand how radionuclides move through this—through soils and subsurface environments. And EM is in a mode where—they fund research for cleanup. They fund the deep vadose zone, for example, which is billions of dollars a year, some of which PNNL, you know, leads for DOE. But the fundamental R&D is just not there. It's not there where it used to be. And it would be great to see that pick up again from the Office of Science.

Mr. SORENSEN. You'd mentioned that perhaps some of the problem here is political. Could you explain that?

Dr. ROSSO. I cannot. It was just pure speculation. And I'd love to back that off if I could, but I can't.

Mr. SORENSEN. Thank you, sir. I've only got a minute left. As a nation, we're investing in carbon capture technology, but there's questions based on safety and sustainability. Dr. Hakala and Ms. Book, either one of you, do we know enough in the geology to know that this is 100 percent safe?

Ms. BOOK. We can flip for it. OK. I'll go first, and then you can go. So just being fast on my feet, I would feel safe with this like in my backyard if the system's designed correctly, OK?

Mr. SORENSEN. Great.

Ms. BOOK. And I say that because there's been longstanding use of CO_2 in the subsurface many, many decades, 40 years plus, OK? And so knowing from that you can't really cite fatalities from it. There's not a body of real big safety concerns that come off of that because the storage of that—its use in oilfield recovery and through pipelines has been very heavily regulated, as well as, from the safety paradigm, very tightly controlled, OK? And DOT PHMSA (Pipeline and Hazardous Materials Safety Administration) provides a really good oversight mechanism for CO_2 and pipeline. And so I think in terms of the subsurface, the decades of safety experience there is well in hand and I think very under control.

Mr. SORENSEN. Dr. Hakala? Or I know I'm running short on time. Do we know enough—are we monitoring below the surface enough?

Dr. HAKALA. Well, we have a few major things in our—to our advantage to ensure the safety. We have the regional partnerships, the regional initiatives, the CarbonSAFE efforts, the pending efforts. We have the National Risk Assessment Partnership, and we also have the SMART effort. And so when you think about some of the fundamental to applied work that's happening through NRAP and SMART, NRAP is looking at how can we quantify the risk of a site so that you can make good decisions about what type of site you want to develop? And so that's built off of years of the labs working together, the years from the oil and gas industry experience, and pulling in new knowledge from sites that are under—the demonstration sites.

With the real-time monitoring and application of computational tools in AI, we're going to be able to understand what's happening

in real time so that things that may have been a problem in the past won't be a problem because you can deal with it faster. So I think we're in a really good position to ensure the security and safety of these systems.

Mr. SORENSEN. Thank you for that. Chairman, I yield.

Mr. KEAN. Thank you. The gentleman yields back.

I now recognize Mrs. Foushee from North Carolina for five minutes of questions.

Mrs. FOUSHEE. Thank you, Mr. Chair and Ranking Member Bowman, for convening this here. And welcome and thank you to all of you for your testimonies today.

I am proud to represent North Carolina's 4th Congressional District, home to Duke University in Durham, where, last year, researchers and students drilled a 400-foot hole on campus to study geothermal potential across the university's campus and the region. So my first question is for Mr. Serrurier. Much has been said about geothermal energy in the Western part of the United States. What technological advancements need to be made to tap into eligible geothermal resources here in the Eastern part of the country?

Mr. SERRURIER. Thank you, Congresswoman. And it's great to hear about the progress at Duke. My brother-in-law attended, and I'm sure he'll be happy to hear that.

I think there's a couple—there's a lot of different ways that geothermal energy can be used in many different applications. What we're doing at Fervo is digging about 8,000-plus-feet deep into super what would I think normal people consider super hot. It's considered less hot for geothermal energy purposes. But that's a technology that we are ready to deploy today in the West, and deploying it in the West will bring down those costs so we can access deeper resources in less understood geologies, the Eastern half of the country. So it's something that can be applied from a technical perspective across the country right now. As we get better drill bits, as we get better sensing of the subsurface and more data about where those thermal resources sit in different geologies, particularly in the Eastern side of the country, then we'll be able to access economically to develop power generation, heating and cooling, industrial heat applications. The world is our oyster at that point.

Mrs. FOUSHEE. Thank you for that.

And, Dr. Rosso and Dr. Wainwright, you both discussed how DOE has been proactive in supporting subsurface research and development to fill critical gaps. What are the biggest challenges that must be addressed to advance the field of geoscience and its applications?

Dr. ROSSO. I'd come back to sensing, subsurface sensing. We need new tools that basically give us orthogonal information to traditional sensing tools like seismic and distributed temperature and acoustic. We need to be able to see the state of stress in rocks before we drill into them so that—so we don't create problems like slippage on a preexisting fault. So it's—I would throw it at sensing, developing new technologies, innovating really, not just incrementally advancing existing technology, but coming up with entirely new ways to sense the state of stress in the subsurface. This would be one frontier that I would point out.

Mrs. FOUSHEE. Dr. Wainwright?

Dr. WAINWRIGHT. I totally agree. I would say that long-term predictability of subsurface is a grand challenge. One of our biggest challenges is that subsurface is heterogeneous and we cannot see unless we drill wells. So, yes, sensing technologies and imaging technologies between wells, 3D visualization of subsurface are rapidly developing. And also, coupled processes like heat, water, chemistry interacting each other and those processes are very difficult to model. This is another grand challenge. And DOE has supercomputers, the world's first supercomputer, for example. Those computational resources are really powerful to simulate and predict these complex processes in subsurface.

Mrs. FOUSHEE. Would anyone else care to comment?

Ms. BOOK. I'd love to add from our perspective, and probably Fervo, is that we'd like to see more and more focus on pushing the heat frontier in terms of the tools. So you're always limited. When you hit a certain temperature profile, the tools will start to fail if it gets too hot. And so that's been a barrier that's been very difficult to cross in the history of geothermal and subsurface exploration. And so I would say that. And then downhole sensors is an area that that we can always work to advance more particularly on that heat frontier as it gets hotter.

Did you want to add anything?

Mr. SERRURIER. No, I would just add that we do have the technologies to deploy today, and iterating and building on those technologies in new conditions becomes even better for the resource. So we are drilling at heats that are commercially productive. We are seeing fiberoptic sensing work in those conditions, the drill bits work in those conditions, but to make this the fully realized resource that it can be, the geothermal can be, will require going to higher—deeper depths, higher heats. And obviously, doing that more economically with better technology is going to make that more feasible.

Mrs. FOUSHEE. Mr. Chairman, that's my time. I yield back.

Mr. KEAN. Thank you. The Chair now recognizes Mr. Fleischmann from Tennessee for five minutes of questions.

Mr. FLEISCHMANN. Thank you, Mr. Chairman, and welcome to this distinguished panel. It's always good to see you all. I'm Chuck Fleischmann. I represent the people of the Third District of Tennessee, more specifically, the great city of Oak Ridge, located in Anderson and Roane Counties and that wonderful DOE reservation. I appreciate you all participating today.

In my district, Oak Ridge National Laboratory is conducting research and development on a variety of areas surrounding the subsurface technologies. For example, DOE's Advanced Scientific Computing Research program, known as ASCR, has seen a major recent success with the deployment of Frontier at ORNL, the world's fastest exascale computer. From rare-earth mineral recovery and reuse efforts to developing advanced materials for geothermal well construction and operating the country's largest open-access battery manufacturing research and development center, the national labs are a key player in our country's energy future.

Dr. Rosso, can you explain how the national labs utilize funding to fill gaps that private industry may not be able to invest in during early technology development?

Dr. ROSSO. Thank you for the question. Let me talk about computing. Computing of the kind of—and scale that's available at Oak Ridge such as the leadership plus exascale computers are totally essential to what I've been referring to all along, and that is developing new ways to actually detect and see below the surface between boreholes. So it's—that aspect that you mentioned is important.

With regard to your other question, which I've already forgotten, I don't know if you'd be kind enough to repeat that so that I can——

Mr. FLEISCHMANN. Yes.

Dr. ROSSO [continuing]. Direct it——

Mr. FLEISCHMANN. How national labs utilize funding to fill gaps that private industry may not be able to invest in during early technology development.

Dr. ROSSO. Well, it's all about establishing collaborations between the experts that exist in national labs and universities and—yes, and giving them real resources to actually dedicate time and attention and the development of students on these topics, right, for the next-generation workforce. So that's essential.

Mr. FLEISCHMANN. Thank you, sir.

Dr. ROSSO. Thank you.

Mr. FLEISCHMANN. Dr. Hakala, can you give us some examples of how technologies initially started in a national lab have evolved into commercially successful enterprises by private industry?

Dr. HAKALA. I think—thank you very much for that question. And the one example that I'm most familiar with is where there was a significant investment in understanding directional drilling and hydraulic fracturing technologies. And that's—some of that fundamental research that was performed years ago has then—has now been applied and deployed in multiple regions, you know, for unconventional oil and gas. And more recently, it's being explored and applied in geothermal as well to look at the technology leveraging across different technology spaces.

Mr. FLEISCHMANN. Thank you. I know my time is waning, but, Dr. Wainwright, how have high-performance computer—supercomputers transformed your research in environmental remediation and understanding the subsurface?

Dr. WAINWRIGHT. Yes, my team routinely use high-performance computing for groundwater simulations. For example, we were able to quantify the impact of extreme weather events on EM sites. There are many concerns about how extreme rain events would impact the waste disposal cells, for example. These supercomputers are really helpful for us to model these impacts and predict the future consequences if there are.

Mr. FLEISCHMANN. Thank you. I'm going to try to get this question in, and I'll open it up for whomever wants to answer. After the Bureau of Mines was dissolved in 1996, statutory authority for mining R&D was transferred to the Department of Energy. While there are mining technology-related research efforts run through NETL and ARPA–E (Advanced Research Projects Agency—En-

ergy), there is no active Federal program focused on R&D dedicated to hard rock mining and new mining technologies. Can any of you comment on the importance of R&D in creating an economically viable domestic mining industry? And what role do you recommend the Federal Government play including the national lab system, as we just discussed, in supporting advanced mining technologies?

Dr. HAKALA. Thank you very much for that question. I'm happy to start the answer to that. Something that is happening across the Department of Energy currently is the Critical Minerals Collaborative, and so that is focused on leveraging our past investments, leveraging all of the prior knowledge, leveraging knowledge from the Critical Minerals Institute, and then making sure there's a coordinated effort to develop the supply chain.

Mr. FLEISCHMANN. Thank you. Anybody else want to comment? I know I'm past my time, Mr. Chair, but if anybody else would like to briefly comment, I'm open. Yes?

Dr. WAINWRIGHT. In terms of the waste management side, Office of Environmental Management and Office of Legacy Management have been managing uranium mill tailing sites, for example, building stable disposal cells. Those technologies and experience could be transferred to general mining sites.

Mr. FLEISCHMANN. Excellent. Thank you. And again, I thank this distinguished panel. Mr. Chair, I yield back.

Mr. KEAN. The gentleman yields back.

Seeing no other questions, I thank the witnesses for their valuable testimony and the Members for their questions. The record will remain open for 10 days for additional comments and written questions from Members.

The hearing is adjourned.

[Whereupon, at 3:53 p.m., the Subcommittee was adjourned.]

Appendix

Additional Material for the Record

Documents submitted by the Western Governors' Association

WESTERN GOVERNORS' ASSOCIATION

MARK GORDON
GOVERNOR OF WYOMING
CHAIR

MICHELLE LUJAN GRISHAM
GOVERNOR OF NEW MEXICO
VICE CHAIR

JACK WALDORF
EXECUTIVE DIRECTOR

July 31, 2023

The Honorable Brandon Williams
Chairman
Subcommittee on Energy
Committee on Science, Space, and Technology
House of Representatives
2321 Rayburn House Office Building
Washington, DC 20515

The Honorable Jamaal Bowman
Ranking Member
Subcommittee on Energy
Committee on Science, Space, and Technology
House of Representatives
2321 Rayburn House Office Building
Washington, DC 20515

Dear Chairman Williams and Ranking Member Bowman:

With respect to the Committee's July 26 hearing, Unearthing Innovation: The Future of Subsurface Science and Technology in the United States, attached please find Western Governors' Association (WGA) Policy Resolution 2022-01, Energy in the West, which includes Western Governors' collective, bipartisan policy recommendations related to energy innovation and technology.

In addition, WGA would like to provide the Committee with the June 2023 report of the Western Governors' Heat Beneath Our Feet initiative. The report conveys recommendations for accelerating the development and deployment of geothermal technologies in the West accumulated through a rigorous, yearlong stakeholder process including federal, state, and industry partners.

I request that you include these documents in the permanent record of the hearing, as they articulate Western Governors' policy positions and recommendations on these important issues.

Thank you for your consideration of this request. Please contact me if you have any questions or require further information.

Sincerely,

Jack Waldorf
Executive Director

Attachments

Policy Resolution 2022-01

Energy in the West

A. BACKGROUND

1. Energy policy and the development of sustainable energy resources are major priorities for every Western Governor.

2. Western Governors recognize that approaches to energy use and development vary among our states and territories. However, the Governors remain committed to the development of policies and utilization of state energy endowments that result in sustainable practices that can benefit citizens, the region, the nation, and the world.

3. Electricity generation and delivery systems are undergoing rapid, significant change across the West. The increasing integration of renewable energy and distributed energy resources, electrification of vehicles and buildings, and retirement of traditional energy generating assets are all contributing to fundamental shifts in the electric sector. Several western states have accelerated these developments by enacting legislation to create targets or deadlines to further support renewable energy.

4. In addition, some energy systems face heightened threats from digital and physical sources, including wildfires, severe storms, heat waves, droughts, and other extreme weather events. Ensuring the reliability of energy generation and delivery systems despite these threats is a priority of every Western Governor.

5. Western states and communities are served by a diverse mix of electricity providers. Investor-owned utilities, public power utilities, and rural electric cooperatives all serve an invaluable role in delivering reliable, affordable power across the West. These electricity providers are characterized by differences in federal and state oversight, governance structures, capital assets, and geographic service territories.

6. The presence of federal lands affects energy projects and infrastructure deployment across the West. Planning, permitting, and siting energy generating assets and transmission and pipeline infrastructure can require close coordination between states, private developers, utilities, and one or more federal agencies. Western Governors are committed to working with federal agencies to create an effective state-federal partnership in energy development, land management, and environmental protection.

7. Western energy production is indispensable to meeting national energy demands. Because of this, the West is in a strong position to lead the development of energy systems that make the best use of land and resources and balance technical, economic, environmental and cultural considerations. The West provides a diverse range of energy resources:

   a. Western states have the vast majority of high-yield geothermal energy capacity in the United States.

b. Western states supply the majority of non-federal United States petroleum.

c. Western states are at the forefront of unconventional natural gas production and produce the majority of the nation's natural gas. Natural gas currently accounts for approximately 40 percent of the nation's electricity generation mix.

d. The West produces the largest output of hydropower in the nation.

e. Western states have the largest contiguous areas of land-based wind power resources in the nation and have over two-thirds of the nation's installed capacity. In addition, the Pacific Ocean offers some of the best offshore wind resources in U.S. waters.

f. The West has some of the highest-identified solar energy resource areas in the country and the majority of installed solar capacity.

g. Western states produce the largest portion of coal in the United States.

h. The West has the largest contiguous areas of high-yield biomass energy resource potential in the nation.

i. Western states are uniquely situated to produce low carbon intensity, clean hydrogen to facilitate greater economic development and decarbonization efforts.

j. Western states have conventional nuclear power generation facilities, produce all domestic uranium, and are at the forefront of advanced nuclear reactor technology development.

8. Western states are also leading the way in the development and deployment of innovative energy storage technologies. Utilities across the West have installed a range of battery technologies to improve grid function, flexibility, and resilience.

9. Western states and Pacific territories have the resources to drive job creation and economic development through broad growth in the energy industry.

10. The Merchant Marine Act of 1920 has prevented certain noncontiguous states and territories from being supplied with domestically produced energy commodities.

B. GOVERNORS' POLICY STATEMENT

Governors' Energy Priorities

1. Western Governors recognize the following as energy policy priorities for the West:

    a. Secure the United States' energy supply and systems, and safeguard against risks to cybersecurity and physical security.

    b. Ensure energy is clean, affordable, equitable, and reliable by providing a balanced portfolio of resources.

c. Increase energy efficiency associated with electricity, natural gas, and other energy sources and uses to enhance energy affordability and to effectively meet environmental goals.

d. Advance efficient environmental review, siting, and permitting processes that facilitate clean energy development and the improvement and construction of necessary energy infrastructure, while ensuring environmental and natural resource protection.

e. Improve the United States' electric grid's reliability and resiliency.

f. Protect western wildlife, natural resources, and the environment, including clean air and clean water, and reduce greenhouse gas emissions.

g. Make the West a leader in energy education, technology development, research, and innovation.

h. Utilize an all-of-the-above approach to energy development and use in the West, while protecting the environment, wildlife, and natural resources, and reducing emissions.

Grid Modernization and Resilience

2. A robust, resilient, and well-maintained energy delivery system is vital to the economy and quality of life in the West. Grid infrastructure in the West faces potential disruptions due to natural disasters, particularly wildfires, as well as growing cyber threat landscape. Increased grid threats due to wildfires and extreme weather events highlight the need to use and develop energy systems that are both reliable and combat climate change. Upgrades to transmission and distribution infrastructure, including information technology systems, are needed to properly address these risk factors, as well as anticipated increased electricity demand. Coordination between electricity providers and states in energy markets can lead to cost-effective energy for ratepayers and leverage regional resources.

3. Transmission infrastructure in western states often crosses one or multiple federal lands jurisdictions. In these situations, close coordination between states, utilities, and federal agencies is needed to ensure that projects are planned, permitted, and sited in a timely, efficient manner. Western Governors encourage federal agencies to streamline project-permitting reviews to minimize timelines without compromising environmental and natural resource protection or states' roles in those processes.

4. Western Governors encourage Congress to provide federal agencies, particularly the Bureau of Land Management (BLM), the Environmental Protection Agency, the Department of Energy (DOE), the Federal Energy Regulatory Commission, U.S. Forest Service (USFS), Bureau of Ocean Energy Management, and U.S. Fish and Wildlife Service with additional support to enhance staff and resource capacity to conduct environmental review and permitting activities associated with transmission infrastructure.

5. Western Governors recommend federal agencies leverage designated West-wide Energy Corridors to support the effective and efficient permitting and siting of energy infrastructure assets. Where applicable, Western Governors encourage the BLM and USFS to integrate designated corridor specifications into local land use plans.

6. Western Governors believe clear, coordinated and consistent wildfire mitigation strategies including application of federal vegetation management practices is integral to maintaining the health of western forests, preventing dangerous and damaging wildfires, and maintaining grid reliability. The Governors support effective and efficient cross-jurisdictional coordination that enables vegetation management for federal transmission rights-of-way.

Innovation and Technology

7. Western Governors encourage innovation and application of energy storage, including battery, hydrogen, pumped hydropower, and compressed air technologies, where cost-effective.

8. The U.S. has the opportunity to continue global leadership in carbon capture and storage (CCUS) research and technology development, while further deploying CCUS technologies, where cost-effective, that provide financial benefits to our nation's entire value chain.

9. The President and Congress should consider federal incentives to expand cost-effective deployment of carbon dioxide (CO_2) capture at power plants and other industrial sources.

10. Federal policies aimed to limit CO_2 emissions should promote, and not impede, development and deployment of CO_2 capture and commoditization. Federal regulations should allow states to create programs tailored to individual state needs, industries and economies and consider permanent CO_2 storage that results from enhanced oil recovery in meeting federal regulatory objectives.

11. Western Governors are committed to considering advanced and small modular reactors as an energy resource.

12. Western Governors are committed to developing regional hydrogen hubs to spur economic development and add more clean energy sources to the region's resource mix.

13. The developing floating offshore wind industry presents a strong economic and sustainable energy generation opportunity for the West. Western states can work collectively, and in consultation with Tribal governments and in coordination with stakeholders, to address workforce, economic, infrastructure, social, environmental, and manufacturing challenges associated with offshore wind planning, siting, and deployment.

14. Western Governors commend efforts by the United States Geological Survey and state geological surveys to identify potential, critical minerals deposits for alternative energy technologies and other consumer products vital to modern society.

15. Governors also support development of emerging tools and technologies that address barriers to mineral supply chain reliability, including technologies that help recycle or reuse existing critical mineral resources for use in electric vehicles and other clean energy technologies.

16. Western Governors are committed to leveraging the vast expertise in the West's industry, academic institutions, and national laboratories to make the region an international hub for new energy technology research and development, as well as energy education.

17. Western Governors encourage Congress and DOE to support and fund research, development, demonstration, and deployment of advanced energy technologies.

18. Western Governors support the creation of public-private research and development partnerships among industry, academia, the national labs, and federal agencies to identify promising new technologies, including energy efficiency technologies that advance clean energy with reduced environmental impacts.

Economic and Workforce Development

19. Western Governors and states are committed to encouraging training and education in energy-related fields and ensuring there is an adequate workforce operating under the highest safety standards.

20. Many western states and communities have been affected by localized job losses due to changes in the energy sector and the closure of coal power plants. Western Governors and states are working diligently to facilitate the creation of employment opportunities for displaced energy sector workers.

21. Western Governors offer their support for the U.S. Department of Agriculture (USDA) Rural Energy for America program, which has benefited farmers, ranchers and rural businesses that are often underserved by other federal energy efforts.

22. Western Governors support funding and long-term authorization for the State Energy Program (SEP), Weatherization Assistance Program (WAP), and Low-Income Home Energy Assistance Program (LIHEAP).

23. Western Governors support legislative measures that promote flexibility for rural electric cooperatives to refinance or adjust loans secured through the USDA Rural Utilities Service.

24. Western Governors support increasing the development and use of energy storage and low- and zero-emissions vehicles and associated infrastructure. WGA's Electric Vehicles Roadmap Initiative Report provides valuable insights on strategies to effectively integrate electric vehicle charging equipment with local grid infrastructure.

25. Western Governors call on the federal government to lift a barrier to domestic free trade between the contiguous United States and the noncontiguous states and territories by the Merchant Marine Act of 1920 by allowing those jurisdictions to receive energy commodities produced in the mainland but transported by foreign vessels, should those jurisdictions, and the jurisdictions whose ports are being used to ship these materials, desire it.

26. Redundant federal regulation of energy development, transport, and use is not required where sufficient state or territorial regulations exist. Existing state authority should not be replaced or impeded by Congress or federal agencies. Where additional regulations are necessary, federal agencies should consult and coordinate with states and tribes to ensure collaboration and understanding of unique circumstances within individual states and tribal nations.

C. GOVERNORS' MANAGEMENT DIRECTIVE

1. The Governors direct WGA staff to work with congressional committees of jurisdiction, the Executive Branch, and other entities, where appropriate, to achieve the objectives of this resolution.

2. Furthermore, the Governors direct WGA staff to consult with the Staff Advisory Council regarding its efforts to realize the objectives of this resolution and to keep the Governors apprised of its progress in this regard.

This resolution will expire in December 2024. Western Governors enact new policy resolutions and amend existing resolutions on a semiannual basis. Please consult http://www.westgov.org/resolutions for the most current copy of a resolution and a list of all current WGA policy resolutions.


WESTERN
GOVERNORS'
ASSOCIATION
The Heat
Beneath Our Feet
The Initiative of Colorado Governor Jared Polis

Dear Friends and Colleagues,

When I was elected as Chair of Western Governors' Association by my colleagues, I knew that I wanted to choose an initiative with the potential to improve the lives of all Westerners. That is why I worked with Western Governors' Association to launch the Heat Beneath Our Feet initiative, which is taking a bold and bipartisan approach to advance the development and deployment of geothermal energy. Jump-starting the adoption of geothermal energy technologies can create new opportunities to boost local economies; provide low-cost, reliable power, heating, and cooling to communities; and assist in meeting our renewable energy and energy security goals.

As we move towards true energy independence, the environmental benefits of geothermal energy generation can help position the West for further economic, environmental, and quality of life success. While eliminating almost all emissions compared to traditional energy sources, geothermal resources do not sacrifice reliability and can generate much needed baseload power.

The West is uniquely situated to take advantage of this energy source. While the United States accounts for 25 percent of the world's installed geothermal energy capacity, western states contain fully 95 percent of that capacity. Geothermal energy holds the potential to create jobs and provide reliable, low-cost domestic and secure energy. Consumers also benefit from direct applications of geothermal energy. Geothermal heat pumps are estimated to use 25 to 50 percent less energy than conventional heating or cooling systems, saving people money.

The Heat Beneath Our Feet initiative evaluated strategies to scale geothermal technologies across the West. Factors such as available geothermal resources, differing energy policy landscapes, workforce maturity, and emerging technologies were taken into account when compiling this report. The recommendations contained within this report were generated through a rigorous stakeholder process and vetted by subject matter experts over the course of the initiative.

In true western fashion, businesses have embraced the entrepreneurial spirit and are growing the geothermal sector into a robust economic generator. Colorado is joined by other western states in working to ensure that these companies have our support on the front lines of geothermal innovation.

I would like to extend my gratitude to all our state, academic, industry, and federal partners, including the U.S. Department of Energy, as well as to our initiative sponsors who contributed their time and expertise to this initiative's workshops, webinars, and podcasts. I look forward to continuing to work with them to advance the development and deployment of geothermal energy to successfully tap the heat beneath our feet.

Sincerely,

Jared Polis
Governor of Colorado
WGA Chair

Greetings Friends of the West,

Very few know what it takes to provide reliable and affordable energy to millions of people, but you can be certain to count Western Governors among them. The West has long been a leader in American energy production and leads the nation in the new frontiers of clean renewable energy development. It is no surprise that Western Governors are at the forefront again, this time with geothermal.

Beginning in July of 2022, WGA Chair and Governor of Colorado Jared Polis launched his Heat Beneath Our Feet initiative aimed at exploring opportunities to accelerate the development of geothermal resources. As a result, WGA convened stakeholders from public, private, and non-profit organizations to drill down to the issues holding back the expansion of geothermal energy in the West.

We are grateful to those who participated in our series of work sessions, webinars, and podcasts held throughout the year. Their enthusiasm was matched by the support of Governors who hosted initiative tours and work sessions, including former Governor David Ige of Hawaii, Governor Brad Little of Idaho, Governor Spencer Cox of Utah, and Governor Polis.

As geothermal is having a moment on the national stage, attracting the attention of policymakers at all levels of government, this report can be used by any stakeholder interested in learning about the potential of geothermal energy in the West and how its development can be supported. If the level of engagement from members of the geothermal community is any indication, this resource has a bright future.

If you have followed WGA's previous chair initiatives, you know they provide a rare venue for pragmatic, bipartisan policy discussions that lead to meaningful solutions. The effectiveness of past initiatives is evidenced by the support we received from Governors throughout the West to complete the work needed for this final report. It is also a testament to my predecessor, Jim Ogsbury, who saw nine Chair initiatives across the the finish line over the past ten years and set us up for success on Heat Beneath Our Feet.

I would like to extend my gratitude to Governor Polis for his leadership as WGA Chair over this past year – WGA would not exist without Governors, year after year, taking up the mantle to lead our organization. Further, the support we received from our sponsor community and stakeholders for this endeavor was immense and appreciated beyond measure. Our work on this initiative would not have been possible without them.

Sincerely,

Jack Waldorf
Executive Director
Western Governors' Association

EXECUTIVE SUMMARY

Colorado Governor Jared Polis, Chair of the Western Governors' Association (WGA), launched The Heat Beneath Our Feet initiative in 2022 to examine opportunities for and barriers to the accelerated development and deployment of geothermal energy technologies. The potential of geothermal energy in the West is vast, and offers significant advantages and benefits in efforts to expand the portfolio of renewable energy resources. Advances in technology and increased interest in developing domestic sources of low-cost, reliable, clean energy have brought greater attention to the energy potential of the heat beneath our feet.

Beneath Boise's City Hall lies an intricate network of pipes that act as a heat exchanger for the city's geothermal district heating systems. Idaho workshop participants toured the mechanical room at City Hall to view the infrastructure.

The initiative examined the various market, technology, and policy factors that affect the development of geothermal resources. Through a rigorous stakeholder process that included four workshops, six tours, a public survey, and a webinar series, the Heat Beneath Our Feet initiative generated recommendations for increasing the development and deployment of geothermal energy in the West including:

- **Improve resource assessment and data collection:** Increasing federal funding for resource assessments, coordinating efforts to target areas with the greatest potential, improving the federal repository of data relevant to geothermal development, and leveraging data from the oil and gas industry, as well as new technology, will increase our understanding of subsurface resources and foster additional geothermal development.
- **Mitigate risk in drilling and exploration:** Risk and uncertainty contribute to relatively high up-front costs for geothermal development. Those costs can be abated by continuing federal investment to reduce uncertainty in geothermal exploration, exploring models to help developers secure financing for exploratory drilling and mitigate drilling risk, and extending existing tax incentives for the oil and gas industry to include geothermal development.
- **Optimize permitting and improve regulatory certainty:** Permitting timelines can also be prohibitive for geothermal development. Lengthy delays can be mitigated by providing tools and resources to help stakeholders navigate the geothermal development process, increasing agency capacity for leasing and permitting, developing streamlined processes and categorical exclusions for geothermal leasing on par with other energy categories, expanding oil and gas exploration regulatory efficiencies to geothermal development, and collaborating with tribes and communities prior to and during project development.
- **Expand funding opportunities:** U.S. Department of Energy (DOE) funding for demonstration projects and the Geothermal Technologies Office (GTO) should be increased. Investment in energy transition communities should be encouraged.
- **Implement incentives for consumer adoption:** Expedite the deployment of tax incentives, rebates, and end-user applications to spur the adoption of geothermal heating and cooling.
- **Develop workforce and contractor ecosystem:** Geothermal energy can generate good jobs and create opportunities for workers and communities affected by the energy transition. Workforce development in the geothermal industry should be supported, including through the development of training and certification programs.
- **Increase awareness and education to develop geothermal markets:** Develop guidance for policymakers, regulators, and utilities to better promote geothermal energy.

The Heat Beneath Our Feet initiative report is a resource for policymakers and stakeholders. Initiative recommendations can assist in accelerating geothermal technologies, which can play a significant role in meeting the West's energy needs for a clean and sustainable future.

Background

Geothermal energy is a valuable but remarkably untapped resource in the West. The heat stored within the Earth can support a wide spectrum of end uses, including reliable, domestic, and renewable electricity generation for the grid, renewable building heating and cooling, underground thermal energy storage, and other direct use applications for agriculture, recreation, and industry. Advances in technology and increased interest in developing domestic sources of reliable, clean energy have brought greater attention to the underutilized potential of this ubiquitous energy resource.

Western states pioneered the development of geothermal technology and contain the vast majority of working geothermal resources in the United States. In the 1890s, Boise, Idaho, established the nation's first geothermal heating district, providing heat to residential and commercial buildings. Today, Boise's geothermal heating district, including the original Warm Springs Water District, is the largest in the nation, heating over six million square feet – including the Idaho State Capitol. The West pioneered the use of geothermal energy to generate electricity, too. The first geothermal electrical generation unit in the western hemisphere was constructed in California in 1960. The Geysers geothermal field is now the largest in the world, with a net generation capacity of more than 800 megawatts of electricity.[1]

Responsible development of geothermal power can address several critical needs for future U.S. energy demands. It is a domestic energy source, has a small surface footprint, and produces close to zero carbon and other air emissions, making it a clean and sustainable energy resource. Additionally, geothermal resources are always available, providing stability to the electric grid.

Passive geothermal energy can also address one of the biggest categories of energy use: building heating and cooling. Heating and cooling are the largest annual uses of electricity in the residential sector, accounting for more than 40 percent of an average home's electricity use.[4] Currently, natural gas is the primary heating fuel in much of the West. While natural gas prices can fluctuate based on market conditions, global events, and weather, the

Grid Stability Through Dispatchable Energy

Geothermal electricity generation provides consistent, reliable power. Geothermal power plants can have a capacity factor of 90 percent or higher, meaning that they operate at their maximum output level 90 percent of the time.[2]

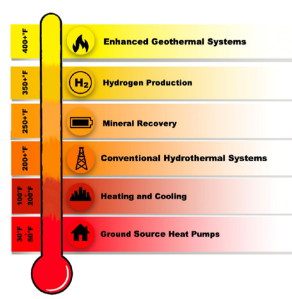
Geothermal power can also be dispatchable, meaning that electricity production can vary (ramp up or down) as needed. Dispatchable energy is an important complement to renewable resources that have more variable generation. As the West continues to decarbonize energy systems with variable sources of renewable power such as wind and solar, geothermal can balance these sources and ensure reliability in the system.

Compared to more traditional dispatchable energy sources like natural gas, the environmental impacts (e.g., land use footprint, greenhouse gas emissions, and air pollutants) of modern geothermal power plants are negligible. The surface footprint per GWh of electricity is smaller than coal, solar, or wind.[3]

Geothermal Energy 101

Geothermal energy is the thermal energy generated from natural geological processes and radioactive material decaying in the Earth's crust. In general, the temperature increases at an average background thermal gradient around 86 degrees Fahrenheit per kilometer (though portions of the West exhibit a higher-than-average geothermal gradient). The range of temperatures of geothermal resources can be harnessed for different purposes.

At relatively shallow depths - a couple of feet to a couple hundred feet - subsurface temperatures are stable year-round and are typically similar to room temperature and can be used for heating in winter and cooling in summer. Deeper wells extending thousands of feet below the surface can intersect natural or enhanced geothermal reservoirs with much hotter temperatures to support electricity generation.



Preparing for drilling at the Puna Geothermal Venture, operated by Ormat Technologies Inc. The exploration and drilling phases often bring the highest risk for failure and the most cost to geothermal development.

costs of heating and cooling with geothermal are far more consistent. By harnessing the steady temperature of the Earth, geothermal systems can displace most of the energy needed to heat and cool buildings.

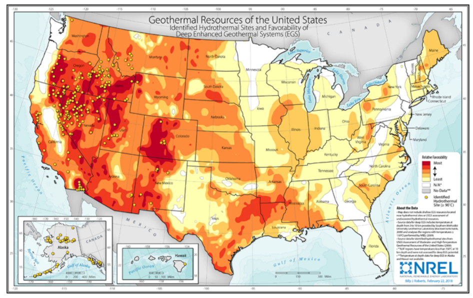
Opportunities to utilize passive geothermal energy for heating and cooling, electricity generation, and certain industrial, recreational, and agricultural applications have vastly expanded since the development of the early examples noted above. Yet despite the many benefits geothermal energy offers, it still accounts for only 0.4 percent of electrical generation in the United States and is not yet widely utilized at scale for heating and cooling applications.[5] Advancements in subsurface technologies from the oil and gas industry over the last two decades are improving the feasibility of geothermal systems. Expertise, efficiency, and safety practices in horizontal drilling and hydraulic fracturing have opened new possibilities for where geothermal developments can be located.

Geothermal is attracting the attention of policymakers at all levels of government.[6] Since WGA began work on this initiative, Congress has passed significant tax incentives for geothermal projects, DOE has committed hundreds of millions of dollars through the Energy Earthshots Initiative to research and develop geothermal energy, and states have begun to implement their own geothermal policies.

In 2019, DOE published GeoVision, an in-depth technical analysis detailing the vast potential for geothermal energy development in the United States. A comprehensive report on the current status of geothermal deployment is provided in the National Renewable Energy Laboratory (NREL) publication, 2021 U.S. Geothermal Power Production and District Heating Market Report.[7] The initiative toured geothermal sites in four states - Colorado, Utah, Hawaii, and Idaho - but geothermal energy is utilized throughout the West; examples of geothermal development in every western state and territory are included in the case studies section.

Geothermal Potential in the West

Geothermal energy can be used for a range of applications depending on the temperature and characteristics of the resource. Technological advancements are continually expanding the bounds of where and how geothermal energy can be harnessed cost effectively. Generally, high temperatures are needed to generate electricity, while lower temperatures can be utilized for industrial processes (e.g., agriculture) or building heating and cooling.



"This map depicts the potential for development of hydrothermal and EGS systems in the United States as of 2018. Further analyses, including the DOE's 2019 GeoVision report and NREL's 2023 Enhanced Geothermal Shot Analysis, modeled the associated potential electricity capacity. The 2023 analysis concluded that the United States potentially has 90.5 gigawatts of electricity capacity that could be deployed by 2050, mostly in the West, including over 80 gigawatts from enhanced geothermal system deployment after 2030. This is more capacity than the entire U.S. nuclear fleet in 2021.

Figure courtesy of the National Renewable Energy Laboratory.

Electricity Generation

Geothermal power plants utilize conventional hydrothermal reservoirs as well as emerging enhanced geothermal system reservoirs to produce geothermal fluids for power generation across a few differing power plant configurations (e.g., dry steam, flash, binary cycle). Produced fluids are reinjected to the subsurface reservoir after heat has been extracted. Additionally, modular binary power plant units, which use a heat exchanger with a working fluid with a lower boiling point, are an emerging technology area for coproduction from oil and gas wells. A comprehensive description of geothermal technologies and power plant configurations is available in the DOE GeoVision report.

Most geothermal power plants in use today utilize conventional hydrothermal resources, which are sources of naturally occurring hot water found at variable depths in the subsurface. Hydrothermal resources require a heat source, a fluid source (usually deeply circulating groundwater), and permeable pathways in Earth's crust allowing for fluid circulation (open faults, open fractures, and/or interconnected pore spaces in rocks). Hydrothermal resources are primarily found in western states, where geologic conditions cause naturally elevated heat flow and permeable pathways.

You may have experienced hydrothermal yourself: hot springs and geysers are expressions of underground hydrothermal systems and can aid in their identification, but many hydrothermal resources have no surface expression and are therefore more challenging to identify. These "hidden" systems hold significant potential in the West: The United States Geological Survey (USGS) estimates that the United States holds 23,038 megawatts of electricity of undiscovered hydrothermal resources compared to 5,128 megawatts of electricity already discovered.[8] Hidden hydrothermal systems are sometimes inadvertently discovered through mining exploration.

When a hydrothermal system is discovered, it must be characterized, usually by drilling test wells, to determine if enough heat, water, and permeability are present to produce cost-effective electricity. The investment necessary to characterize a system and deem it a viable resource can carry significant risk. As a result, an average of only 13.6 wells were drilled per year from 2015 through 2019.[9]

In locations throughout the West, there is sufficient subsurface heat, but water and permeability are often lacking. Enhanced geothermal systems (EGS) use advancements from the oil and gas industry, such as directional drilling and hydraulic fracturing, to engineer the necessary subsurface reservoirs to create permeability. This, combined with advancements in drilling technology, now allow for geothermal developers to potentially access resources beyond conventional hydrothermal systems, increasing the availability and locations of geothermal electricity resources.

To create EGS projects, a production-

injection well is drilled into hot, dry rock with limited permeability and fluid content. Water is injected at high pressure to create or improve fractures within the rock to create a reservoir, then a second production well is drilled to intersect the fracture system and extract the heat from the rock mass. Additional production wells may then be drilled to meet power generation requirements.

EGS is not yet cost-competitive and technical challenges remain,[10] but the DOE Energy Earthshots Initiative has set a goal of reducing the cost of EGS to $45 MWh by 2035, in the same range as onshore wind today.[11] Research and development are underway to advance the commercial viability of EGS, most notably at the DOE-funded Frontier Observatory for Research in Geothermal Energy (FORGE) in Milford, Utah. This is complemented by other investments into research and development by DOE, such as the Geothermal Limitless Approach to Drilling Efficiencies (GLADE) project in Colorado. GLADE is exploring drilling deeper and faster by using existing and novel drilling technologies to reduce the cost of developing geothermal wells.

Additional advancements in technology could further broaden the utilization of geothermal energy. Closed-loop geothermal systems extract heat through sealed wells which recirculate the geothermal fluid, eliminating the loss of fluid to the surrounding formation. While this type of system is not yet commercial, closed-loop systems have significant potential and, if successful, advantages over other technologies since the type of fluid could potentially be changed from water to a more efficient heat transfer medium, such as supercritical carbon dioxide. Additionally, closed-loop systems may reduce environmental impacts and risk since fluid is not injected into underground reservoirs.

Co-production and conversion of oil and gas wells are also areas of potential growth. In co-production, hot water produced by oil and gas extraction is used to generate electricity. Converting orphaned oil and gas wells to geothermal production is also possible. Given the rising trend of the electrification of drilling rigs in the oil and gas industry, many wells are also co-located with transmission. The intersection of oil and gas electrification with the potential for end-of-life conversion to geothermal electricity is an important consideration when weighing if and when to cap wells at end of life.

Heating and Cooling

Geothermal heating and cooling applications leverage the shallow subsurface as a heat source and sink, using a variety of system configurations for space conditioning of buildings. These configurations include direct use of geothermal fluid extracted from a subsurface reservoir, closed-loop vertical borehole field ground heat exchanger, standing column wells, surface water ground loops, and horizontal slinky systems, among others.

Heating and cooling applications of geothermal energy utilize much lower temperatures than electricity generation. These technologies rely on either the constant temperatures in Earth's crust for heat exchange (geo-exchange, or heating/cooling via geothermal heat pumps), or shallow subsurface geothermal heat for direct use. Direct use applications use hot water from a hydrothermal resource piped to a building, greenhouse, or industrial facility.

Heat pumps use electricity to move heat from one area to another and have been used for over a century. Geothermal heat pumps, also called ground source heat pumps (GSHP) harness the steady temperature of the Earth at depths as shallow as 10 feet, which is warm relative to the air in winter and cool relative to the air in summer. GSHPs save the average homeowner money by using 25-50 percent less electricity than a conventional heating system, as they are able to move more heat than the direct electricity input.[12]

Direct use can be scaled up to serve multiple buildings in a district or community in what is called a district heating system. The largest and oldest heating district in the country is located in Boise, Idaho, and has been operational since 1893. Geothermal water is pumped from a well in the Boise Foothills and runs downtown through a pipe system to retain water heat. Water is then pumped through a heat exchanger that cools the effluent and the energy is used to heat buildings. There are 23 active geothermal heating districts in the U.S., all of which are located in western states.

GSHP technology can be used to heat and cool buildings of any size or across

Heating Efficiency

Heat pump technology is more efficient than traditional heating systems because it uses the existing heat in the ground or air, saving consumers money and helping reduce carbon footprint. An air-source heat pump uses the ambient temperature of the outside air to provide heating or cooling to a building. A GSHP takes advantage of the constant underground temperatures (about 55 degrees Fahrenheit), allowing it to run efficiently year-round regardless of weather conditions.

This high level of efficiency can help balance utility electric grid capacity as buildings electrify their heating and cooling, with some research showing even higher efficiency gains for networked geothermal systems or thermal energy networks. For example, electric resistance heating produces approximately one unit of heat per one unit of electricity, while GSHPs may produce (i.e., move) three or four units of heat for each input of electricity. While direct use requires a hydrothermal or EGS resource, GSHPs can be utilized anywhere with the installation of a ground heat exchanger.

multiple buildings on a distribution network in what is called a geo-exchange system. A networked series of pipes circulate a working fluid to absorb or release heat, using a ground loop as a renewable heat source in the winter and a heat sink in the summer. These systems are highly efficient and can provide significant cost savings, making it a compelling option for universities, campuses, and large buildings like stadiums. After converting its campus to a geothermal heating and cooling system in 2008, Colorado Mesa University in Grand Junction, Colorado, reported an annual savings of over $1.5 million. In 2022, those savings went directly toward reducing student tuition by two percent.

To achieve an even larger scale, heat pumps can be integrated into thermal energy networks, which are utility-scale infrastructure projects that connect multiple buildings, neighborhoods, or subdevelopments into a shared network with sources of thermal energy. Rather than each building needing its own borehole, multiple buildings in a network can share the same thermal sources. Thermal energy networks can allow utilities to manage and operate geothermal systems for heating and cooling.

The drill at Utah FORGE, which is currently drilling a 10,000-foot-deep geothermal well to test Enhanced Geothermal Systems.

Additional Applications of Geothermal Energy

Geologic Thermal Energy Storage: Underground rock formations can be used to store energy over long periods. Excess energy can be captured and stored underground as thermal energy and then recovered and utilized when needed. This storage method can complement energy resources with higher variability to store for peak demand.

Hydrogen Production: Utilizing geothermal electricity production to power electrolysis of water to produce hydrogen creates "green hydrogen," a renewable, clean fuel source with little to no carbon footprint at the point of production.

Operating electrolyzers powered with geothermal energy consistently can reduce the cost of hydrogen production on a per unit basis. While other renewable energy sources such as wind or solar have variable production, colocation of geothermal electricity with hydrogen production could lower production costs and eliminate the need to build transmission to connect electrolyzers to the grid or distributed energy sources.

Mineral Extraction: Geothermal brines can contain a variety of dissolved minerals and salts, such as lithium. Lithium extraction from geothermal brines is an active area of research, particularly at the Salton Sea geothermal field in southern California. This technology makes geothermal a potential domestic source for the production of some critical minerals.

Direct Air Capture (DAC): Direct air capture is the process of moving air over material that captures carbon dioxide from the atmosphere, which then can be injected into the subsurface for permanent storage or utilized for a variety of industrial processes. Solid system direct air capture requires temperatures ranging from 176-248 degrees Fahrenheit (80-120 degrees Celsius) and a reliable source of electricity, both of which can be provided by geothermal energy systems. Additional research on the potential synergy between direct air capture and geothermal energy systems could provide viable technology to address carbon capture needs potentially at much lower operating costs than other approaches to powering DAC.

Recommendations

The Western Governors' *Heat Beneath Our Feet initiative*, under the leadership of WGA Chair, Colorado **Governor Jared Polis**, examined the various market, technology, regulatory, and policy factors that affect the development of geothermal resources and evaluated strategies to accelerate the deployment of geothermal technologies across the West. WGA conducted a rigorous stakeholder process, engaging with over 500 stakeholders through an online survey, tours, work sessions, and a webinar series.

These discussions with energy experts, state and federal agencies, and other stakeholders brought together a wide array of perspectives. Their expertise and input are reflected in the policy recommendations included in this section. Recommendations are organized into three categories based on the type of geothermal resource and use they apply to: electricity generation, heating and cooling, and market development and transition opportunities.

Electricity Generation

Improve Resource Assessment and Data Collection

A significant barrier to the development of new geothermal electricity generation projects is the upfront cost and risk. De-risking geothermal projects can result in much lower costs. Much of the immediate potential for electricity generation in western states is in the development of conventional hydrothermal resources without surface features. Since electricity generation depends on site-specific factors like the subsurface heat and permeability of the rock, even when a hydrothermal resource is found there is no guarantee development will succeed. Existing technologies and exploration methods can also estimate where they may occur, but with low reliability. Innovative exploration methods and improved data are needed to better image the subsurface and improve prospecting for these types of resources.

Recommendation:
Increase federal funding for resource assessments.

Better data and the development of regional resource assessments can increase the rate of exploration success. At the federal level, USGS is responsible for mapping and assessing energy and mineral resources, including national-scale geothermal resource assessments. This data can be used to develop models, analyses and decision-making tools for geothermal resource targeting.

Geothermal resource identification requires relatively granular data, which is lacking in much of the West and both costly and time consuming to collect. USGS, in partnership with DOE's GTO, is pursuing several projects to collect data at the needed scales across the West.

GTO led an initiative from 2015 to 2020 to develop a Play Fairway Analysis (PFA) for geothermal resource assessments. A PFA is a data mapping method adopted from the oil and gas industry to create a geostatistical map of probable geothermal resources. Assessments are conducted at a basin or regional scale. Further federal development or support of PFA mapping initiatives to assess geothermal resources would assist in the siting of geothermal projects.

Congress should provide USGS and DOE with funding to increase the pace and scale of data collection, mapping and resource assessments and facilitate collaboration with state geological surveys. DOE should also leverage synergies with other programs, such as USGS's Earth Mapping Resources Initiative (MRI) that are complementary efforts and in which states are already partners, to expedite efforts to assess geothermal resources. Large scale mapping and data collection can benefit from significant economies of scale and generate far greater return than a hit or miss approach from private funding sources that would add to project costs.

Recommendation: Coordinate with states to target areas with greatest potential.

Partnership with states and state geological surveys is critical, both to identify areas with the highest potential for geothermal development across a range of factors, and to leverage relevant data states already possess. States serve a critical function as primary sources and stewards of geospatial, scientific, and technical datasets that support the development of renewable energy resources. State geological surveys should have the opportunity to provide input and recommendations on where USGS and GTO prioritize resource assessment efforts in their states.

Recommendation: Improve the federal repository of relevant geothermal development data and the ability to interact with it.

When siting projects, geothermal developers consider multiple factors such as heat gradients, grid capacity, transmission, and environmental justice. The federal geothermal data repository should seek to incorporate data relevant to those factors, such as mapping overlays of critical habitat for endangered species, hydrological data, and existing transmission capacity. These resources, while not all directly related to geothermal development, capture unique aspects of regional and basin specific landscapes and other characteristics that affect the siting and deployment of geothermal projects. This data will allow for locations ideal for the siting of geothermal development to be more easily located. This federal repository could build on NREL's Geothermal Prospector and should be publicly available and easily accessible online.

Recommendation: Leverage data from the oil and gas industry.

The oil and gas industry and the mining industry are natural partners in the development and deployment of geothermal technology and resources. Both industries rely heavily on subsurface expertise that could help reduce the exploration and drilling costs of the geothermal industry. These operators should be encouraged to share data from existing operations with geothermal developers. Further, public-private partnerships with DOE should be encouraged to reduce the cost of drilling for geothermal wells through project demonstration grants.

Governors can facilitate the collection of data from existing oil and gas wells and facilitate geothermal permitting under a similar structure as existing drilling. Orphaned oil and gas wells under the state's control or directive could be used to collect temperature gradient data or could even be converted into a geothermal resource. Developing and sharing, in an open call for collaboration, an inventory of orphaned wells could save states the cost of plugging wells and reduce exploration and drilling costs to geothermal developers.

Mitigate Risk in Drilling and Exploration

While Play Fairway Analysis mapping provides a good estimate of where geothermal resources may be located, subsurface activities are needed to confirm their presence. Often requiring drilling, the confirmation of viable resources can cost millions of dollars without the promise of success. This risk drives up the cost of financing geothermal developments. Federal agencies should consider reducing risk in this phase of development through support for technological advancements, insurance, tax incentives, and regulatory improvements.

Recommendation: Continue federal investment in reducing uncertainty in geothermal exploration.

In 2020, DOE launched the Hidden Systems Initiative to provide grants for the research and development of innovative subsurface technologies. Research and development from these grants could tailor drilling technologies to geothermal resources and provide useful geological data, both of which help minimize the financial risk of confirming a resource. Congress should extend authorization and increase funding for the Hidden Systems Initiative.

Recommendation: Explore models to help developers secure financing for exploratory drilling.

The high risk and high upfront cost of geothermal development resulting from uncertainty in the viability of resources is a significant barrier to the industry's growth. To offset some of the risk and encourage investment, DOE offered several programs from the late 1970s

Governors Jared Polis and Spencer Cox with join the team from Cyrq Energy at its Thermo Geothermal Power Plant in Utah.

to the late 1980s. One of those programs was the User-Coupled Confirmation Drilling Program (UCDP) cost-sharing grant, through which a developer paid 80 percent of the cost if a project was successful and only 10 percent if the resource did not prove to be viable. The U.S. experienced the most growth in geothermal power capacity during the period this program was offered.

Globally, programs to mitigate the upfront risk of geothermal development, such as guaranteed loans and public financing, are common. European markets have addressed this challenge by offering insurance for geothermal exploratory drilling. In the U.S., there are currently limited programs at the federal level to help geothermal developers get past the high-risk early stages of development. DOE should explore the feasibility of cost share programs, such as guaranteed loans, insurance, and grants, and assess the effect these mechanisms would have on the geothermal industry.

Recommendation: Extend existing tax incentives for the oil and gas industries to geothermal development.

Despite the similarity of exploration activities in the geothermal and oil and gas industry, some regulatory and tax incentives that currently apply to exploratory wells drilled for oil and gas do not apply to geothermal exploration. Oil and gas companies can deduct intangible drilling costs, defined as costs related to drilling that have no salvageable value, from their income tax. Congress should extend this tax treatment to the geothermal industry.

Optimize Permitting and Improve Regulatory Certainty

Difficulty navigating the permitting process can also hinder geothermal development. Opportunities exist to optimize those processes that could result in shorter development timelines, thereby reducing costs for developers and encouraging more exploration and discovery of geothermal resources.

Advancements in geothermal drilling technology, such as those developed at Utah FORGE, are increasing the rate of drill penetration and reducing the cost of developing geothermal wells.

Many geothermal resources are located on federal lands managed by the Bureau of Land Management (BLM) and U.S. Forest Service (USFS). Timelines for permitting approval can include up to six separate environmental reviews, which typically can require seven to ten years to complete. Regulations also vary by state and by the type of geothermal development. Efficient permitting and a clear and consistent regulatory environment would help foster the geothermal industry.

Recommendation: Provide tools and resources to help proponents navigate the geothermal development process.

DOE should coordinate with states to maintain publicly available resources detailing the state and federal requirements that apply to geothermal development in each state. DOE's Regulatory and Permitting Information Desktop

(RAPID) toolkit is an excellent tool to provide easy access to federal and state permitting information and best practices. The RAPID toolkit should be updated to include all western states and maintained to ensure that it reflects up-to-date and accurate information.

Because the majority of geothermal resources in the West occur on BLM land, BLM should also ensure that relevant information and regulations are easily accessible to developers. BLM maintains a resource page for geothermal development, but more information on the conversion of oil and gas wells to geothermal development would be helpful, as would integration of BLM's information with DOE's RAPID toolkit.

Recommendation: Increase agency capacity for leasing and permitting.

BLM and USFS need adequate staffing and expertise at their local offices to approve and process geothermal lease nominations. Geothermal lease nominations for projects proposed on federal surface lands not managed by BLM must be approved by both agencies, meaning that both agencies must complete an environmental review process under the National Environmental Policy Act (NEPA). This process can take up to four years. While it is critical to conduct thorough and comprehensive environmental reviews, the length of that process can be affected by staffing shortages, competing priorities, and inexperience with geothermal development.

After leasing, geothermal projects require at least two subsequent NEPA reviews conducted by BLM for resource confirmation activities and utilization plans. Field offices with experience permitting geothermal development are generally more efficient and able to process permits more quickly than those that have not. These additional steps are above and beyond those generally required for similar activity on state, tribal, or private land and therefore largely exclude federal land from geothermal opportunities.

The Department of the Interior (DOI), USFS, and Congress should ensure that the relevant agencies are adequately staffed to review permits in a timely fashion. DOI and USFS should also ensure agency staff have access to technical experts to build staff expertise in geothermal development. A partnership with DOE's GTO should develop training materials, standard operating procedures, and provide technical support to field and district offices.

Recommendation: Develop streamlined processes for geothermal leasing on par with other energy categories.

In 2008, BLM and USFS released the Final Programmatic Environmental Impact Statement for Geothermal Leasing in the Western United States to facilitate decisions on geothermal lease applications. This remains an effective tool to help the agencies process lease nominations. As a next step, BLM should establish priority leasing areas for geothermal energy, as it has done for wind and solar energy in Instruction Memorandum No. 2022-027. Priority leasing areas should shorten development timelines for projects with the greatest technical and financial feasibility and the least anticipated natural and cultural resource conflicts on BLM-administered lands.

Cyrq Energy's Thermo Geothermal Power Plant, which sustainably produces power used in Anaheim, California.

Recommendation: Expand oil and gas exploration regulatory efficiencies to geothermal development.

Exploration in the oil and gas industry has benefited from Section 390 of The Energy Policy Act of 2005, which authorizes BLM to apply a categorical exclusion when approving exploratory drilling for oil and gas resources. Categorical exclusions apply to categories of activities that an agency has determined have no significant impact to the human environment and thus do not require an environmental assessment or environmental impact statement under NEPA. They can be an effective tool to streamline environmental review processes in specific circumstances defined by the agency. Congress should expand Section 390 to include geothermal exploration, which would allow agencies to use the existing categorical exclusion to facilitate increased geothermal exploration and the discovery of new resources without compromising environmental protections.

Recommendation: Fund research on the water usage of EGS.

Increasing the share of U.S. electricity produced from geothermal energy is not expected to increase the water demand of the power sector overall. Geothermal technologies do not require fresh water and can operate with brackish or even municipal wastewater – a significant benefit in the arid West. Water can also often be retained in a closed system. Air cooling and passive geothermal cooling also represent viable alternatives to water cooling in arid areas.

It is also critical to ensure the efficient use and protection of water resources for the development of EGS. DOE should fund water efficiency research as part of the Enhanced Geothermal Shot and related EGS efforts.

Lauren Boyd, the Acting Director of the Geothermal Technologies Office, addressed Governor Jared Polis and Alejandro Moreno, the Acting Assistant Secretary for Energy Efficiency and Renewable Energy, during an initiative workshop at the National Renewable Energy Laboratory in Golden, Colorado.

Recommendation: Collaborate with tribes and communities, including consultation prior to and during project development.

Geothermal resources can occur on tribal lands across the western United States. Even when these opportunities are not on tribal land, they can occur in areas with historical or cultural significance to tribes. Where relevant, it is important to consult tribes at the beginning of a potential geothermal project and ensure that the resource is developed in a way that does not damage sensitive historical and cultural resources. To help developers consider these factors in siting decisions, data layers incorporating the location of these resources should be included in federal geothermal repositories and considered in the development of priority leasing areas.

Expand Funding Opportunities

Improved data leading to higher confidence in locating resources and permitting process improvements that shorten development timelines will help reduce uncertainty and risk in geothermal development and make it more attractive to investors and capital markets.

Recommendation: Expand funding for demonstration projects.

Congress should expand funding for programs that support geothermal demonstration projects such as those under the DOE Loan Program Office's Title 17 Clean Energy Financing program. Further demonstration of geothermal projects could open market avenues for electrical generation and heating that spur private investment.

Congress should continue to fund the FORGE project and establish additional EGS demonstration projects in the West. The FORGE demonstration project is developing technologies and techniques necessary to commercialize EGS and build confidence in the industry.

Recommendation: Encourage development in energy transition communities.

The Inflation Reduction Act (Pub. L. 117–169) includes bonus credits for renewable energy development that occurs in energy communities, which are defined to include communities with substantial employment driven by the coal, power plants, and the oil and gas sector. This is an important provision to stimulate job creation and economic development in communities

Jon Gunnerson, the Geothermal Coordinator for the City of Boise, explains to workshop participants how the Boise Warm Spring Water District has expanded operations from heating just a handful of buildings in 1892 to now sustainably heating 6 million square feet of building space.

affected by the energy transition. Where the economic benefits are justified, DOE should target funding towards these communities for the conversion of existing oil and gas wells to geothermal energy as part of a just transition. Due to years of development in these areas, the local geology is well understood, thereby lowering the risks and costs associated with exploration. Areas with existing coal and natural gas power plants also have transmission infrastructure already in place.

Recommendation: Increase funding levels for the Geothermal Technologies Office.

The Energy Act of 2020 authorized funding for GTO at $170 million annually through Fiscal Year (FY) 2025. Appropriations in recent years have been significantly below the authorized level. In FY23, Congress appropriated $118 million for the office, the lowest level among DOE renewable energy offices. Congress should appropriate sufficient funds to the GTO to establish a strong research and development capability and to execute the recommendations contained in this report.

Heating and Cooling

Implement Incentives for Consumer Adoption

Home-, neighborhood-, and subdevelopment-level passive heating and cooling applications of geothermal energy are proven technologies that have been used in the West for over a century. The Inflation Reduction Act extended the 30 percent investment tax credit through 2032 for geothermal projects that meet prevailing wages and apprenticeship requirements. Project developers can receive up to an additional 20 percent if projects meet domestic content requirements and are located in energy communities. The efficient rollout of these programs to end-users is critical to the adoption of geothermal heating and cooling systems, including networked geo-exchange systems or thermal energy networks, and the following recommendation would assist in developing these underutilized assets.

Recommendation: Expedite the deployment of tax incentives, rebates, and end-user applications.

The Inflation Reduction Act both increased and expanded the tax credits and rebate program for the installation of geothermal heating systems. The Internal Revenue Service should move quickly to implement these programs so that consumers can begin taking advantage of them as soon as possible and define domestic content requirements in as expansive a manner as permissible under federal law.

Transitional Opportunities and Market Development

Growing the geothermal industry will create jobs and economic opportunity for workers across the West. Geothermal electricity generation creates long-term jobs in the operation of geothermal power plants and has a fully domestic supply chain, making these projects strong candidates for the full federal investment tax credit with opportunities for apprenticeship programs. The following recommendations would help develop the workforce needed to take advantage of geothermal energy potential and address the need for greater public awareness of the benefits of geothermal energy deployment.

Develop Workforce and Contractor Ecosystem

The initial phases of geothermal exploration and resource assessment are valuable job creators and utilize much of the same equipment, contractors, and expertise as the oil and gas industry. Heating and cooling also offer significant potential for job growth in manufacturing, design, installation, and maintenance. In both cases, the skills in demand are transferable across multiple sectors.

Amanda Kolker, the laboratory program manager for Geothermal at the National Renewable Energy Laboratory, discussed the benefits of geothermal energy during a WGA workshop at the facility in Golden, Colorado.

Recommendation: Create opportunities for workers and communities affected by the energy transition.

Since many of the skills and positions needed for geothermal energy development are highly transferable from the oil and gas industry and conventional power plant operations, there is an opportunity to target investment to communities that are experiencing the loss of jobs and economic activity due to the closure of power plants and other effects of the energy transition. As technology advances, it may even become possible to repurpose shuttered coal- or natural gas-fired power plants as geothermal power plants. Conversion of oil and gas wells could also provide transition opportunities to communities and workers affected by the energy transition. Congress should establish a mechanism within DOE that leverages existing expertise and relationships in the national labs to conduct education and workforce development. Congress and DOE, in conjunction with other federal agencies, should also consider opportunities to target these communities with resources and training, and collaborate with relevant trade unions to expedite its deployment in communities.

Recommendation: Support workforce development in the geothermal industry.

For consumers to adopt GSHPs, homebuilders, contractors, and heating and cooling specialists will need to have the expertise and skilled workforce to offer those services at competitive prices. Policymakers should support the development of industry-wide training opportunities and collaborate when applicable with trade unions that perform this work. The industry should work closely with states to develop and scale up training pathways to meet this workforce demand.

Increase Awareness and Education to Develop Geothermal Markets

Lack of awareness of geothermal energy and its potential in the West is another barrier to greater use of geothermal resources. The geothermal market has many stakeholders, including policymakers, regulators, utilities, consumers, local governments, and tribal communities. Understanding of geothermal energy needs to be raised in each group of stakeholders to increase the deployment of geothermal projects in the West.

Recommendation: Develop guidance for policymakers, regulators, and utilities to conduct cost-benefit analyses of geothermal energy.

Many of the advancements in geothermal energy have been made in the last decade and incorporating novel advancements into utility resource planning can be challenging. One difficulty is that the value of geothermal energy is not always fully realized in traditional methods of calculating energy costs, such as the levelized cost of energy, and attributes of geothermal such as the dispatchable nature, extremely low operating costs coupled with longevity, reliability, and negligible emissions, are often left out of planning. Working with utilities to understand how integration of geothermal resources would work within their market or dispatch construct could help capture the total cost and savings to their system. Greater awareness of the firm, clean nature of geothermal energy could build more confidence in the resource and lead to utilities encouraging geothermal solicitations in their bids. DOE should develop guidance on how to incorporate the full value of geothermal projects into resource planning.

Workshops, Webinars and Podcast

Colorado Mesa University Geo-Exchange Tour

September 27, 2022

The Heat Beneath Our Feet Initiative kicked off with a tour of the geo-exchange heating and cooling system at Colorado Mesa University (CMU).

Using less than half of the electricity required by a traditional HVAC system, the geo-exchange heating and cooling system at CMU controls the climate in 70 percent of the buildings on campus (1.2 million square feet).

In the summer, it absorbs excess heat from the buildings on campus and either stores it underground for later use or transfers it to other facilities in need – it even heats the University's Olympic-sized swimming pool. In the winter, the system pumps the geothermally heated water 500 feet below the school into the buildings on campus for heating purposes. Doing so reduces the University's carbon footprint by nearly 18 metric tons a year and saves $1.5 million a year on energy costs, savings that were passed directly along to reduce student tuition.

It has been so successful, the University is not only expanding the system to all of the new construction on campus, but it is also working with the city of Grand Junction to explore options for expanding the system into the surrounding community.

"This is an exciting example of community-scale geothermal," Colorado Governor Jared Polis said at the workshop. "Once we build this great geothermal heating and cooling system, we can leverage it to help extend the benefits and savings to the community."

TOP: Governor Jared Polis toured the geo-exchange system at Colorado Mesa University (CMU) with University President John Marshall. With additional state funding approved by Governor Polis, CMU hopes to become the first university in the country to use geo-thermal energy to heat and cool 100 percent of its campus. BOTTOM: During his tour, Gov. Polis also met with CMU students who received a 2 percent reduction in tuition last year due to the energy savings from the University's geo-exchange system.

As the country looks to electrify much of its heating and cooling needs, Amanda Kolker, Geothermal Program Manager at the National Renewable Energy Laboratory, said, "This is one of the few solutions" to successfully do so without overwhelming the grid.

"The 'electrify everything' pathway will be a difficult one for the grid to accommodate unless our alternatives to gas-fired heating and cooling are highly efficient and resilient," she said. "That's why the work being done [at CMU] is so important to highlight and build on."

Following the tour, WGA hosted a webinar with Will Toor, the Executive Director of the Colorado Energy Office, and Kent Marsh, the Vice President for Capital Planning Sustainability and Campus Operations at CMU. Together they discussed the nuances of geothermal heat exchange systems, opportunities to replicate this technology throughout the West, and challenges to implementation.

Hawaii Workshop

October 9-10, 2022

To learn about the potential for geothermal electricity generation, former Hawaii Governor David Ige hosted a workshop for the Heat Beneath Our Feet initiative at Puna Geothermal Venture in October of 2023.

"Geothermal energy can be a bipartisan solution to our energy challenges across the West and I am proud that Hawaii can be an example to the nation and the world for renewable energy," Governor Ige said.

Located atop the Kapoho Geothermal Reservoir in the East Rift Zone of the Kilauea volcano, the Puna Geothermal Venture uses mile-deep production wells to bring geothermally heated fluid to the surface and produce steam, which is then used to power turbines that generate 38 megawatts of electricity for the Big Island of Hawaii each year – roughly 10 percent of the community's use. With the potential for the Kapoho Geothermal Reservoir to produce 200 megawatts of power each year, Ormat Technologies, Inc. plans to expand the plant's capacity by another 8 megawatts in the coming years.

Following a tour of the power plant, experts from DOE, USGS, Los Alamos National Laboratory, and the Colorado Energy Office discussed the potential for geothermally generated electricity to stabilize the grid when the sun isn't shining or the wind isn't blowing, as well as to sustainably power emission-reducing technology like carbon capture plants, green hydrogen production, and electric vehicles.

By expanding the state's use of its geothermal resources, Scott Glenn, the Chief Energy Officer for the Hawaii State Energy Office, said Hawaii hopes to become a net-negative carbon emitter by 2045.

TOP: "Workshop participants tour Puna Geothermal Venture in Hawaii, which provides up to 10 percent of the Big Island's power." BOTTOM: "During the workshop, participants got a chance to visit Volcanoes National Park, where the power of geothermal was on full display.

"[Geothermal energy] can drive our negative emission goals by helping to power direct air capture or some of these other really innovative, cutting-edge technologies that are very expensive right now," Glenn said. "The low, low price that geothermal can offer, makes them much more viable and puts them on the table."

In addition to the environmental benefits that come with being a net-negative carbon emitter, Paul Thomsen, the Vice President of Business Development at Ormat Technologies, Inc. added that doing so could cut the state's energy costs.

"The energy rate [for geothermal] that's before the Public Utilities Commission today is 5.7 cents per kilowatt hour," Thomsen said. "Most western states are 9 to 12 cents. In Hawaii, they're paying rates as high as 20 cents per kilowatt hour. So geothermal has the ability to save ratepayers in Hawaii $60 million a year in the price of energy."

After exploring the Puna Geothermal Venture in Hawaii, WGA hosted a webinar featuring Glenn, Thomsen, and Nicole Lautze, principal investigator with the Hawaii Groundwater and Geothermal Resources Center at the University of Hawaii. Their conversation focused on the potential for geothermally generated electricity to stabilize the grid and sustainably power emission-reducing technology like carbon capture plants, green hydrogen production, and electric vehicles.

Idaho Workshop

October 24, 2022

In 1892, The Boise Warm Springs Water District in Idaho became the first community in the world to tap into a geothermal reservoir for heating purposes. Though the system initially only provided heat to a handful of buildings, today it encompasses four water districts that collectively heat over six million square feet of building space and over 300 homes.

Ultimately, it reduces the city's carbon footprint by approximately 20,000 tons of carbon dioxide per year – the equivalent of removing more than 4,000 cars from the road – and saves the city millions of dollars per year on electricity costs.

"You just can't beat the value of geothermal," Idaho Governor Brad Little said during the Heat Beneath Our Feet initiative workshop that he hosted in October.

While the expansion of the Boise Warm Springs Water District over the last 130 years is a perfect example of how geothermal resources can be leveraged to sustainably meet a community's heating needs, most areas do not have such easy access to geothermal resources as Boise does.

"We know more about the bottom of the ocean or the surface of Mars than we do about what's underneath half of Nevada," James Faulds, the Nevada State Geologist and a professor at the University of Nevada Reno's Bureau of Mines and Geology, told the geothermal experts that attended the workshop.

However, by extrapolating subsurface data and drilling technologies from other industries – especially the oil and gas industry – geothermal resource mapping can be radically improved and reduce the financial risk of developing geothermal resources.

"Through various kinds of statistical analysis," Faulds said, "we came up with an algorithm that allows us to go out there and say, 'that spot in the middle of this valley looks very promising for geothermal.' Those are hidden resources that our estimates suggest are three-quarters or more than our current resources."

TOP: At Boise's Warm Springs Water District production wells, system operators demonstrate the importance of materials selection when designing district heating systems. Despite high corrosion rates, Boise has successfully avoided system failures by implementing engineering and technological advancements. BOTTOM: Idaho Governor Brad Little discussed the benefits the city has reaped as a result of Boise's use of its geothermal resources.

This kind of innovative analysis, Nick Goodman, the CEO of Cyrq Energy, said will drive geothermal development for years to come – especially if geologists like James Faulds get access to better data.

"A lot of the geothermal that's operating today came from data in the '70s and '80s," he said. "Conventional geothermal systems of tomorrow are going to come from these hidden systems and industry doesn't have the ability to do that upfront work, it's just not set up for it... I guarantee you that 10 years from now we will have operating geothermal plants that are a result of the work these labs are doing."

To continue the conversation after the workshop, WGA hosted a webinar to discuss strategies for improving geothermal resource assessment mapping and project permitting. It featured Claudio Berti, the Director and State Geologist at the Idaho Geological Survey, Lorenzo Trimble, the Geothermal Program Lead at the Bureau of Land Management, and Jon Gunnerson, the Geothermal Coordinator for the City of Boise.

Utah Workshop

December 12, 2022

EGS can augment the power potential of existing geothermal reservoirs, or even create geothermal reservoirs where they are not naturally occurring, by improving the permeability of subsurface rock.

To advance the development of EGS technologies, DOE funds an underground field laboratory in southwestern Utah, the Frontier Observatory for Research in Geothermal Energy (Utah FORGE).

WGA hosted a workshop in Cedar City, Utah, to discuss the potential for this exciting technology and what can be done to make it commercially viable.

"Geothermal potential is inexhaustible… but you can't meet U.S objectives to produce 60 megawatts [of geothermal power] using conventional hot spring systems," Dr. Joseph Moore, the principal investigator at Utah FORGE, said. "They're just not big enough. We need to be able to drill everywhere across the country… and if you want an electrical plant anywhere, you could use EGS."

The key innovation that is required to deploy EGS around the world, Dr. Moore said, is tools capable of withstanding the sustained heat encountered drilling geothermal wells.

"New tools are absolutely required to build an EGS system," he said. "Our project at Utah FORGE is not to generate electricity, it's to de-risk these tools and to create the reservoir… to develop the road map so that developers and others in any country can take the road map and build the system."

To learn more about this exciting technology and its potential use across the West, WGA hosted a webinar with Dr. Moore and Jaina Moan, the Director of External Affairs with the Nature Conservancy. They discussed the tools and technology necessary to make EGS commercially viable, including strategies for navigating the permitting process.

Colorado Workshop

February 24, 2023

The Colorado workshop of the Heat Beneath Our Feet initiative was hosted at the NREL Energy Systems Integration Facility in Golden, Colorado, where Colorado Governor Jared Polis was joined by Alejandro Moreno, the Acting Assistant Secretary of the U.S. Department of Energy and Deputy Assistant Secretary for Renewable Power.

During the workshop, experts from Geothermal Rising, Fervo Energy, and BlueGreen Alliance, among others, spoke with utilities about strategies for incorporating more geothermal energy onto the grid.

"There's enormous potential for everything from geothermal passive heating and cooling systems to geothermal electricity," Governor Polis said. "We want to make sure we have an accelerated process in place, given the nature of the climate emergency, for geothermal to be deployed."

"This needs to be a nationwide approach," Moreno said. "The federal government has really significant resources to accelerate this transition… but we know that the real work in making this happen is going to take place in states across the West. It's the decisions made at the state and local level every day that ultimately determine what this energy future looks like."

Dr. Martin Keller, Director of NREL, spoke about the need to scale geothermal energy use in a similar fashion to that of wind and solar power.

The biggest hurdle to deployment, utilities said, is a lack of quality subsurface mapping and access to drilling and transmission technology that can effectively work in extreme temperatures. While these issues add a significant layer of cost and complexity to geothermal deployment, industry advocates noted that the 24/7 reliability, long-term cost savings, lack of carbon emissions, and job opportunities for oil and gas workers must be considered in the cost-benefit analysis if this technology is to reach its full potential.

"Solar took 30 years to go from super expensive to now being one of the cheapest ways to produce electricity," Martin Keller, the director of NREL and president of the Alliance for Sustainable Energy, said. "But we don't have 30 years for some of these new technologies. We only have about 10 to bring these technologies to scale and then deploy."

Topics of discussion at the workshop, including integrating geothermal resources onto the grid, opportunities to transition energy workers to the geothermal sector, and geothermal public education and market development, were highlighted in a subsequent webinar. It featured Amanda Kolker, the laboratory program manager for Geothermal at NREL, Chris Markuson, the Western States Director with the BlueGreen Alliance, and Bryant Jones, the Executive Director of Geothermal Rising.

Utah FORGE

June 9, 2023

In June, the initiative returned to Utah, where Colorado Governor Jared Polis was joined by Utah Governor Spencer Cox to visit Utah FORGE. During the visit, Utah FORGE was actively drilling a geothermal well that will reach a total length of 10,700 feet. Once finished drilling through hard crystalline granite, the well will reach a vertical depth of 8,265 feet, where the temperature will be 440 degrees Fahrenheit. "[Utah FORGE] is an essential stepping stone to large scale EGS development" Dr. Joseph Moore, the principal investigator at Utah FORGE, said. "It is being used to build the roadmap for EGS, any developer or country can take this roadmap to build these systems... Worldwide there is no other field-scale facility for EGS research."

The two Governors also visited the Thermo Geothermal Power Plant in Minersville, Utah. This power plant, operated by Cyrq Energy, has a capacity of 14.5 megawatts, generated by three production wells and five injection wells. Thermo supplies electricity to the City of Anaheim, California, through transmission completed by PacifiCorp.

TOP: Governors Jared Polis and Spencer Cox with WGA's Executive Director Jack Waldorf and the team from Cyrq Energy at its Thermo Geothermal Power Plant in Utah. BOTTOM: Dr. Joseph Moore, the managing principal investigator at the Utah FORGE lab explained his work on Enhanced Geothermal Systems to Governor Jared Polis and Governor Spencer Cox.

Webinars

More Than Just Heat

While geothermal energy is often associated with electricity generation and heating and cooling needs, its ability to store huge amounts of energy is another critical component of its community benefit. To explore this potential, WGA hosted a webinar with **Keith Malone**, the public affairs officer for the Hydrogen Fuel Cell Partnership, and **Sarah Jewett**, the Vice President of Strategy for Fervo Energy.

Renewable Energy Incentive Parity

The Inflation Reduction Act transitioned current investment tax and production tax credits to a "technology-neutral" tax credit for low-carbon technologies and energy sources. In light of this development, WGA hosted a webinar with **Sean Porse**, the data, modeling, and analysis program lead at the U.S. Department of Energy, **Bryce Carter**, the program manager for emerging markets and geothermal at the Colorado Energy Office, and **Landon Stevens**, the senior program director for the electricity sector at Clear Path Energy, to discuss strategies for leveraging these new tax credits and providing developers with stable, long-term funding.

Geothermal Energy at Home

GSHPs are a proven technology to heat and cool buildings of many sizes and use. To explore the deployment of geothermal heating and cooling applications, WGA hosted a webinar and was joined by **Jeff Hammond**, Executive Director of the International Ground Source Heat Pump Association, **Heather Deese**, Senior Director of Policy & Regulatory Affairs at Dandelion Energy, **Ryan Dougherty**, President of The Geothermal Exchange Organization, and and **Terry Proffer**, GeoExchange Designer and Geologist with Major Geothermal.

Podcast

The Well of the Future: Repurposing Oil and Gas Wells for Geothermal Energy Production

With over 80,000 orphaned oil and gas wells in the U.S., repurposing those wells for geothermal energy production would not only save millions of dollars in costs to cap wells, but also reduce the financial burden of drilling a geothermal well. WGA hosted an episode of its Out West podcast series with Johanna Ostrum, the Chief Operating Officer of Transitional Energy; Will Pettitt, the Geothermal Discipline Lead at Baker Hughes; and Will Gosnold, a professor of geological engineering at the University of North Dakota to explore how this could help make both industries more efficient and sustainable.

Case Studies

Alaska

Chena Hot Springs, a remote off-grid community near Fairbanks, Alaska, has successfully implemented a geothermal microgrid that has been operating since 2006. The 680 kW isolated geothermal plant offsets diesel generation, resulting in significant cost savings for the community. In the first year of operation, the plant saved more than $650,000 in diesel fuel costs and reduced electricity costs from $0.30 to $0.05/kWh.[14]

The geothermal plant utilizes the lowest-temperature geothermal electricity source in the world at 71°C, with power generation enabled by the availability of near-freezing river water and seasonal subzero air temperatures for power cycle heat rejection. Creating a cascade-of-use system, waste heat from the plant is used for district heating, greenhouses, seasonal cooling using absorption chilling, a spa, and other uses.

Additionally, the Aurora Ice Museum at Chena Hot Springs utilizes geothermal energy to maintain a year-round frozen environment. An ammonia-water-based absorption chiller runs on 73°C geothermal heat and provides 15 tons of -29°C chilling. The chill brine circulates through an air handler, which cools an annular space in the ice hotel between the ice walls and the external insulation. The success of these geothermal projects in Alaska demonstrates the potential for geothermal energy to provide cost-effective and sustainable energy solutions in remote communities.

American Samoa

In 2015, DOI awarded American Samoa $1.13 million to support a geothermal drilling program to test for resource potential on the island of Tutuila. The American Samoa Power Authority partnered with DOI office of Insular Affairs and NREL to complete a resource assessment with hopes that geothermal energy could be developed into a baseload energy source for island communities. The drilling program was completed and found that although the islands may have volcanic resources, assessments suggested the resources would be too high risk for geothermal development and electricity generation would not likely be commercially viable with current technologies.[15]

Arizona

Arizona has abundant low-temperature geothermal resources that have been tapped for aquaculture and other direct use applications. Nearly all aquaculture operations in Arizona use geothermally heated water to produce shrimp, tilapia, and catfish. Using waters 20-40°C, farmers are able to grow larger and healthier fish faster and longer throughout the year. The benefits of controlled rearing temperature have been found to increase growth rates by 50-100%, raising the number of harvests per year, resulting in increased profits.

California

California's successful geothermal energy industry can be attributed to a combination of favorable geologic conditions, supportive policies, and market demand. California's unique geologic features, characterized by high volcanic and tectonic activity, provide the foundation for some of the oldest geothermal installations in the U.S. The Geysers, located in the Mayacamas Mountains, has been operating since the 1960s and is the largest geothermal field in the world. Its 18 geothermal power plants and more than 350 wells use dry steam cycles to continuously generate more than 800 MW of electricity.[16]

Geothermal resources are also abundant in Imperial Valley, which has become a testbed for research and technology testing and is being developed for power production as well. Salton Sea is the site of 11 commercial-scale geothermal power

plants, as well as a lithium research site funded by DOE. In partnership with Lawrence Berkeley National Lab and Geologica Geothermal Group, the project will seek to characterize and quantify lithium deposits in the hypersaline geothermal brine, providing additional value to the area's vast geothermal resources. Community education and engagement has helped spur support for geothermal development throughout the region, bringing in tax dollars and good paying jobs to a previously disadvantaged community.

In addition to significant resources, California has implemented supportive policies that have created a favorable environment for geothermal energy development. Recent bills passed by the California Legislature codified the state's goal of achieving 90% renewable energy and zero-carbon electricity by 2035, creating new opportunities for renewable energy projects including geothermal. The California Energy Commission and the California Public Utilities Commission have also implemented programs to reduce resource risk and encourage the growth of the geothermal industry such as loan guarantees, low-interest loans, and grants for exploration and drilling.

The expensive costs of electricity in the state have helped increase the competitiveness of geothermal as a power source. Throughout California, market demand for geothermal energy has grown due to the rising demand for power purchase agreements (PPAs) from community choice aggregators (CCAs). Since 2020, California's CCAs have been key drivers in the growth of the geothermal industry, committing to long term agreements with geothermal energy suppliers like Cyrq, Ormat, Controlled Thermal Resources, and Calpine to generate nearly 300 MW of new-build resources in the next decade.

Colorado

For decades, Colorado has leveraged geothermal resources for direct use applications and residential heating and cooling. Geo-exchange installations like those at Colorado Mesa University have been effective at reducing energy costs and continue to be installed throughout the state. In recent years, Colorado has become a leading proponent for geothermal energy, creating state programs and offices to bolster the development and implementation of geothermal statewide. In 2023, Governor Polis signed a regulatory pathway for gas utilities to develop thermal energy networks and, working with the legislature, passed an estimated $140 million in refundable tax credits for geothermal energy over the next ten years, including $35 million for a merit-based state investment tax credits for geothermal electricity projects.

In 2022, DOE awarded a $9 million grant to Occidental Petroleum to test geothermal drilling technologies in the Denver-Julesberg Basin through the Geothermal Limitless Approach to Drilling Efficiencies (GLADE) project. Partnering with NREL and Colorado School of Mines, the project will drill twin, high temperature geothermal wells using existing and innovative drilling technologies to drill deeper and at higher temperatures at a faster rate, ultimately seeking to increase daily drilling rates by at least 25%. The twin wells system allows for drilling speeds to be compared and validated for a multitude of systems, including EGS.

Governor Jared Polis toured the facilities at the National Renewable Energy Laboratory in February, where he was able to see several renewable energy demonstration projects and learn how they compare to geothermal energy.


A lava flow from the eruption of Kilauea in 2018 is visible beyond Puna Geothermal Venture.

Guam

A team from NREL and the U.S. Navy's Geothermal Program Office conducted a reconnaissance assessment on the geothermal potential in Guam in 2010. Although Guam has no obvious surface features suggesting geothermal potential and had never been explored for geothermal resources, researchers located a steam vent and hot water well, suggesting the presence of geothermal fluids in the subsurface.[17] Using LIDAR technology, the Navy conducted additional assessments and provided funding to drill temperature gradient wells in the locations identified for geothermal potential. To date, no commercial or large-scale geothermal projects have been developed in Guam.

Hawaii

In 2008, the State of Hawaii, in partnership with DOE, signed a Memorandum of Understanding to collaborate on reducing the state's dependence on imported fossil fuels. This MOU, which was recommitted in 2014, launched the Hawaii Clean Energy Initiative, which created ambitious energy and climate goals and made the state to be the first to commit to 100% renewable energy by 2045. Today, renewable portfolio standards (RPS) and net negative emissions targets are central to Hawaii's clean energy policy. The RPS established in 2015, aims for 40% net electricity generation by 2030 and The 2018 Zero Emissions Clean Economy Target revised previous statues to target net negative carbon emissions statewide by 2045. The state continues to rapidly move towards these goals and since establishing the renewable portfolio standard in 2015, usage of renewable energy usage has nearly doubled statewide.

Hawaii's unique geography and geologic features make geothermal an especially attractive and viable renewable energy option. Hawaii's electricity system is comprised of six standalone grids, independently creating and delivering power for each island. Currently, commercial scale geothermal electricity generation is only operational on Hawaii Island (at Puna Geothermal Venture) and accounts for roughly 18% of total electricity consumption on the island. At current capacity, Hawaii Island's grid is the most manageable for geothermal, but ongoing research and development efforts by the state, as well as private developers, are investigating ways to develop geothermal resources on other islands, especially on Oahu, the population center of the state with the highest energy needs.

Idaho

Idaho's volcanic landscape makes it an ideal location for geothermal energy development. The state has over 1,000 wells and 200 springs that can be used to extract geothermal energy and has several commercial geothermal power plants, including the Raft River Enhanced Geothermal System Project, which provides about 11 MW of net capacity.

In addition to generating electricity, geothermal energy is also used to heat buildings and grow plants. Boise is home to the nation's first geothermal district heating system, and the city's geothermal heating utility delivers naturally heated water through over 20 miles of pipeline to more than 6 million square feet of building space. The Idaho Statehouse is the only geothermally heated capitol building in the nation, and district heating is also currently being used for space heating at several of the Boise State University campus buildings.

Kansas

GSHPs are deployed in a variety of commercial and residential buildings across the state: In Lawrence, the Castle Tea Room was retrofitted with a GSHP system during renovation to provide heating and cooling, as well as hot-water radiant floor heating; the Regional Correctional Facility at Fort Leavenworth includes a GSHP system with 480 bore holes drilled up to 280 feet deep, providing heating, cooling, and refrigeration; Greensburg, Kansas, which was devastated by a tornado in 2007, has been rebuilding with an emphasis on green technology, including GSHP systems in several new or rebuilt homes and buildings, such as a school campus, city hall, and the Kiowa County Courthouse.[18]

Montana

Montana State University researchers helped pilot a new type of geothermal heating and cooling system that could reduce the cost of the technology. The team of engineering faculty and students guided the installation of an innovative closed-loop piping configuration as part of a major expansion at a rural school in Winifred. The closed-loop configuration utilizes shallower geothermal boreholes than a traditional system, resulting in shorter drilling periods. Since drilling is typically the biggest expense associated with geothermal heating and cooling systems, the technique could lead to significant cost savings.

If the cost savings in installation significantly overcome any reduction in energy performance from the shallower boreholes, there could be a wide range of applications for this new type of geo-exchange system, including residential development or in places where deep boreholes are prohibitive due to shallow aquifers or other limitations.

Cross-industry partnerships and collaboration between trade workers, engineers, geothermal designers, and academics facilitated innovative technology design, ultimately reducing costs and demonstrating how a traditionally expensive system can be viable in a rural and underserved community.[19]

Nebraska

Located in Lincoln, The Bridges is the state's first fully geothermal residential neighborhood. The development has six large geothermal ponds, which provide the foundation for the geothermal heat exchange unit used in each home. Residents are required to utilize geothermal heating and cooling and the geothermal transfer lines that connect homes to the cooling unit are included in the price of the house. Homeowners save between 30-70% on energy costs and use significantly less electricity.

Nevada

As one of the top producers of geothermal energy in the country, Nevada has a well-established geothermal industry and strong industry expertise. This technical expertise and a streamlined state permitting process allow projects in Nevada to advance relatively quickly, making it an attractive location for both startups and established developers.

Collaboration and robust stakeholder engagement have also been instrumental in the success of geothermal energy in Nevada. The industry has worked closely with government agencies, local communities, and research institutions to develop projects that are socially responsible and environmentally sustainable. Located in Churchill County, Enel's Stillwater Triple-Hybrid Plant is a first of its kind facility, combining binary cycle geothermal power with solar photovoltaic and solar thermal. Enel's collaborative approach from the outset was a key factor in the project's success. Project proponents held public forums to educate local communities, address concerns, and incorporate feedback. Partnering with the Desert Research Institute, extensive environmental studies were conducted to understand wildlife, vegetation, and environmental risks and to establish a mitigation plan. Since being commissioned in 2009, Stillwater has provided hundreds of jobs, millions of dollars in local investment and has generated enough electricity to power more than 17,000 homes annually.[20] Electricity generated at this facility is also used to power Wynn Las Vegas, made possible by a PPA signed in 2018 with the resort.

Additionally, Nevada has favorable policies and incentives that have supported the growth of the geothermal industry. For example, the state offers a 55% property tax abatement for geothermal power systems with at least 10 MW capacity. Nevada has also focused on streamlining administrative processes and permitting authorities for developing geothermal resources, with state-level geothermal legislation and policy development active in the state.

New Mexico

With the sixth-highest geothermal potential in the U.S., New Mexico has attracted the interest of developers who are actively looking to develop the resource. In 2021, Canadian company Eavor successfully drilled an 18,000-foot well bore in southwest New Mexico using their new technology, proving that it can potentially access deep subsurface hot-rock formations that offer massive amounts of clean, renewable energy. The completed well is the deepest hole ever drilled in New Mexico and has demonstrated enormous potential for unleashing a virtually unlimited source of clean energy for electricity generation and for heating and cooling.[21]

Beyond demonstrating drilling potential, Eavor's operation exemplified the lucrative employment opportunities for oil and gas industry workers in geothermal. Two conventional drilling rigs were used on this project, employing dozens of oil and gas workers. Partnerships and investments from drilling rig operating companies ensure stability and provides continual opportunity for workers.

In 2022, the state legislature formed a geothermal working group, comprised of private developers and other stakeholders, to explore local development potential and recommend action to increase investments in both geothermal electricity generation and heating and cooling. Work group findings may pave the way for future legislation to help further encourage geothermal development across New Mexico.

North Dakota

A team from the University of North Dakota introduced a geothermal energy project to the community of New Town. The project proposal, which was recognized by DOE GTO's Geothermal Collegiate Competition, involves using existing gas wells to draw hot water from deep aquifers, generating geothermal energy to heat buildings, grow food, and create jobs.[22]

The project sought to raise awareness about geothermal district energy generation and to provide a forum for discussion among local tribal leaders to consider renewable energy sources like geothermal. Project proponents engaged with members of Mandan, Hidatsa, and Arikara Nations to understand the cultural and historical contexts of energy in the area and to design a project to maximize community impact. Meaningful tribal consultation in proposal development sparked a new interest in geothermal amongst some New Town tribal leadership.

Northern Mariana Islands

Initial resource assessments conducted in 2008 suggest that there is significant potential for geothermal energy in the Northern Mariana Islands. On South Pagan, the size of the hydrothermal reservoir and the chemistry of the hot springs suggests a geothermal reservoir exists with an estimated generating capacity of 50-125 MW. On other islands like Saipan, deep faulting may allow deep thermal waters to migrate upwards, creating opportunities for low and medium temperatures resources.[23] Deeper temperature gradient wells would be necessary to determine full potential for geothermal power generation.

Oklahoma

As part of DOE's Wells of Opportunity program, researchers at the University of Oklahoma were awarded $1.7 million in 2022 to repurpose abandoned oil and gas wells for geothermal energy. The project uses four hydrocarbon wells to produce geothermal energy for an elementary and middle school in nearby Tuttle.[24] The benefit from recycling existing oil and gas well infrastructure is expected to create considerable savings for the schools.

Retired oil wells may give Oklahoma significant advantage in developing geothermal assets, given the risk, cost, and environmental impact of drilling geothermal wells is significantly reduced by utilizing retired or abandoned infrastructure. Of the many retired wells in Oklahoma,
a large number are believed to be viable for geothermal energy and in many cases, are located near schools, farms, factories, and other structures that could be beneficiaries of the energy produced.

Oregon

In recent years, Oregon has seen significant growth in geothermal energy production, in particular for direct use and heating and cooling. In 2020, Oregon produced 2.9 trillion Btu of geothermal energy, with 1.2 trillion Btu used for heating and cooling residential, commercial, and industrial spaces.[25] The city of Klamath Falls has long utilized geothermal heat sources to heat buildings, residences, pools, and sidewalks. Other examples of direct use of geothermal heat in the state include drying agricultural products, aquaculture, heating greenhouses, swimming pools and hot springs resorts. Oregon has more than 2,000 thermal wells and springs delivering direct heat to buildings, communities, and other facilities, demonstrating the versatility of geothermal energy as a renewable source of heat.

Beyond direct use applications, Oregon's volcanic geology has supported geothermal power production for more than a decade. Since 2010, AltaRock Energy's Newberry EGS Demonstration project, NEWGEN, has conducted ongoing research to stimulate fracture zones, demonstrate diverter technology, and develop a conceptual model of the EGS reservoir. The project site, located on the western flank of Newberry Volcano, is one of the largest geothermal heat reservoirs in the West and could generate up to 10 GW of electricity using super hot rock extraction technology.[26] If successful, NEWGEN would likely become world's first super hot rock demonstration project and could lead to the construction of a 35MW binary cycle geothermal plant that could generate electricity to be exported or used to power surrounding communities.

Oregon's success in geothermal energy has been bolstered by state-level financial assistance programs, such as property tax exemptions for properties equipped with alternative energy systems, as well as programs that support the development of geothermal heating systems. Additionally, Oregon's designated authority from the Environmental Protection Agency to issue Class V injection permits has been effective at expediting the exploration and development process.

South Dakota

Geothermal district heating is being used in various parts of South Dakota for space heating. In Midland, a municipal well drilled in 1969 supplies hot water to heat approximately local buildings and spaces including schools, churches, campgrounds, downtown municipal buildings, residential buildings and homes. This system is relatively low maintenance and requires few personnel to maintain, making it a cost-effective solution for a rural town.[27]

Texas

Since 2021, the Texas geothermal industry has seen rapid growth, with more than a dozen geothermal startups establishing themselves in the state. Many of these ventures are led by oil and gas industry veterans and have leveraged that extensive expertise to develop innovative technology solutions and form valuable partnerships.

Sage Geosystems and the Bureau of Economic Geology at the University of Texas at Austin launched a joint venture aimed at developing a prototype using advances in oil and gas drilling technologies to drill multiple wells to produce electricity by circulating a fluid deep in the earth to absorb heat from the magma. The 2021 Phase I feasibility study used nearly 50-year-old abandoned oil and gas wells in South Texas to test the model. The project is designed to demonstrate geothermal ability to provide constant, load-following power generation in an isolated microgrid at Ellington Field Joint Reserve Base and meet 100% of the Base's current electricity needs.[28] Phase I and II of the project were funded through a Small Business Technology Transfer award, under the Air Force Innovation Program and if successful, Sage Geosystems is expected to build the first prototype geothermal project at Ellington.

Utah

Situated within the Basin and Range Province, Utah provides immense potential for not just conventional hydrothermal systems, but also EGS and other innovative technologies. Rapid and innovative development has been bolstered by supportive state policies and initiatives. In the early 2000s, the state established a Utah Geothermal Working Group to facilitate collaboration between industry stakeholders, regulators, and local communities, fostering a supportive environment

Governor Jared Polis and Governor Spencer Cox get an up-close tour of Cyrq Energy's Thermo Geothermal Power Plant in Utah.

for geothermal projects. Today, recent programs and policies aimed at incentivizing geothermal development have spurred advancements in the state. The Utah Renewable Energy Systems Tax Credit provides financial incentives for the installation of geothermal systems, reducing the upfront costs for property owners. In addition to federal investments such as Utah FORGE, private developers continue to site projects in Utah, most recently, Thermo, a 14MW generating facility operated by Cyrq.

Washington

Washington has potential for geothermal energy production due to its location along the Cascade Range. However, the low cost of electricity generated from the state's abundant hydropower has limited the development of geothermal resources. In addition, there are challenges associated with geothermal exploration in the state, such as the lack of high-temperature resources.[29] In 2010, Washington Public Utilities District conducted an exploratory drilling study in Snohomish County to test geothermal potential. Exploratory efforts ceased in 2012 after drilling hit bedrock. In 2014 and 2017, DOE awarded funds to the Washington Geologic Survey to validate additional areas of geothermal potential; WGS published these results in a favorability map.

Most of Washington's urban areas like Tacoma and Seattle lie outside of feasibility areas for potential geothermal electricity production. However, GSHPs in these areas capitalize on the regions' low-temperature geothermal resources.

Wyoming

In 2022, Petrolern published a study for the Wyoming Energy Authority assessing the feasibility of geothermal opportunities in Wyoming. The study found that Wyoming's geothermal resources are generally moderate to low temperatures and situated in localized regions throughout the state. Low temperature geothermal utilization technologies such as geothermal heat pumps, direct use heating, and Organic Rankine Cycle electricity generation are applicable to these resources. Financial analysis showed that new drilling of prospects has low commercial viability, while repurposing existing wells has moderate viability. Synthetic Geothermal Reservoir has potential for high commercial viability, but additional work is needed to fully assess its economic viability.[30] Though protected from development, Wyoming's most notable geothermal feature, Yellowstone National Park, continues to be a significant economic source for the state, bringing in millions of tourism dollars annually.

Sponsor Acknowledgments

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Participant Acknowledgements

Colorado Mesa University Kickoff Tour

Grand Junction, Colorado
September 27, 2022

- The Honorable Jared Polis, Governor of Colorado
- Amanda Kolker, Geothermal Program Manager, National Renewable Energy Laboratory
- Jennifer Livermore, Senior Geothermal Project Analyst, U.S. Department of Energy Geothermal Technologies Office
- Brad McCloud, Area Manager, Community Relations Western Colorado, Grand Junction Lions Club, Xcel Energy
- Lorenzo Trimble, National Geothermal Program Lead, Bureau of Land Management
- Lyn White, Director of Government Relations, Western Governors' University

CMU Recap Webinar

October 6, 2022

- Kent Marsh, Vice President for Capital Planning, Sustainability, and Campus Operations, Colorado Mesa University
- Will Toor, Executive Director, Colorado Energy Office

Hawaii Workshop

October 9-10, 2022

- The Honorable David Ige, Governor of Hawaii
- William Aila, Chairman, Hawaiian Homelands Commission
- Erick Burns, National Geothermal Resources Investigations Project Leader, U.S. Geological Survey
- Suzanne Case, Chairperson, Hawaii Department of Land and Natural Resources
- Allen Clarkson, Director of Government Relations, Western Governors Association
- Luke Frash, Research Scientist, Los Alamos National Laboratory
- Scott Glenn, Chief Energy Officer, Hawaii State Energy Office
- Nick Goodman, Chief Operating Officer, Cyrq Energy
- Keith Hay, Senior Director of Policy, Colorado Energy Office
- Nicole Lautze, Principal Investigator, Professor, Hawaii Groundwater and Geothermal Resources Center
- Jennifer Livermore, Senior Geothermal Project Analyst, U.S. Department of Energy Geothermal Technologies Office
- Melissa Miyashiro, Executive Director, Blue Planet Foundation
- Sabrina Nasir, Senior Special Assistant, Hawaii Governor David Ige
- Jim Ogsbury, former Executive Director, Western Governors' Association
- Riley Saito, Energy Specialist, County of Hawaii
- Monique Schafer, Renewable Energy Project Specialist, Hawaii State Energy Office
- Paul Thomsen, Vice President of Business Development, Ormat Technologies
- Michael Turner, Director of Building Innovation and Energy Finance, Colorado Energy Office
- Lyn White, Director of Government Relations, Western Governors' University

Hawaii Recap Webinar

October 20, 2022

- Scott Glenn, Chief Energy Officer, Hawaii State Energy Office
- Nicole Lautze, Principal Investigator, Professor, Hawaii Groundwater and Geothermal Resources Center

Idaho Workshop

Boise, Idaho October 24, 2022

- The Honorable Brad Little, Governor of Idaho
- Eric Anderson, President, Idaho Public Utilities Commission
- John Anderson, Economic Development and Innovation Advisor, Idaho Power Company
- Claudio Berti, Director and State Geologist, Idaho Geological Survey
- Erick Burns, National Geothermal Resources Investigations Project Leader, U.S. Geological Survey
- Alexis Clark, Hydrogeologist, Idaho Geological Survey
- Grant Cummings, Policy Associate, ClearPath
- Jared Dalebout, Geologist, Bureau of Land Management
- Patrick Dobson, Geothermal Systems Programs Lead, Lawrence Berkeley National Laboratory
- Juan Escobar, Head of Geoscience, Eagle Ford Asset, BPX Energy
- Jim Faulds, Nevada State Geologist, Professor, Nevada Bureau of Mines and Geology, University of Nevada, Reno
- Nick Goodman, Chief Executive Officer, Cyrq Energy
- Richard Horsley, Energy Manager, U.S. Air Force
- Bryant Jones, Executive Director, Geothermal Rising
- Jennifer Livermore, Senior Geothermal Project Analyst, U.S. Department of Energy Geothermal Technologies Office
- George Lynch, Legal Counsel, Idaho Governor's Office of Energy and Mineral Resources

- Travis McLing, Research Scientist, Idaho National Laboratory
- Andrew Mendoza, Deputy Base Civil Engineer, United States Air Force 366th Civil Engineer Squadron
- Roy Mink, Geohydrologist, Mink Geo-Hydro Inc.
- Scott Nichols, Regulatory Affairs Manager, Ormat Technologies
- Jim Ogsbury, former Executive Director, Western Governors' Association
- Richard Stover, Administrator, Idaho Governor's Office of Energy and Mineral Resources
- Mick Thomas, Division Administrator, Minerals, Navigable Waterways, Oil and Gas, Idaho Department of Lands
- Lorenzo Trimble, National Geothermal Program Lead, Bureau of Land Management

Idaho Recap Webinar

November 7, 2022

- Claudio Berti, Director and State Geologist, Idaho Geological Survey
- John Gunnerson, Geothermal Coordinator, City of Boise
- Lorenzo Trimble, National Geothermal Program Lead, Bureau of Land Management

Utah Workshop

Cedar City, Utah December 12, 2022

- The Honorable Spencer Cox, Governor of Utah
- Phillip Ball, Chief of Geothermal Innovation, Clean Air Task Force
- Bryce Carter, Emerging Markets Program Manager, Geothermal, Colorado Energy Office
- Patrick Dobson, Geothermal Systems Program Lead, Lawrence Berkeley National Laboratory
- Joel Edwards, Chief Technical Officer, Zanskar Energy
- Robin Hansen, Petroleum Engineer, Geothermal Program Lead, Bureau of Land Management
- Amanda Kolker, Geothermal Program Manager, National Renewable Energy Laboratory
- Stephen Lisonbee, Rural Advisor to Governor Cox
- Travis McLing, Research Scientist, Idaho National Laboratory
- Jaina Moan, External Affairs Director, The Nature Conservancy
- Joseph Moore, Principal Investigator, Utah FORGE, EGI, University of Utah
- Johanna Ostrum, Chief Operating Officer, Transitional Energy
- Jeffrey Sallow, Geologist, U.S. Forest Service
- Greg Todd, Director, Utah Governor's Office of Energy Development
- Mike Visher, Administrator, Nevada Division of Minerals

Utah Recap Webinar

December 19, 2022

- Joseph Moore, Principal Investigator, Utah FORGE, EGI, University of Utah
- Jaina Moan, External Affairs Director, The Nature Conservancy

NREL Workshop

Golden, Colorado February 24, 2023

- The Honorable Jared Polis, Governor of Colorado
- John Anderson, Economic Development and Innovation Advisor, Idaho Power Company
- Koenraad Beckers, Research Engineer, Energy Conversion and Storage Systems Center, National Renewable Energy Laboratory
- Kelly Blake, Division Director, President, Navy Geothermal Program, Geothermal Rising
- Lauren Boyd, Acting Director, U.S. Department of Energy Geothermal Technologies Office
- Bryce Carter, Emerging Markets Program Manager, Geothermal, Colorado Energy Office
- Cynthia Connor, Policy Director, Offsets and Emerging Technology, Chevron New Energies
- Kristin Elowe, Planning and Environmental Coordinator, Bureau of Land Management
- Juan Escobar, Head of Geoscience, BP
- Neil Ethier, Vice President of Business Development, Eavor
- Jonathan Ho, Energy System Modelling Engineer, National Renewable Energy Laboratory
- Joseph Islas, Geologist, Bureau of Land Management
- Sarah Jewett, Vice President of Strategy, Fervo Energy
- Bryant Jones, Executive Director, Geothermal Rising
- Kimilia Jones, Commercial Manager, Chevron New Energies
- Amanda Kolker, Geothermal Program Manager, National Renewable Energy Laboratory
- Justin LeVeque, Section Chief, Research and Emerging Issues, Colorado Public Utilities Commission
- Jennifer Livermore, Senior Geothermal Project Analyst, U.S. Department of Energy Geothermal Technologies Office
- Matt Mailloux, Policy Advisor, ClearPath
- Chris Markuson, Western States Director, BlueGreen Alliance
- Travis McLing, Research Scientist, Idaho National Laboratory
- Alejandro Moreno, Acting Assistant Secretary, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy
- Johanna Ostrum, Chief Operating Officer, Transitional Energy
- Amy Robertson, Senior Manager, State Government Relations and External Affairs, Tri-State Generation and Transmission Association
- Michelle Slovensky, Intelligent Campus Program Manager, National Renewable Energy Laboratory

- Faith Smith, Researcher, Strategic Energy Analysis Center, National Renewable Energy Laboratory
- Mark Silberg, Special Advisor on Climate and Energy, Colorado Governor Jared Polis
- Will Toor, Executive Director, Colorado Energy Office
- Lorenzo Trimble, National geothermal Program Lead, Bureau of Land Management
- Kathryn Valdez, Director, Carbon-Free Technology Policy, Xcel Energy
- Jack Waldorf, Executive Director, Western Governors' Association

NREL Recap Webinar

March 2, 2023

- Bryant Jones, Executive Director, Geothermal Rising
- Amanda Kolker, Geothermal Program Manager, National Renewable Energy Laboratory
- Chris Markuson, Western States Director, BlueGreen Alliance

Webinar: More Than Just Heat

January 23, 2023

- Sarah Jewett, Vice President of Strategy, Fervo Energy
- Keith Malone, Public Affairs Officer, Hydrogen Fuel Cell Partnership

Webinar: Renewable Energy Incentive Parity

March 29, 2023

- Bryce Carter, Emerging Markets Program Manager, Geothermal, Colorado Energy Office
- Sean Porse, Data, Modelling, and Analysis Program Lead, U.S. Department of Energy Geothermal Technology Office
- Landon Stevens, Senior Program Director, Electricity, ClearPath

Webinar: Geothermal Energy at Home

May 3, 2022

- Jeff Hammond, Executive Director, International Ground Source Heat Pump Association
- Heather Deese, Senior Director of Policy and Regulatory Affairs, Dandelion Energy
- Ryan Dougherty, President, Geothermal Exchange Organization (GEO)
- Terry Proffer, GeoExchange Designer and Geologist, Major Geothermal.

Podcast: The Well of the Future: Repurposing Oil and Gas Wells for Geothermal Energy Production

November 2022

- Will Gosnold, Professor of Geological Engineering, University of North Dakota
- Will Pettitt, Geothermal Discipline Lead, Baker Hughes
- Johanna Ostrum, Chief Operating Officer, Transitional Energy

Survey Respondents

- Anzar Consulting
- B2E Consultation
- Bain Geophysical Services, Inc.
- Baker Hughes
- Baseload Power US
- Billings County, North Dakota
- California Department of Conservation
- California Geothermal Heat Pump Association
- Chaffee County, Colorado
- City of Salida, Colorado
- Clean Air Task Force
- ClearPath
- Colorado Public Utilities Commission
- Colorado State University
- Dandelion Energy
- Deerstone Consulting
- Eavor Technologies Inc.
- Egg Geo LLC
- Fervo Energy
- Fire and Ice Geothermal Heating and Cooling LLC
- Geopoint Generation
- Geothermal Exchange Organization
- Geothermal System Designer
- Gunnison County, Colorado
- Halliburton
- IGSHPA
- Lake County Resources Initiative
- Lawrence Berkeley National Laboratory
- Murasaki Resort
- National Renewable Energy Laboratory
- National Wild Turkey Federation
- Natural Resources Defense Council
- Nevada Department of Wildlife
- Nu-Tech Heating & Cooling LLC
- Ormat Technologies
- PB USA
- Petrolern
- Poudre Valley REA
- Quaise Energy
- Rio Grande Geothermal
- Southwest Energy Efficiency Project
- Stevens County, Washington
- Sustainable Transportation and Energy Holdings
- Tacoma Power
- Texas Geothermal Energy Alliance
- Theodore Roosevelt Conservation Partnership
- Transitional Energy
- U.S. Geological Survey
- United Association
- United Power
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- Vallourec USA Corporation
- Washington Department of Natural Resources
- Washington Geological Survey
- Xcel Energy

References

[1] United States Geological Survey (USGS). "The Geysers Geothermal Field." U.S. Geological Survey, 2023, www.usgs.gov/volcanoes/clear-lake-volcanic-field/geysers-geothermal-field

[2] U.S. Department of Energy. "Geothermal FAQs." U.S. Department of Energy, Energy Efficiency & Renewable Energy, 2023, www.energy.gov/eere/geothermal/geothermal-faqs

[3] U.S. Department of Energy. "GeoVision: A Vision for the Future of Geothermal Energy in the United States." 2019. www.energy.gov/eere/geothermal/articles/geovision-full-report.pdf

[4] U.S. Energy Information Administration (EIA). "Residential Energy Consumption Survey." 2021. https://www.eia.gov/consumption/residential/

[5] U.S. Energy Information Administration (EIA). "Geothermal Power." 2022. www.eia.gov/energyexplained/geothermal/geothermal-power.php

[6] U.S. Department of Energy. "GeoVision: A Vision for the Future of Geothermal Energy in the United States." 2019. www.energy.gov/eere/geothermal/articles/geovision-full-report.pdf

[7] National Renewable Energy Laboratory (NREL). "2021 U.S. Geothermal Power Production and District Heating Market Report." NREL, July 2021. https://www.nrel.gov/docs/fy21osti/78291.pdf

[8] Gagnon, P. et al. (2022) National Renewable Energy Laboratory (NREL), 2022 Standard Scenarios Report: A U.S. Electricity Sector Outlook. Available at: https://www.nrel.gov/docs/fy23osti/84327.pdf (Accessed: 01 June 2023).

[9] National Renewable Energy Laboratory (NREL). "2021 U.S. Geothermal Power Production and District Heating Market Report." NREL, July 2021. https://www.nrel.gov/docs/fy21osti/78291.pdf

[10] U.S. Department of Energy. "Enhanced Geothermal Systems (EGS): Unlocking the Power of Geothermal Energy." U.S. Department of Energy, September 2022, www.energy.gov/sites/default/files/2022-09/EERE-ES-Enhancing-Geothermal-508-v2.pdf

[11] IEA, Actual and forecast onshore wind costs, 2016-2025, IEA, Paris https://www.iea.org/data-and-statistics/charts/actual-and-forecast-onshore-wind-costs-2016-2025, IEA. License: CC BY 4.0

[12] Energy Efficiency & Renewable Energy. "Choosing and Installing Geothermal Heat Pumps." U.S. Department of Energy, U.S. Department of Energy, 11 Jan. 2023, www.energy.gov/energysaver/choosing-and-installing-geothermal-heat-pumps

[13] Stringfellow, W.T., and P.F. Dobson. "Technology for the Recovery of Lithium from Geothermal Brines." Energies 14, no. 20 (2021): 6805. doi:10.3390/en14206805.

[14] Robins, Jody, et al. "2021 U.S. Geothermal Power Production and District Heating Market Report." National Renewable Energy Laboratory, U.S. Department of Energy, July 2021, www.nrel.gov/docs/fy21osti/78291.pdf

[15] Ness, J. Erick, et al. "Energy Action Plan - National Renewable Energy Laboratory (NREL)." National Renewable Energy Laboratory, U.S. Department of Interior Office of Insular Affairs, Sept. 2016, www.nrel.gov/docs/fy16osti/67091.pdf

[16] United States Geological Survey. "The Geysers Geothermal Field." U.S. Geological Survey, 2023, www.usgs.gov/volcanoes/clear-lake-volcanic-field/geysers-geothermal-field.ii

[17] Baring-Gould, Ian, et al. "Guam Initial Technical Assessment Report - National Renewable Energy..." National Renewable Energy Laboratory , U.S. Department of Interior Office of InsularAffairs , Apr. 2011, www.nrel.gov/docs/fy11osti/50580.pdf

[18] Evans, Catherine. "Geothermal Energy and Heat Pump Potential in Kansas." KGS Pub. Inf. Circ. 31Playas in Kansas and the High Plains, Kansas Geologic Survey, Apr. 2006, www.kgs.ku.edu/Publications/PIC/pic31.html

[19] Amende, Kevin. "MSU Researchers Help Pioneer Geothermal Technology That Could Reduce Cost." Montana State University, 18 Nov. 2021, www.montana.edu/news/21624/msu-researchers-help-pioneer-geothermal-technology-that-could-reduce-cost

[20] Enel Green Power. "Stillwater Triple Hybrid Plant, USA." Enel Green Power, https://www.enelgreenpower.com/our-projects/operating/stillwater-hybrid-plant

[21] Robinson-Avila, Kevin. "There's Almost Unlimited Clean, Geothermal Energy under Our Feet. New Tech Could Help Unleash That Potential in New Mexico." Albuquerque Journal, 28 Jan. 2023, www.abqjournal.com/2568570/theres-an-almost-unlimited-amount-of-clean-geothermal-energy-under-our-feet-new-tech-could-help-unleash-that-potential-in-new-mexico.html

[22] Murphy, Connor. "New Idea for New Town, N.D.: Geothermal Energy." UND Today, University of North Dakota, 1 Nov. 2022, blogs.und.edu/und-today/2022/11/new-idea-for-new-town-n-d-geothermal-energy/

[23] Mink, Leland Roy, et al. Geothermal Resource Assessment of the Commonwealth of the Northern ..., Apr. 2012, www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/1635.pdf

[24] Warren, Sarah. "OU Researchers Receive Department of Energy Grant to Pioneer Demonstration and Repurposing of Retired Oil Wells into Geothermal Wells." The University of Oklahoma, 24 Jan. 2022, www.ou.edu/mcee/news/news-releases/ou-researchers-receive-department-of-energygrant-to-pioneer-dem

[25] Oregon Department of Energy (OR DOE). 2022 Biennial Energy Report: Energy by the Numbers. Oregon Department of Energy, 2022, www.oregon.gov/energy/Data-and-Reports/Documents/2022-BER-Energy-by-the-Numbers.pdf

[26] Boyd, Tonya. "Geothermal Use in the Dakotas. Geo-Heat Center Quarterly Bulletin, Vol. 31, No. 1 (Complete Bulletin). A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources." Geo-Heat Center Quarterly Bulletin, Oregon Institute of Technology , 1 May 2012, www.osti.gov/servlets/purl/1209221

[27] Sage Geosystems. "Sage Geosystems Featured in Canary Media Article, "This Texas geothermal startup is storing energy in the ground."" Sage Geosystems, 2023, https://www.sagegeosystems.com/sage-geosystems-featured-in-canary-media-article-this-texas-geothermal-startup-is-storing-energy-in-the-ground/

[28] Steely, Alex. Fact Sheet Washington Geological Survey Geothermal Resources in ... - DNR, Washington Department of Natural Resources, 2023 www.dnr.wa.gov/publications/ger_fs_geothermal_resources.pdf

[29] Petrolern LLC. Final Report of Geothermal Resource and Applicable Technology for Wyoming, Wyoming Energy Authority , July 2022, wyoenergy.org/wpcontent/uploads/2022/11/Petrolern_FinalReportWYGeothermalPotentialAndApplicableTechnology_FINAL1Aug2022.pdf

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