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OPPORTUNITIES AND CHALLENGES FOR ADVANCED GEOTHERMAL ENERGY DEVELOPMENT IN THE UNITED STATES

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

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OPPORTUNITIES AND CHALLENGES FOR ADVANCED GEOTHERMAL ENERGY DEVELOPMENT IN THE UNITED STATES

THURSDAY, JUNE 20, 2019

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 9:56 a.m. in Room SD–366, Dirksen Senate Office Building, Hon. Lisa Murkowski, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

The CHAIRMAN. We are going to have an opportunity this morning to talk about an area that I have great, great enthusiasm for, and my only regret is that we are not seeing enough, in my view, focus on the issue of our extraordinary assets that are below our Earth's surface—and this is geothermal. So as we welcome our panelists to the table here this morning, again, I want to thank my colleagues for their interest in this.

We had an opportunity just a few weeks ago to go to the Arctic, yet again with several colleagues. We were in Iceland and had the opportunity to see the extraordinary potential of a nation that has decided that they are going to take advantage of their renewable resources with a goal and a vision to be 100 percent renewable.

It is not all through geothermal, many of their renewables come to them through their hydro resources, but then they supplement that with geothermal and the opportunity to not only use geothermal for heating, to thaw the ice and the snow off their sidewalks, for their public swimming pools, but for everything as innovative as drying the bones and skins of cod that come from the processing facility so that they can be sent over to African nations as a protein base. It is what they are able to do when they have this extraordinary resource—a good example of the almost limitless power of the Earth's internal heat.

It is countries like Iceland, the Philippines, Kenya, and El Salvador that have realized the enormous potential of this emissions-free resource. They have made it a majority source in their energy supply mix. But unfortunately, outside of several states in the West, geothermal has been historically overlooked here in this country.

It is interesting that on this Committee we have so many members that actually have geothermal interests in their states. Senator Lee from Utah, Senator Risch from Idaho, Nevada enjoys the benefits of geothermal. We certainly have it in Alaska. We have great opportunities throughout the country, and I think being able to identify those opportunities should be a priority.

Whether it is used for heating our homes or keeping the lights on, geothermal provides clean and always-on energy that requires no external backup. We talk a lot about well, we have great potential for the wind but what happens when the wind isn't blowing? Great potential for the sun and solar, but what happens when it is nighttime and the sun is not out?

You do not hear that with geothermal. These resources are constant. They are reliable. There is no such thing as fluctuating, intermittent earth heat. So that is a pretty big advantage here.

A new report from the Department of Energy entitled "GeoVision: Harnessing the Heat Beneath Our Feet," calls geothermal the untapped energy giant. They have determined in this report that geothermal could represent a much, much larger percentage of the U.S. energy mix by 2050. We could be looking at a 26-fold increase from where we are today. This rivals the growth of solar, wind, and hydraulic fracturing. So the potential is out there. I think it is pretty extraordinary.

I was a little disappointed in that report that Alaska was not featured in it, but we will keep working on that. Setting that aside, I look forward to hearing more about what went into the report. I think it is a pretty useful roadmap for what could lie ahead.

GeoVision does a good job of laying out the technical and the non-technical barriers that have kept us from realizing geothermal's potential. It shows that if we can address them, through policy and innovation, this resource can make a huge contribution to America's future.

When I talk to folks about geothermal, one of the things they tell me is that, well it is challenging because we are viewed as a "mature" renewable. If you are mature, there is not a lot of interest in doing something new because what is new? This is stuff that has been around forever and what more can be done to enhance it? I think that is part of the reason for the conversation here today.

Regulatory reforms alone, we understand, could double geothermal capacity and technology improvements focused on exploration, discovery, development and management of these resources could, again, increase geothermal electric power generation nearly 26-fold from where we are today. I think that is significant.

In Alaska, we have pretty abundant supplies of geothermal. I tell people you have an Aleutian Chain down there that is nothing more than a string of volcanoes around the South-Central area—great potential for geothermal there that we have visited with an estimated 2.4 gigawatts of possible generation there. The most current assessment ranks us behind only California and Nevada in generation potential. We are starting to take advantage of this resource around the state.

I think you have been to Chena Hot Springs haven't you, Mr. Simmons? If you haven't, Dan Brouillette has.

Mr. SIMMONS. Yes.

The CHAIRMAN. We have had several others from the Department of Energy that have come to our renewable energy fair and seen the benefits of low temperature geothermal there at Chena that provides for heat and power to this small resort far, far below the cost of diesel electricity which is how they were generating their power. In Juneau, our state capital, geothermal heat pumps support the airport. We also, again, have promising regions on the Seward Peninsula, interest in what is going on just North of Nome and, of course, I mentioned the Aleutian Islands. These are pretty exciting prospects for a state where the cost of power generation is a significant challenge and where the opportunity for a clean, reliable resource like geothermal could go a long way toward easing that burden.

I am looking forward to our panel this morning. This is the first hearing that we have had on geothermal since 2006. How could that possibly be? It is such an exciting area. Wow. We are going to fix that today.

We have five experts who can tell us more about the findings in the new GeoVision report as well as other recent developments. We have Mr. Daniel Simmons, who is the Assistant Secretary of Energy for the Office of Energy Efficiency and Renewable Energy. Mr. Timothy Spisak, who is the State Director for New Mexico, Oklahoma, Texas, and Kansas at the Bureal of Land Management (BLM). We have Katherine Young, the Geothermal Program Manager at the National Renewable Energy Lab (NREL). We always love having folks from NREL here. We have Mr. Tim Latimer, who is the Founder and CEO of Fervo Energy, and Mr. Paul Thomsen, the Vice President of Business Development for Ormat. We like what is going on at Ormat.

Senator Manchin.

STATEMENT OF HON. JOE MANCHIN III, U.S. SENATOR FROM WEST VIRGINIA

Senator MANCHIN. Chair Murkowski, thank you for holding this hearing today on advanced geothermal technologies. I would like to thank each of you for being here and for sharing your expertise with all of us today.

Geothermal has been an exciting resource to follow in West Virginia. We have a few hot spots, and we are looking to put in a blue lagoon. I want you all to know, if you have not been to the Blue Lagoon, we want every state to have one.

But I want to tell you something. If you see how these two beautiful women on my left and right—we were on this trip with Chair Murkowski to the Arctic and we all went to the Blue Lagoon. The mineral facials, I have found out, only work on women.

[Laughter.]

Did not do a thing for us, not a thing.

In the Arctic the climate impacts are so severe and immediate that every one we spoke with considers it a matter of survival rather than a matter of partisan discord. What I walked away from the meetings we had with all the Arctic nations was that they do not look at it as a political divide. They look at it as something that unites them, because it is a matter of survival for them.

I would encourage all of my colleagues, especially any of you all out there, if you get a chance, to go to the Arctic. It is something special. When you see the fisheries their communities depend on change, or a foreign ship passes through those straits that would have been blocked by sea ice, you have to face the realities that climate change is the new way.

Another thing that I could not believe, and we are seeing for the first time, cruise ships are building ice cutter cruise ships. That tells you the impact that the Arctic is going to have to deal with, and they are concerned about that. But when cruise ships know that there is a market and they are willing to build an ice cutter cruise ship, it tells you that things have changed.

One of the standout climate solutions I saw on the trip was the widespread adoption of geothermal energy in Iceland. Although I understand Iceland relies on the southern conventional geothermal technologies to heat their homes and power their grid, it struck me that technology was valuable because of its usefulness across the different applications. If the people of Iceland can harness their hot springs and underground resources to generate clean energy, it makes me think there are even more ways to utilize this set of climate solutions here in the United States if we support the needed research and development. It always goes back to investing in things that we need to be investing in.

The International Energy Agency, the IEA, reports that global geothermal power generation stood at an estimated 84.8 terawatt-hours in 2017. That is about the amount of energy used by eight million American homes each year. The IEA expects global geothermal power capacity to rise to over 17 gigawatts in the next five years with the biggest capacity additions expected in Indonesia, Kenya, the Philippines, and Turkey. These four countries include markets where China has rapidly expanded its trade, exporting coal power technologies, financing power plants and other infrastructure, and importing raw materials like titanium. Helping American companies capture the lion's share of the growing global geothermal market and even expand it further is a worthy goal. It would also enable the United States to continue our global leadership in clean energy innovation and climate solutions. The members in our Committee represent some of the states where geothermal energy is a significant part of the renewable power in heating and cooling. In fact, virtually all of our members' states have a stake in enhanced geothermal systems that are within reach.

A whole host of new technologies and methods are changing the outlook for geothermal, from adapting drilling techniques from the oil and gas industry to utilizing more accurate mapping of the resources.

In West Virginia, we are also beginning to see opportunities. A 2010 Southern Methodist University study found that West Virginia is particularly well-suited for geothermal development, including exporting geothermal electricity generation, and adopting district heating in some cities' industrial sites and other university campuses. Perhaps most interesting is a proposed geothermal facility in an abandoned coal mine in Mingo County which is seeking to use the heat in a large aquaponics facility. My understanding is that this is only the beginning for the potential resources in my State of West Virginia, with up to $27 billion in potential investment across enhanced geothermal technologies through 2050.

So enhanced geothermal presents an opportunity to draw on proven technologies, and with a little work on research, development, and deployment, make a significant impact on clean electricity, heating, and cooling.

I look forward to hearing from you all, each one of you, with your expertise, and we are excited to have a new direction, especially in my state.

Thank you, Madam Chairman.

The CHAIRMAN. Thank you.

I have given everybody's brief introduction and titles and, because we would like to get into the meat of the hearing, we will dispense with further background bios and just invite you all to provide your testimony to the Committee this morning.

We would like for you to try to keep your comments to about five minutes. Your full statements will be included as part of the record. We truly appreciate you being here and helping to educate us on where we are with geothermal.

Mr. Simmons, welcome, and if you would like to begin your comments?

STATEMENT OF HON. DANIEL R. SIMMONS, ASSISTANT SECRETARY, OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY

Mr. SIMMONS. Thank you, Chairman Murkowski, Ranking Member Manchin and members of the Committee. Thank you for the opportunity to discuss geothermal energy development and activities that the United States Department of Energy (DOE) is undertaking to help secure America's energy future.

As an always-on energy source that harnesses Earth's natural heat, geothermal energy provides baseload power with flexibility to ramp on and off. Geothermal power plants can provide essential grid services and operate in a load following mode; helping to support reliability and flexibility in the U.S. grid and ultimately facilitate a diverse, secure energy mix.

DOE's Geothermal Technologies Office invests in R&D to reduce costs and risks associated with geothermal development. DOE and the Geothermal Technologies Office recently released the GeoVision report which summarizes data confirming that there is more that geothermal can do for the country.

The GeoVision analysis represents a multiyear collaboration among industry, academia, national laboratories, and federal agencies. The effort assessed opportunities to expand nationwide geothermal energy development through 2050. The GeoVision analysis explored three electric sector scenarios. Under the business as usual scenario, geothermal electricity capacity grows to six gigawatts by 2050, about double what it is today.

However, under the improved regulatory timeline scenario, project development timelines could be halved leading to installed geothermal capacity to more than double that of the business as usual scenario up to 13 gigawatts by 2050. These results show that reduced timelines from first exploration to full power plant operations can strongly impact the amount of geothermal energy on the U.S. grid.

The technology improvement scenario illustrates the opportunity for dramatic growth in geothermal energy to potentially 60 gigawatts of installed generation capacity by 2050 which is more than a 26-fold increase over today. For context, that would be 8.5 percent of all U.S. electricity generation in 2050 compared to less than one percent today.

The GeoVision analysis also shows how geothermal can significantly enhance heating and cooling solutions for American residential and commercial customers through direct use and heat pump technologies.

It also examined economic benefits and opportunities for desalination, critical minerals recovery and hybrid applications.

Perhaps most critically, the report includes a roadmap of actionable items for all geothermal stakeholders. This call to action outlines the opportunities and challenges for advancing geothermal development in the United States.

DOE is already addressing many of the action areas in the GeoVision roadmap with our current research portfolio. I'd like to highlight a few of these activities being spearheaded by the Geothermal Technologies Office.

Our flagship initiative, the Frontier Observatory for Research and Geothermal Energy, or FORGE, is a dedicated site for scientists and engineers to develop, test and accelerate breakthroughs in enhanced geothermal systems, or also called EGS. EGS commercialization is required to harness the full potential of geothermal energy.

Last summer, the Geothermal Technologies Office selected the final FORGE site at Milford, Utah, with a University of Utah-led team. Starting late this summer, FORGE funding will support tasks necessary for program management and oversight as well as annual competitive R&D solicitations open to the entire stakeholder community.

Drilling can represent up to half the cost of a geothermal project. The Geothermal Technologies Office's Efficient Drilling for Geothermal Energy Activity is funding 11 projects to investigate new, more cost-effective drilling techniques and technologies.

Finding geothermal resources, especially systems with no obvious surface expression, remains an expensive challenge to geothermal development. The Geothermal Technologies Office's Play Fairway Analysis (PFA) initiative uses datasets combined, dataset combinations, to pinpoint high potential areas. The Geothermal Technologies Office is currently funding validation drilling for five Play Fairway projects. Early indications show remarkable success at several of these sites.

As part of the Advanced Energy Storage Initiative in the Department of Energy's Grid Modernization Initiative, the Geothermal Technologies Office is funding geothermal-related projects to analyze power curtailment, enhanced reservoir thermal energy storage, and improved dispatchability, along with studies to determine the economic feasibility of low temperature, deep direct use technologies in regions around the country.

Geothermal research is critical to the Department's all technologies energy strategy. We have made great strides in adding geothermal as part of a portfolio of affordable energy options and will continue to do so with DOE's robust R&D portfolio.

DOE is committed to working in partnership with industry, academia, national laboratories, and other federal agencies to support the next generation of geothermal R&D while working with Congress to ensure appropriate stewardship of taxpayer dollars.

I appreciate the opportunity to appear before the Committee today to discuss DOE's work in geothermal research and look forward to the questions.

[The prepared statement of Mr. Simmons follows:]

Testimony for the Record

The Honorable Daniel R. Simmons

Assistant Secretary
Energy Efficiency and Renewable Energy

FOR A HEARING ON

Examining Geothermal Energy Development

BEFORE THE
UNITED STATES SENATE
COMMITTEE ON ENERGY AND NATURAL RESOURCES

June 20, 2019
Washington, D.C.

Introduction

Chairman Murkowski, Ranking Member Manchin, and members of the Committee, thank you for the opportunity to discuss the opportunities and challenges of geothermal energy and the activities that the U.S. Department of Energy is undertaking to secure America's future through energy independence, scientific innovation, and national security.

The Geothermal Technologies Office and Geothermal Energy

The Geothermal Technologies Office (GTO), within DOE's Office of Energy Efficiency and Renewable Energy (EERE), conducts research and development (R&D) to reduce costs and risks associated with geothermal development by supporting innovative technologies that address key exploration and deployment barriers.

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

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

Geothermal is on a path to becoming a widely available renewable energy source, a "50-state" solution. As Secretary Perry said just last month, "There is enormous untapped potential for geothermal energy in the United States. Making geothermal more affordable can increase our energy options for a more diverse electricity generation mix and for innovative heating and cooling solutions for all Americans." This comment accompanied the release of the *GeoVision* report on May 30, 2019. We know there is more that geothermal can do for this country, and how to get there is outlined in the *GeoVision* report.

***GeoVision* Study & Results**

I'm excited to share the results of the *GeoVision* report with you today and what it means for the future of geothermal.

The *GeoVision* analysis represents a multiyear collaboration among industry, academia, the National Laboratories, and federal agencies to evaluate the potential for different geothermal resources. The effort assessed opportunities to expand nationwide geothermal energy deployment through 2050 by improving technologies, reducing costs, and addressing project development barriers such as long permitting timelines.

The study highlights the vast potential for geothermal energy in both the electric and non-electric sectors to 2050.

The *GeoVision* study explored three scenarios in the electric sector. Under the business as usual scenario, geothermal generation capacity grows to 6 GW by 2050, about double what is available today.

However, under the improved regulatory timeline scenario, geothermal capacity could more than double beyond business as usual, to 13 GW by 2050. Results indicate that reducing the timeline from first exploration to full power plant operations can have a strong impact on the amount of geothermal energy on the U.S. grid.

In the technology improvements scenario, geothermal can realize dramatic growth in geothermal electricity generation and potentially increase geothermal generation more than 26-fold from today's level—reaching 60 GW of installed capacity by 2050. This capacity would make up 3.7% of total U.S. installed capacity in 2050, and generate 8.5% of all U.S. electricity generation.

The *GeoVision* analysis also shows how geothermal can profoundly enhance heating and cooling solutions for American residential and commercial consumers through direct-use and heat-pump technologies. Technology improvements could enable more than 17,500 geothermal district-heating installations nationwide, up from the 21 installations in use today. Additionally, 28 million U.S. households could realize cost-effective heating and cooling solutions through the use of geothermal heat pumps, up from 2 million geothermal heat pumps currently installed.

The *GeoVision* analysis also examined economic benefits to the U.S. geothermal industry; investigated opportunities for desalination, critical materials recovery, and hybridization with other energy technologies for greater efficiencies and lower costs; and quantified potential environmental impacts of increased geothermal deployment.

Perhaps most critically, the *GeoVision* analysis includes a roadmap of actionable items for all geothermal stakeholders to reduce technology costs and speed up project-development timelines. This call to action outlines the opportunities and challenges that lie ahead for advancing geothermal development in the U.S. and includes four Action Areas:

1. Research related to resource assessments, improved site characterization, and key technology advancements;
2. Regulatory process optimization;
3. Maximizing full value of geothermal energy; and
4. Improved stakeholder collaboration.

Current Research

The *GeoVision* Roadmap is meant to serve as a guide that the collective geothermal community, including DOE, can use to allow the nation to harness the untapped potential offered by geothermal resources. DOE is already addressing many of these action areas with our current research portfolio. I'd like to highlight just a few of the activities spearheaded by our Geothermal Technologies Office.

Frontier Observatory for Research in Geothermal Energy (FORGE)

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

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

Efficient Drilling for Geothermal Energy (EDGE)

Early-stage R&D in drilling technologies presents an opportunity for innovation that can have a big impact in making new geothermal development more economical. Drilling operations can be up to 50% of the cost of geothermal development. Given that much of the drilling occurs in the early stages of a project, complications from drilling failures can lead to cascading consequences resulting in overall project failure. Enabling the geothermal industry to drill more efficiently will reduce both the risk and cost and can help spur industry to expand capacity in the near-term.

GTO solicited projects in FY 2018 to enable the geothermal industry to double the average penetration rate for a geothermal well and improve the industry standard drilling rate of 250 feet per day by 2025. GTO has funded 11 projects covering three research areas: (1) reducing non-drilling time, (2) advanced drilling technologies, and (3) innovative partnership models.

Play Fairway Analysis (PFA)

A major barrier to the development of the large geothermal resources in the United States is the difficulty in locating blind geothermal systems (i.e., systems with no obvious surface expression), along with the great expense of exploratory drilling. GTO has made a priority of advancing the state of the art in exploring for blind hydrothermal systems, and key among these technologies is the concept of play fairway analysis. Already successfully used in the oil and gas sector, play fairway analysis can be a key tool for decision making in any exploration project. GTO's efforts to adapt play fairway methods for use in geothermal exploration, with the ultimate goal of quantifying and reducing risk in geothermal exploration, have been very successful to date.

The goal of GTO's Play Fairway Analysis is to use combinations of data sets to pinpoint high-grade potential drilling areas. The initiative, which will wrap up in early 2020, is comprised of three phases. Phase 1, a desktop analysis phase, supported 11 projects, including projects in Idaho, Utah, Oregon, Washington, Hawaii, Nevada, and New Mexico. Validation is key to reproducibility; reproducibility is the key to cost and risk reduction, and to industry adoption of new techniques. In the final, current phase of Play Fairway, GTO is funding validation drilling for five of these projects. Results are still being analyzed, but early indications show astounding successes at several of the sites.

Advanced Energy Storage Initiative (AESI)

GTO supports R&D in the Advanced Energy Storage Initiative as part of DOE's Grid Modernization Initiative. Energy storage is critical to advance a flexible, resilient electrical grid and expand affordable mobility options from a diverse suite of energy resources, including both the electric and the non-electric sectors.

Within AESI, GTO is supporting geothermal-related projects seeking to analyze power curtailment, enhance reservoir thermal energy storage, and improve dispatchability through ground source heating and cooling and hybrid technologies. These projects focus on opportunities for flexible generation, controllable loads, and new approaches to the broader concept of energy storage to increase energy reliability and resilience.

In the non-electric sector, a subset of advanced energy storage systems, Deep Direct-Use (DDU), which utilizes low temperature ($<150^0$C) geothermal resources, has the potential to lower the cost of heating and cooling for university campuses, industrial parks, and military installations across the entire U.S., as well as address more global energy storage and resilient grid needs. GTO is funding six DDU studies to determine the economic feasibility of these technologies in various regions around the country.

Other current GTO R&D

GTO is making significant strides in addressing additional R&D challenges and seeking innovative solutions for technology improvements, such as:

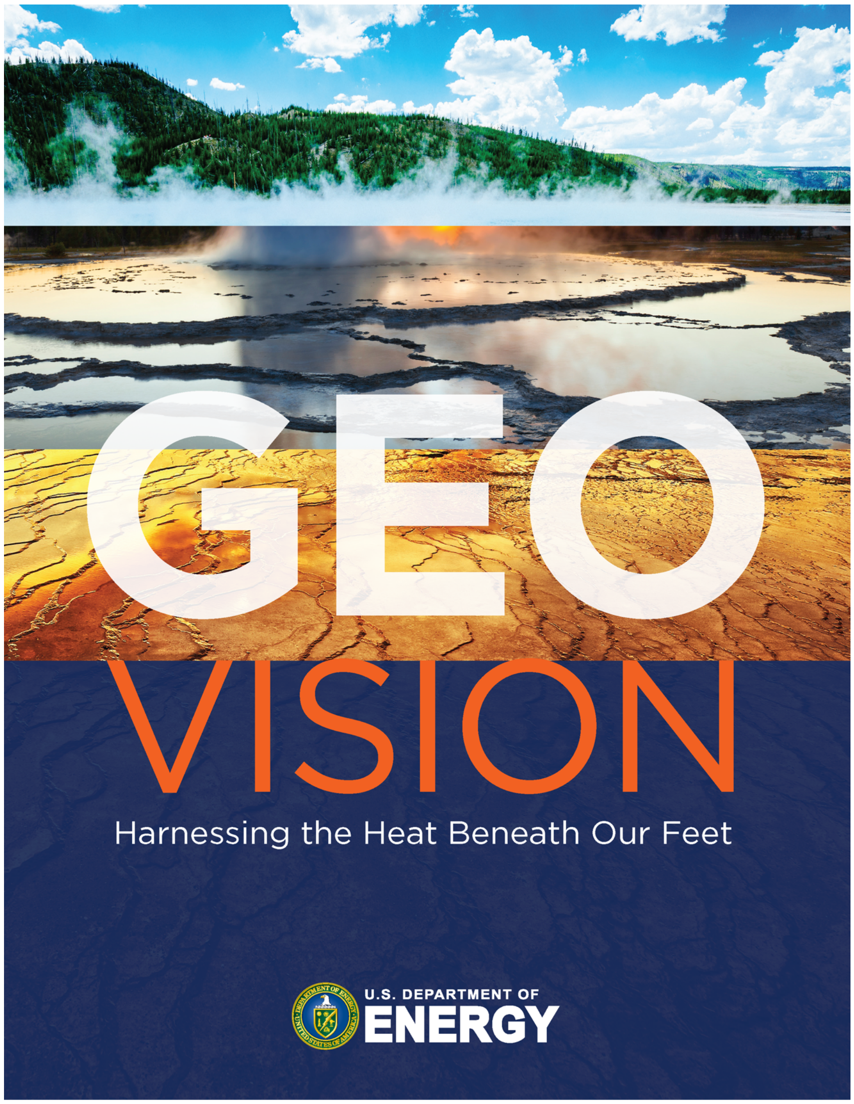
- Zonal Isolation for Geothermal Reservoirs – technologies that can target specific zones efficiently and predictably for creating extensive and optimized fracture networks

- Waterless Stimulation – investigating new stimulation methods applied to geothermal wellbores that do not use conventional water-based fluids to ease the demands for water for energy uses, especially in water-starved regions of the U.S.
- Machine Learning for Geothermal Energy – new analytical tools to boost exploration and development of geothermal resources, and to maximize the value of the rich datasets utilized in the geosciences
- Lost Circulation & State of Stress - improved technologies for understanding subsurface stress, as well as novel or improved means for dealing with lost circulation events are key to lowering the cost of accessing geothermal resources

Conclusion

Geothermal research is an integral component of the Department's applied energy research and development portfolio. Geothermal energy has great potential to address this country's needs for energy affordability, energy integration, and energy storage. We've made great strides in adding geothermal energy as part of the portfolio of affordable energy options, and we'll continue to do so with a strategic and targeted R&D portfolio to continue to strengthen our energy security and independence.

DOE is committed to working in partnership with industry, academia, national laboratories, and other federal agencies to support the next generation in geothermal R&D, while ensuring appropriate stewardship of taxpayer investments. I appreciate the opportunity to appear before this committee to discuss DOE's work in geothermal research and the *GeoVision* report. Thank you for your time.


GEO
VISION
Harnessing the Heat Beneath Our Feet
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ENERGY

Sunset over a U.S. Department of Energy geothermal test site (Naval Air Station Fallon in Nevada).
Photo credit: Dick Benoit

Foreword

This report is being disseminated by the U.S. Department of Energy (DOE). As such, the document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by DOE. As detailed in Chapter 1, the report was reviewed both internally and externally prior to publication, even though it does not constitute "influential" information, as that term is defined in DOE's information quality guidelines or the Office of Management and Budget's Information Quality Bulletin for Peer Review (Bulletin).

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Unless otherwise specified, all photos are submissions from the Geothermal Resources Council's Annual Geothermal Amateur Photography Contest.

Letter from the Director

The Earth beneath our feet contains vast energy potential, enough to power the global electric grid many times over. This natural geothermal heat radiating from the Earth's mantle—a byproduct of our solar system's formation billions of years ago—is virtually limitless in supply. Over the past century, geothermal researchers and operators have worked to harness this resource. Geothermal is an increasingly valuable contributor to energy diversity—and for good reason: it's an "always-on," renewable, 50-state solution that can provide flexible electricity and heating and cooling solutions to all Americans.

To grow as a national solution, geothermal must overcome significant technical and non-technical barriers in order to reduce cost and risk. The subsurface exploration required for geothermal energy is foremost among these barriers, given the expense, complexity, and risk of such activities. Early-stage research into technology improvements can help reduce development costs and improve exploration and production, all of which are essential to achieving geothermal's full potential. Realizing this potential will, in turn, drive investment in America's energy diversity. The status of geothermal energy mirrors the oil and gas industry at a time when unconventional oil and gas reserves were known, but the technology did not exist to produce them economically. Through research and collaboration, the oil and gas industry was able to tackle those barriers and attain access to previously untapped resources.

To evaluate similar opportunities for the success of geothermal energy, the U.S. Department of Energy's Geothermal Technologies Office (GTO) initiated the *GeoVision* analysis. This rigorous technical analysis evaluated future geothermal deployment opportunities based on three core objectives:

- Increased access to geothermal resources
- Reduced costs and improved economics for geothermal projects
- Improved education and outreach about geothermal energy through stakeholder collaboration.

The *GeoVision* analysis concludes that meeting all three of these objectives can result in a sizable increase in America's use of geothermal energy. Analysis results show that, with technology improvements, geothermal power generation could increase nearly 26-fold from today—representing 60 gigawatts of installed capacity by 2050. This capacity is paired with tremendous potential for using geothermal energy for heating and cooling: *GeoVision* analysis models indicate the opportunity for more than 17,500 district-heating installations as well as heating and cooling for the equivalent of more than 28 million households using geothermal heat pumps by 2050. Achieving the deployment levels in the *GeoVision* analysis can also deliver substantial value to all Americans by contributing to the long-term portfolio of affordable energy options and providing environmental benefits. Through increased geothermal deployment, America could realize a stronger geothermal energy sector, a more stable power grid, and economic and environmental benefits.

In the pages that follow, you will gain insight into more than just detailed analyses; this report shows us how to move the geothermal dial from what we know exists to what we envision is possible over the next 30 years. The *GeoVision* analysis takes us beyond a declaration of resource potential by illustrating what is real today and painting a picture of what could be real tomorrow.

How the geothermal stakeholder community chooses to impact that reality is fully in our hands. The comprehensive Roadmap presented in this report forms a call for broad stakeholder action across the geothermal community. Through collaboration, we can move toward a common goal of realizing the *GeoVision* deployment levels and the associated benefits to the nation.

The *GeoVision* report reflects a multiyear effort with contributors from industry, academia, national laboratories, and federal agencies. A total of 20 independent experts vetted each step of the analytic process, and a group of more than 40 reviewers representing the domestic and international stakeholder community appraised and commented on the report draft. All participants in this process were instrumental in documenting the state of the industry. On behalf of everyone at GTO, I offer my sincerest thanks to each of you involved in building this view into the future of geothermal energy.

Best regards,

Dr. Susan G. Hamm
Director, Geothermal Technologies Office
U.S. Department of Energy

Introduction

Energy is the heartbeat of America. It touches nearly everything we do every day—from life at home; to work and communication; to critical infrastructure that saves lives in hospitals, strengthens our national security, and transports us to new places. Some of the most vital questions for the United States in the 21st century focus on energy, including: Where will we get our energy, and how can we build secure, reliable, and resilient systems that accommodate a changing energy mix? How do we protect U.S. energy interests and innovation while participating in a global economy? Which energy solutions ensure economic and environmental vitality today and into the future?

Geothermal energy provides an answer to many of these essential questions. The "heat beneath our feet" is an always-on source of secure, reliable, and flexible domestic energy that can be utilized across industrial, commercial, and residential sectors. The use of geothermal energy also offers important benefits to the nation, including grid stability, greater diversity in the portfolio of affordable energy options, efficient heating and cooling, and reduced air pollution.

Despite the benefits of geothermal energy and its ability to meet some of the nation's most pressing energy needs, the United States has tapped only a fraction of its abundant geothermal resources. Harnessing the full potential of U.S. geothermal resources will strengthen domestic energy security and allow the United States to continue its leadership in energy innovation.

To examine this potential for geothermal resources to play a key role in the nation's energy future, the U.S. Department of Energy (DOE) initiated the *GeoVision* analysis. The analysis is based on rigorous modeling and simulation that enabled a team of experts to assess the state of geothermal energy, quantify growth opportunities and associated impacts on the nation, and formulate actions to increase geothermal deployment.

This report, *GeoVision*: *Harnessing the Heat Beneath Our Feet,* summarizes the analyses and discusses the many opportunities that geothermal energy offers in both electric and non-electric uses. The report also highlights the outcomes the United States could realize from increased geothermal deployment and outlines a range of activities necessary to reach this deployment. The goal is to provide a glimpse into the abundant possibilities that geothermal energy has to offer the nation and to highlight some of the steps needed to increase geothermal deployment. The full body of analytical work is detailed in the *GeoVision* Analysis Supporting Task Force Reports, as listed in the references section. Not all assumptions, results, and scenarios used in the analysis are contained within this report.

The *GeoVision* report is organized as follows:

Executive Summary	High-level summary of the *GeoVision* analysis and highlights of key findings
Chapter 1: Developing the *GeoVision*	Overview of the *GeoVision* analysis, approach, and findings
Chapter 2: What is Geothermal Energy?	Brief description of geothermal energy, including electric and non-electric applications in the United States, and barriers to growth
Chapter 3: *GeoVision* Analysis: Models and Scenarios	Summary of the *GeoVision* analysis, models, and scenarios
Chapter 4: *GeoVision* Analysis: Results, Opportunities, and Impacts	Results of the *GeoVision* analysis, including U.S. deployment potential for electric and non-electric uses of geothermal energy and discussion of the potential for geothermal energy to contribute energy diversity and environmental benefits to the nation
Chapter 5: The *GeoVision* Roadmap: A Pathway Forward	Roadmap of actions that, if taken, could support growth in the use and application of geothermal energy in the United States
Appendix A	Acronyms
Appendix B	Glossary
Appendix C	Detailed Modeling Assumptions and Results
Appendix D	Contributors

Geothermal drilling rig near a U.S. Department of Energy test site (Naval Air Station Fallon in Nevada).
Photo credit: Lauren Boyd/U.S. Department of Energy

Executive Summary

Geothermal is America's untapped energy giant.

Geothermal energy is a renewable and diverse solution for the United States—providing reliable and flexible electricity generation and delivering unique technology solutions to America's heating and cooling demands. Geothermal resources can be found nationwide, are "always on," and represent vast domestic energy potential. Only a fraction of this potential has been realized due to technical and non-technical barriers that constrain industry growth.

The U.S. Department of Energy's (DOE's) Geothermal Technologies Office (GTO) engaged in a multiyear research collaboration among national laboratories, industry experts, and academia to identify a vision for growth of the domestic geothermal industry across a range of geothermal energy types. The effort assessed opportunities to expand geothermal energy deployment by improving technologies, reducing costs, and mitigating barriers. The analysis also assessed the economic benefits to the U.S. geothermal industry and the potential environmental impacts of increased deployment—including jobs, consumer energy prices, water use, and air quality—and investigated opportunities for desalination, mineral recovery, and hybridization with other energy technologies for greater efficiencies and lower costs.

The *GeoVision* analysis culminated in this report, *GeoVision*: *Harnessing the Heat Beneath Our Feet.* In addition to summarizing analytical results about geothermal energy opportunities, the report includes a Roadmap of actionable items that can achieve the outcomes of the analysis. The *GeoVision* Roadmap is a comprehensive call to action to encourage and guide stakeholders toward the shared goal of realizing the deployment levels and resulting benefits identified in the *GeoVision* analysis.

The *GeoVision* analysis demonstrates the unique characteristics of geothermal energy and its unrealized potential, including:

- Constant and secure renewable electric power generation with flexible and load-following capabilities that provide essential services contributing to grid stability and resiliency
- Nationwide energy applications through unique capabilities in electricity generation, as well as residential, commercial, and district heating and cooling
- Commercial technologies that are ready to deploy, augmented by developing technologies with vast potential for increased electricity generation and direct-use applications
- Job impacts in both the manufacturing and geothermal sectors
- Revenue potential for federal, state, and local stakeholders, as well as royalty potential for leaseholders.

The *GeoVision* analysis used a suite of modeling tools and scenarios to evaluate the performance of geothermal technologies relative to other energy technologies. The analyses included evaluating the potential role of existing and future geothermal deployment in both the electric sector and the heating and cooling sector. In the electric sector, the analysis considered existing conventional (hydrothermal) geothermal resources as well as unconventional geothermal resources,[1] such as enhanced geothermal systems, or EGS. In the heating and cooling sector, the analysis modeled geothermal heat pumps (GHPs, which are also known as ground-source heat pumps)[2] and district-heating systems (using both conventional and EGS resources).

By evaluating scenarios for increased deployment of geothermal energy, the *GeoVision* analysis provides a foundation to maintain and advance the nation's position as a leader in geothermal energy applications and technology innovation. The models used prevailing and potential future technology assumptions under existing and proposed state and federal policy scenarios. The analysis does not assume or create any previously unintroduced policies; it considers only policies that are in force or have been introduced.

> The *GeoVision* analysis provides a comprehensive assessment of the state of geothermal energy and identifies deployment opportunities and pathways for targeted action that could achieve a shared vision for industry growth.

Key findings of the *GeoVision* analysis:

Technology improvements could reduce costs and increase geothermal electric power deployment.
Improving the tools, technologies, and methodologies used to explore, discover, access, and manage geothermal resources would reduce costs and risks associated with geothermal developments. These reductions could increase geothermal power generation nearly 26-fold from today, representing **60 gigawatts-electric (GW_e)**[3] of always-on, flexible electricity-generation capacity by 2050. This capacity makes up 3.7% of total U.S. installed capacity in 2050, and it generates 8.5% of all U.S. electricity generation. Technology improvements are on the critical path toward achieving commercial EGS. This is vital because the *GeoVision* analysis demonstrates that, relative to other geothermal resources, EGS resources have the potential to provide the most growth in the electric sector. EGS can also support significant growth within the non-electric sector for district heating and other direct-use applications.

Optimizing permitting timelines could reduce costs and facilitate geothermal project development, potentially doubling installed geothermal capacity by 2050.
The *GeoVision* analysis included the examination of key regulatory, permitting, and land-access barriers to geothermal development. Streamlined regulations and permitting requirements can be achieved through a variety of mechanisms to shorten development timelines, which can—in turn—reduce financing costs during construction. For example, the analysis showed that placing geothermal regulatory and permitting requirements on a level similar to that of oil and gas and other energy industries could allow the geothermal industry to discover and develop additional resources and to reduce costs. The *GeoVision* analysis demonstrated that optimizing permitting alone could increase installed geothermal electricity-generation capacity to **13 GW_e** by 2050—more than double the 6 GW_e projected in the Business-as-Usual scenario that serves as the baseline for the *GeoVision* analysis.

Overcoming barriers to geothermal heating and cooling could stimulate market growth.
Geothermal heating and cooling is an underutilized

1 Conventional geothermal resources refer to naturally occurring hydrothermal resources developed using existing technologies (the term "hydrothermal" refers to the combination of water [hydro] and heat [thermal]). Unconventional geothermal resources refer to a class of resources that will require the development of new and innovative technologies to enable economic resource capture. Enhanced geothermal systems, or EGS, are the most significant of the unconventional geothermal resources and are characterized by the presence of a thermal energy source in the Earth's crust that lacks the permeability and/or groundwater necessary for economic energy recovery. These resource characteristics are elaborated in Chapter 2.

2 Heat-pump technologies, which use the thermal properties of the shallow earth to provide renewable and efficient geothermal heating and cooling, are commonly referred to by two different names: geothermal heat pumps, and ground-source heat pumps. The DOE has traditionally referred to this technology and industry as "geothermal heat pumps," and the Internal Revenue Service federal statutes—as well as state renewable portfolio standards that recognize geothermal technology as eligible—have done so historically on the basis of the specific terminology, "geothermal heat pumps." The *GeoVision* analysis uses the term geothermal heat pumps, while acknowledging that some stakeholders, e.g., the International Ground Source Heat Pump Association and the European Union, have started to adopt the name "ground-source heat pumps" to describe the technology and industry.

3 GW_e = gigawatts-electric, which is power available in the form of electricity—in the case of geothermal, converted from heat energy in the Earth. The *GeoVision* analysis also considers gigawatts-thermal (GW_{th}) for direct-use and GHP applications. GW_{th} is the power available directly from heat or thermal energy. In GHP applications, GW_{th} is the heating/cooling capacity of the system itself; for direct-use applications, GW_{th} refers to the heating capacity that is extracted directly from the geothermal heat in the ground and delivered to the direct-use application.

resource for U.S. homes and businesses and an area of key growth potential. The GHP industry is expected to reduce energy costs to residential and commercial consumers and provide greater reliability and consistency in heating and cooling options. The existing installed capacity is about 16.8 gigawatts-thermal (GW_{th}) (Lund and Boyd 2016) and is equivalent to GHP installations in about 2 million households. The *GeoVision* analysis determined that the market potential[4] for GHP technologies in the residential sector is equivalent to supplying heating and cooling solutions to 28 million households, or **14 times greater** than the existing installed capacity. This potential represents about 23% of the total residential heating and cooling market share by 2050. Similarly, the economic potential for district-heating systems using existing direct-use geothermal resources combined with EGS technology advances is **more than 17,500 installations nationwide**, compared to the 21 total district-heating systems installed in the United States as of 2017 (Snyder et al. 2017). These district-heating installations could satisfy the demand of about 45 million households (EIA 2015; McCabe et al. 2019; Liu et al. 2019). Realizing direct-use, district-heating potential will require advancing EGS technology and reducing soft-cost[5] barriers.

Geothermal energy offers economic development opportunities in both rural communities and urban centers across the United States.
The results of the *GeoVision* analysis indicate that taking action consistent with the associated *GeoVision* Roadmap could expand the domestic geothermal industry and potentially add job opportunities in both urban and rural communities. Development of a robust residential and commercial GHP industry could also expand the U.S. geothermal workforce.[6]

Increased geothermal deployment could improve U.S. air quality and reduce CO_2 emissions.
The *GeoVision* analysis indicates opportunities for improved air quality resulting from reductions in sulfur dioxide (SO_2), nitrogen oxides (NO_x), and fine particulate matter ($PM_{2.5}$) emissions. The analysis further identifies opportunities for reduced carbon-dioxide emissions. For the electric sector, this could cumulatively result in up to 516 million metric tons (MMT) of avoided carbon-dioxide equivalent (CO_2e) emissions through 2050. For the heating and cooling sector, impacts through 2050 could cumulatively include up to 1,281 MMT of CO_2e emissions avoided. By 2050, the combined CO_2e reductions for the two sectors is equivalent to removing about 26 million cars from the road annually.

The geothermal deployment levels calculated in the *GeoVision* analysis could be achieved without significant impacts on the nation's water resources.
Compared to the Business-as-Usual scenario, the high levels of deployment evaluated in the *GeoVision* analysis result in a slight increase (~4%) in the amount of water consumed by the power sector in 2050. This increase in consumption can be mitigated through the use of non-freshwater resources such as municipal wastewater and brackish groundwater.

Geothermal energy is secure, reliable, flexible, and constant. It offers the United States a renewable source for power generation as well as heating and cooling of homes and businesses. Geothermal resources and technologies are primed for strong deployment growth and stand ready to provide solutions to meet America's 21st-century demands for energy security, grid stability and reliability, and domestic and commercial heating and cooling needs.

Workers on a drilling rig at The Geysers geothermal field in California.
Photo credit: Robert Hopkins

4 The market potential of a renewable resource is defined broadly as the portion of technical potential that is likely to be deployed considering the technical viability of the project and the reaction of consumers in the market to economic factors (Sigrin et al. 2016, McCabe et al. 2019). See Figure 3-1.

5 Soft costs are non-construction costs incurred before project commissioning, including (among other things): public perception/educating the public, utilities, regulators, and policymakers; risk; financing; permitting; legal fees; insurance; workforce availability and training (including installers and small drillers); political support, e.g., policies, political terms, and regional resources; power purchase agreements; and attracting large players (oil and gas companies).

6 A task force report supporting the *GeoVision* analysis assessed gross job impacts from geothermal deployment compared with business-as-usual scenarios (Millstein et al. 2019). These gross job impacts represent total jobs needed to fulfill increased geothermal deployment. Because those jobs may displace other energy-generation technologies and do not represent the net impact of geothermal jobs on employment within those other sectors, they are not discussed or quantified here. Assessing net job impacts was beyond the scope of the *GeoVision* analysis. Refer to Millstein et al. 2019 for more details about gross jobs impacts.

CHAPTER FOUR

GeoVision Analysis: Results, Opportunities, and Impacts

Grand Prismatic Spring in Yellowstone National Park, Wyoming.
Photo credit: Jim Stimac

Chapter 4

4 *GeoVision* Analysis: Results, Opportunities, and Impacts

As discussed in Chapter 3, the *GeoVision* analysis used detailed, quantitative models to assess geothermal deployment potential under scenarios that consider a range of technologies, market conditions, and barriers. Chapter 3 summarized the *GeoVision* modeling analytics and approach. Chapter 4 presents the modeling results, discusses key takeaways, and presents a summary of impacts to the nation from the levels of geothermal energy deployment projected in the *GeoVision* analysis. Among other findings, the results indicate that geothermal electricity-generation capacity can double based on regulatory reforms alone and that enhanced geothermal systems (EGS) have the potential to supply more than 16% of U.S. electricity generation and support the economic potential for as many as 17,500 district-heating installations by 2050. Findings also indicate that the market potential for geothermal heat-pump technologies is equivalent to supplying heating and cooling solutions to 28 million households. Achieving the levels of deployment discussed in this chapter will require actions aimed at pursuing technology innovations, reducing costs, and overcoming barriers. These actions are discussed in the *GeoVision* Roadmap (Chapter 5).

4.1 Deployment Potential—Electric Sector

The *GeoVision* analysis included modeling of geothermal technology deployment within the electricity market sector for conventional hydrothermal and EGS resources. As discussed in Section 3.2.1, the *GeoVision* analysis included assessing electric-sector opportunities under three primary scenarios: Business-as-Usual (BAU), Improved Regulatory Timeline (IRT), and Technology Improvement (TI). One key finding in the electric-sector modeling is that regulatory reforms assumed in the IRT scenario alone could double the size of installed geothermal capacity through increased access to and development of conventional hydrothermal resources. Additionally, the analysis indicates that improved exploration and drilling technologies envisioned in the TI scenario can assist across the board in the industry's ability to maximize resource capture—including up to 60 gigawatts-electric (GW_e) of electricity-generating capacity by 2050. The most promising growth potential can be realized by advancing early-stage research and development into technologies that support EGS.

4.1.1 Deployment Potential in the Business-as-Usual and Improved Regulatory Timeline Scenarios

The *GeoVision* analysis BAU scenario reflected industry trends and the anticipated future if the industry continues on the same path as 2016 conditions. Results indicate that, under the BAU scenario, installed geothermal net-summer capacity increases from 2.5 GW_e to 6 GW_e by 2050. This result is consistent with existing growth trends in the geothermal industry (Augustine et al. 2019). The BAU scenario serves as the baseline for assessing the impact of other scenarios considered in the *GeoVision* analysis and related studies (Wendt et al. 2018, Millstein et al. 2019, Young et al. 2019).

The Hoch and Vulcan geothermal power plants in California coexist amidst the existing land use.
Photo credit: Martin J. Pasqualetti

The IRT scenario assessed the effect of potential regulatory reforms that could reduce geothermal development timelines by half and triple rates of geothermal exploration and resource discovery. The deployment potentials calculated under the IRT scenario were compared to the BAU scenario to determine the effect regulatory reform alone could have on geothermal development. The results indicate that—using existing geothermal technologies—the geothermal industry could double in size relative to BAU through only regulatory reform (Figure 4-1). The total deployment resulting under the IRT scenario is nearly 13 GW_e by 2050—more than a 5-fold increase over existing installed geothermal capacity and double the installed capacity in 2050 under the BAU scenario. The IRT scenario assumed that applicable regulatory reforms are legally allowed and appropriate for the respective situation.

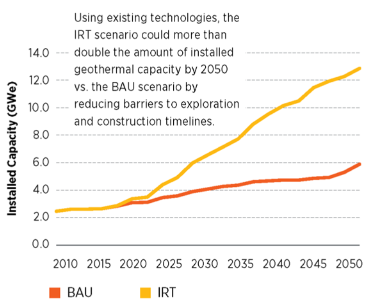


Figure 4-1. Improved Regulatory Timeline scenario results and comparison to the Business-as-Usual scenario for conventional hydrothermal resources

Figure Note: The IRT scenario projects that the geothermal industry could double in size by 2050 compared to the BAU scenario by reducing exploration barriers and construction timelines via regulatory reform. Total deployment in the IRT scenario would reach nearly 13 GW_e by 2050.

The IRT scenario assumed that EGS technologies do not advance beyond existing levels; as such, EGS resources are not commercially viable nor deployed in the Regional Energy Deployment System (ReEDS) model under the IRT scenario. As is the case in the BAU scenario, growth achieved under the IRT scenario is supported entirely by the development of conventional hydrothermal resources, the majority of which are undiscovered hydrothermal resources (Figure 4-2). Exploration that supports conventional hydrothermal resource growth in the IRT scenario results from shorter permitting timelines, which enhance developer access to resources and increase the amount of exploration that can be performed in a given time period.

> Results of the *GeoVision* analysis indicate that—using existing geothermal technologies—the geothermal industry could double in size relative to Business-as-Usual through only regulatory reform.

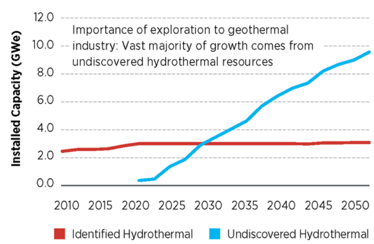


Figure 4-2. Improved Regulatory Timeline deployment results by resource type

Figure Note: Undiscovered hydrothermal resources constitute the majority of the resource capture, which supports overall growth (identified and undiscovered) to about 13 GW_e total (Augustine et al. 2019).

The increased amount and ease of conducting exploration activities under the IRT scenario is assumed to triple discovery rates for undiscovered hydrothermal resources—from 1% to 3% of the total undiscovered resources per year compared to the BAU scenario (Table 3-1). Moreover, the IRT scenario assumes the use of existing exploration technologies. To maximize growth potential across all scenarios, the industry will need to improve exploration technologies so that greater amounts of the undiscovered resource base may be discovered and developed. This result highlights the importance of exploration for facilitating geothermal industry growth and the potential for improved exploration technologies to further advance that growth. When combined with improvements in regulatory timelines, resource access, and drilling technologies, improved exploration technologies present important pathways toward achieving the full deployment potentials identified in the *GeoVision* analysis TI scenario (Section 4.1.2). Actions related to achieving such improvements are discussed in the *GeoVision* Roadmap (Chapter 5).

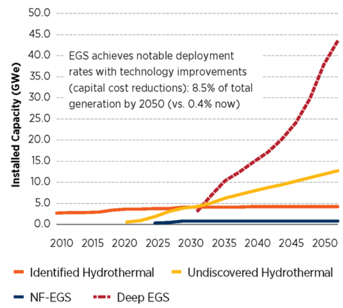


Figure 4-3. Technology Improvement scenario results by resource type

Figure Note: The TI scenario incorporates technology improvements and the resulting cost reductions that drive additional deployment. At the end of the analyzed period (2050), total geothermal deployment in the TI scenario is more than 60 GW_e, with the majority of growth supplied by deep-EGS resource development after 2030 (Augustine et al. 2019). NF-EGS is near-field EGS.

4.1.2 Deployment Potential in the Technology Improvement Scenario

The *GeoVision* TI scenario models the most aggressive and optimistic scenario assumptions and the resulting cost reductions that can drive geothermal deployment. The TI scenario shows particular promise for EGS resource deployment, which stands to benefit substantially from improved technology and reduced capital costs (Table 3-3). The results of the TI scenario indicate the potential for more than 60 GW_e of geothermal power generation net summer capacity, the majority of which would come from deep-EGS resources after 2030 (Figure 4-3). As explained in Section 2.2.1, net summer capacity is defined by the Energy Information Administration (EIA) as, "The maximum output, commonly expressed in MW, that generating equipment can supply to system load, as demonstrated by a multi-hour test, at the time of summer peak demand (period of June 1 through September 30)."

> With technology improvements considered in the *GeoVision* analysis, geothermal power production could support up to 8.5% of total national generation by 2050, as compared to the 0.4% share of total national generation contributed by the existing geothermal industry today.

The levels of deep-EGS deployment shown in Figure 4-3 would require hundreds to more than 1,000 wells to be drilled annually to support EGS project developments. By comparison, the oil and gas industry has been drilling hundreds to more than 1,000 horizontally oriented and hydraulically fractured wells per month (EIA 2018).

With the technology improvements modeled in the TI scenario, geothermal power production could support up to 8.5% of total national generation by 2050, as compared to the 0.4% share of total national generation contributed as of 2017 (Augustine et al. 2019).

Figure 4-4 shows terawatt-hour generation by year within the renewable power sector for the *GeoVision* TI scenario. The results in Figure 4-4 are split into two categories: 1) baseload renewable power—which includes geothermal, hydropower, biopower, and concentrated solar power—and 2) variable-generation renewable power. In the TI scenario, geothermal energy could provide about 57% of the entire baseload renewable power-generation portfolio.[87]

[87] Baseload renewable power includes geothermal, hydropower, biopower, and concentrated solar power.

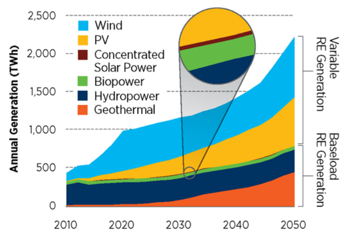


Figure 4-4. Total national generation (terawatt-hours) for the renewable energy (RE) market sector by year for the *GeoVision* Technology Improvement scenario

*Figure Note: The right vertical axis divides the sector into baseload renewable power—which includes geothermal, hydropower, biopower, and concentrated solar power—and variable-generation renewable power. Geothermal power could provide about 57% of the **baseload** RE generation portfolio by 2050 (or 20.4% of all RE generation). Biopower includes landfill-gas generators, co-fired biomass/co-fired coal, and biomass/dedicated biomass. PV is solar photovoltaic.*

The *GeoVision* analysis also evaluated "alternative future" combined scenarios that assess the TI scenario combined with the ReEDS Standard Scenarios.[88] This approach facilitated assessments of external factors—such as electricity demand, fuel prices, technology costs, resource and system constraints, and others—and how those factors combined with technology improvements might change geothermal deployment. One of the combined scenarios that demonstrates potential for geothermal deployment beyond that achievable under the TI scenario alone is summarized in Table 4-1. This particular combined scenario considers the TI scenario in combination with the ReEDS "High Natural Gas Prices" Standard Scenario, which uses scenario projections from the EIA's Annual Energy Outlook 2016. The combined scenario considers a possible future where both the TI scenario assumptions are true and natural-gas prices are assumed to be higher than the 2016 Annual Energy Outlook Reference case for natural-gas projections by using the 2016 Annual Energy Outlook "Low Oil and Gas Resource and Technology" case (Cole et al. 2016b, EIA 2016, Augustine et al. 2019). As noted, the combined scenario represents a possible future situation where geothermal deployment is higher than under the TI scenario alone. The full assessment of combined scenarios considered in the *GeoVision* analysis is summarized in Appendix C and detailed in Augustine et al. 2019.

Scenario	Varied Assumptions	Consistent Assumptions Across Scenarios
TI	None (Mid-case scenario)	Capital and O&M Costs: TI Construction Time, Hydrothermal: 4 years Construction Time, EGS: 5 years Financing: ReEDS Standard WACC (8%)
TI + High Natural-Gas Prices	Future with high natural-gas costs (AEO 2016)	

Table 4-1. Technology Improvement Scenario Combined with a Regional Energy Deployment System Standard Scenario

Table Notes: (1) The combined scenario described here forms the basis for a potential future that has high natural-gas costs in accordance with the AEO's Low Oil and Gas Resource and Technology case (EIA 2016). (2) WACC = weighted-average cost of capital; O&M = operations and maintenance; AEO = Annual Energy Outlook.

Using the combined scenario assumptions in Table 4-1, geothermal deployment levels reach nearly 120 GW_e by 2050 (Figure 4-5) (Augustine et al. 2019). The geothermal technology deployment potentials calculated in the combined scenario comprise less than 10% of total U.S. installed capacity, but would provide over 16% of the country's total generation due to the high capacity factor of geothermal technologies. For the combined scenario, additional deployment compared to the TI scenario alone comes primarily from deep-EGS resources. The amount of installed geothermal capacity expands due to improved

88 The Standard Scenarios are a suite of forward-looking power-sector scenarios that are used within the ReEDS capacity-expansion model (Cole et al. 2016a). The scenarios encompass Earth-system feedbacks, electricity demand growth, electricity generation, existing fleet retirements, fuel prices, the policy and regulatory environment, resource and system constraints, and technology costs. Together, the Standard Scenarios make possible the transparent and quantitative examination of how various inputs impact power-sector development. Moreover, they provide context and data to support understanding of changes in the U.S. power sector and inform stakeholder decision making about its future direction. The Standard Scenarios (Cole et al. 2016a), which are updated each year along with the Annual Technology Baseline, include technology cost and performance assumptions from the Annual Technology Baseline (Cole et al. 2016b).

economic conditions for geothermal (in this case, as higher prices for natural gas). This finding suggests that, under the conditions modeled in the *GeoVision* analysis, geothermal energy growth is limited by the conditions that drive demand for geothermal development and not by resource potential.

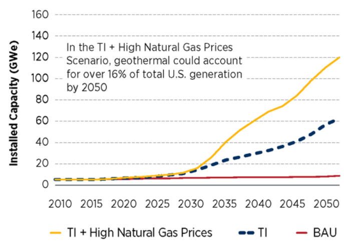


Figure 4-5. Installed geothermal capacity for Technology Improvement scenario compared to a combined scenario and Business-as-Usual

Figure Note: The combined scenario considers the TI scenario in combination with the ReEDS "High Natural Gas Prices" Standard Scenario, which uses scenario projections from the EIA's Annual Energy Outlook 2016. The combined scenario considers a possible future where both the TI scenario assumptions are true and natural-gas prices are assumed to be higher than the 2016 Annual Energy Outlook Reference case for natural-gas projections by using the 2016 Annual Energy Outlook "Low Oil and Gas Resource and Technology" case (Cole et al. 2016b, EIA 2016, Augustine et al. 2019). Appendix C provides additional detail. The combined scenario is compared to the BAU scenario and the TI scenario alone. The TI scenario alone drives greater capacity deployment starting around 2020, with greater growth starting in 2030 from deployment of more deep-EGS resources. The TI + High Natural Gas Prices combined scenario shows similar growth starting in 2030, but grows at a higher rate than the TI scenario alone through 2050. This result indicates that EGS growth is limited by demand and not supply.

4.2 Deployment Potential—Non-Electric Sector

The *GeoVision* analysis assessed opportunities for two non-electric-sector geothermal applications: geothermal direct use for district heating, and geothermal heat pumps (GHPs). Findings illustrate national opportunities for non-electric uses of geothermal energy, with the potential for more than 17,500 geothermal district-heating system installations and a more than 11-fold increase in installed GHP capacity (relative to a 2012 baseline).

> Under a scenario that combined the *GeoVision* analysis Technology Improvement scenario with high natural-gas prices, geothermal deployment levels can reach nearly 120 GW_e by 2050. The deployment potentials for this scenario comprise less than 10% of total U.S. installed capacity, but would represent more than 16% of the country's total generation due to the high capacity factor of geothermal energy.

The *GeoVision* analysis used the Distributed Geothermal Market Demand (dGeo) model for the non-electric sector analysis (Section 3.1.3), and included scenarios for improved technology and—in the case of GHPs—consumer-adoption behaviors. The analysis is summarized in Sections 4.2.1 and 4.2.2 and detailed in McCabe et al. 2019 and Liu et al. 2019.

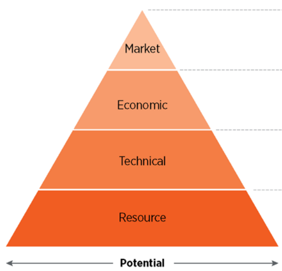
4.2.1 Deployment Potential of Geothermal Direct Use for District Heating

As noted in Chapter 2 (Figure 2-7), there is an immense array of end-use opportunities for geothermal direct-use applications, including agricultural and industrial uses where process heat is required. The *GeoVision* analysis for direct-use applications focused on district heating, which is the most widespread geothermal direct-use application (Lund and Boyd 2015) and which addresses an area of high energy demand: residential and commercial heating at a district scale. The *GeoVision* analysis did not consider district cooling.

Market-potential-based assessments for the geothermal non-electric sector using the dGeo model rely on data about the behavior of individual consumers and their willingness to adopt a technology based on payback period. As explained in Sections 3.2.2 and 3.2.3, geothermal district-heating technologies are deployed by communities whose decision to approve and adopt such installations is complicated by many factors beyond the payback period. As such, the *GeoVision* analysis considered only economic potential for geothermal district heating. As discussed in Chapter 3, economic resource potential represents the portion of total technical potential that is cost effective to recover based on technology costs and anticipated revenues.

The *GeoVision* analysis reports economic potential for geothermal district heating in relation to both the associated conventional hydrothermal and EGS resource bases (i.e., technical and resource potential) and the local demand for district heating (i.e., population density and climate). EGS resources are available over a larger geographic area and represent about 1,000 times more resource potential compared to the corresponding hydrothermal resource potential (McCabe et al. 2019) (Figure 4-6).

The *GeoVision* analysis identified national economic potential for geothermal district heating and confirms that the highest economic potential is co-located with cost-effective resource availability and concentrated heating demand. The economic potential for geothermal district-heating systems using geothermal direct-use resources is more than 17,500 installations nationwide—totaling 320 GW_{th} of heating capacity—with pronounced potential in the Northeast corridor of the United States. Figure 4-7 indicates the most favorable economic potential for geothermal district heating throughout the United States under the *GeoVision* analysis BAU scenario (top left) and under the *GeoVision* TI scenario (top right) (Table 3-5). This economic potential enables cost-competitive development of EGS resources. Both maps include conventional hydrothermal as well as EGS resources. Comparing the economic potential maps to the image of the United States at night (Figure 4-7, bottom left) illustrates the geographic alignment of the widespread EGS resource base and demand centers—discrete population centers that can benefit from geothermal district-heating systems.[89]



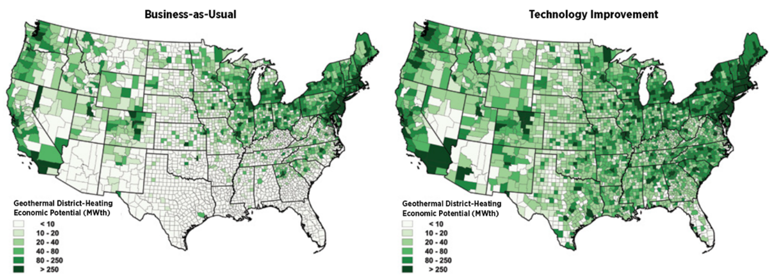
Key Assumptions	Hydrothermal (GW_{th})	EGS (GW_{th})
Policy Implementation/Impacts Regulatory Limits Investor Limits Regional Competition with Energy Sources	–	–
Projected Technology Costs Projected Fuel Costs	4.6 GW_{th} TI	315 GW_{th} TI (2030)
System/Topographic Constraints Land-Use Constraints System Performance	27 GW_{th} TI	1,186 GW_{th} TI (2030)
Physical Constraints Theoretical Physical Potential Energy Content of Resource	46.5 GW_{th} (Mullane et al. 2016)	46,500 GW_{th} (Mullane et al. 2016)

Figure 4-6. Geothermal district-heating deployment potential supported by hydrothermal and enhanced geothermal system resources as a function of resource, technical, and economic potential under the *GeoVision* analysis Technology Improvement scenario

Source: McCabe et al. 2019

Figure Note: Information about district-level consumer behavior for the U.S. geothermal direct-use/geothermal district-heating market was insufficient to enable modeling on the scale of the market potential. The GeoVision analysis assumes that EGS technologies become commercially feasible starting in 2030. "TI" in the Hydrothermal and EGS columns refers to the GeoVision analysis Technology Improvement scenario for geothermal district heating (Section 3.2.3). GW_{th} = gigawatts-thermal.

89 Population centers or groups may include building complexes such as hospitals and campuses. In locations where buildings are more dispersed, district-heating systems would be less cost effective to deploy due to piping costs.



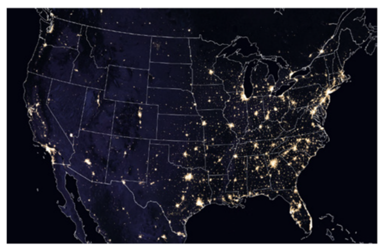


Figure 4-7. Economic potential for geothermal district heating by county in 2050 within the *GeoVision* analysis Business-as-Usual scenario (top left) and Technology Improvement scenario (top right), compared to a satellite image of United States at night, illustrating the geographic location of population centers (bottom left)

Source: McCabe et al. 2019. Satellite image created using data from the National Aeronautics and Space Administration's Earth Observatory.

Figure Note: The distribution of economic potential is closely linked geographically with major population centers. This linkage is illustrated through a comparison to nighttime satellite imagery of the United States (bottom left), which shows the brightly lit locations of population centers. Improved technology costs under the TI scenario result in greater economic potential of geothermal technologies. Deployment potential for geothermal district-heating systems exists throughout the United States, with particular potential concentrated along the Northeast Corridor. The total economic potential for geothermal district-heating systems using geothermal direct-use resources is more than 17,500 installations nationwide.

As is the case for geothermal electricity-generation applications, deployment growth for geothermal direct-use applications such as geothermal district heating will require improved technologies that lower the costs of EGS resource development.

4.2.2 Deployment Potential for Geothermal Heat Pumps

As noted in Section 3.2.2 and Table 3-4, the *GeoVision* analysis looked at two primary scenarios for the GHP market: 1) a Business-as-Usual (BAU) scenario, and 2) a Breakthrough (BT) scenario. In the BT scenario, technology improvements reduce ground heat-exchanger costs by 30%, and improve operational efficiency of GHP systems by 50%. Liu et al. 2019 provides more detail about the GHP analysis.

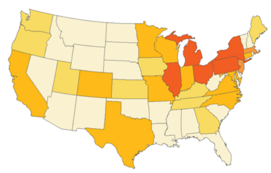
Figure 4-8 illustrates geographically the economic potential for GHP systems under the *GeoVision* analysis BAU and BT scenarios. Under both scenarios, economic potential is most concentrated in the Northeast and Midwest, with New York, Pennsylvania, Illinois, Ohio, and Michigan showing the highest potential—more than 174 gigawatts-thermal (GW_{th})[90] combined for the BT scenario.

Similar to the case for geothermal direct use, the economic potential for GHP systems is the portion of total technical potential that can be deployed where it can provide lower-cost heating and cooling alternatives for consumers. Economic potential is driven by capital costs and fuel costs and can vary with time as these factors change. Economic potential is higher than market potential because market potential is affected

90 Gigawatts-thermal is power available directly in the form of heat, as opposed to gigawatts-electric, which is power available in the form of electricity generated from the conversion of heat or other potential energy.

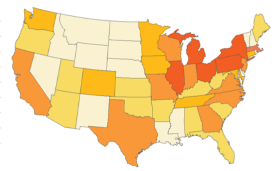
BAU Scenario

State	2050
NY	40.3
IL	28.6
PA	28.5
MI	26.7
OH	26.5
NJ	19.3
MA	19.1
CA	14.5
IN	13.8
VA	13.0



BT Scenario

State	2050
NY	44.9
PA	34.1
IL	32.7
OH	31.8
MI	30.7
CA	24.1
TX	22.5
NJ	22.4
MA	20.8
NC	18.4



GHP Potential (GWth)

< 5 | 5–10 | 10–15 | 15–25 | > 25

Figure 4-8. Economic potential for geothermal heat-pump systems by state in 2050 under the Business-as-Usual (left) and Breakthrough (right) scenarios, with the top 10 states listed separately

by conditions such as the regulatory environment, consumer understanding of the technology, and competing alternatives. GHPs are used at the individual consumer level, so market potential is affected heavily by consumer interest and understanding of the technology and its benefits. Consumer behavior also determines the speed at which full market potential is captured, determining the rate of capacity deployment at any given time. In theory, the capacity-deployment and market-potential curves will eventually meet, and consumer-adoption rates essentially determine how quickly that happens.

Figure 4-9 illustrates the economic-potential results for GHPs under the BAU and BT scenarios, as well as the related market potential and capacity deployment. The *GeoVision* analysis considered two consumer-adoption rates (Liu et al. 2019). Figure 4-9 assumes the more optimistic consumer-adoption rates, under which people are more likely to purchase a GHP system for a given payback period, and is based on adoption profiles observed within the solar photovoltaics market (Section 3.2.2 and Table 3-4).

The *GeoVision* analysis concludes that market potential for geothermal heat pumps is more than 14 times larger than existing capacity. This potential could translate to heating and cooling for about 28 million U.S. homes.

Using the more optimistic consumer-adoption rate (NREL Optimistic), the BAU and BT scenarios both show significant GHP market potential, underscoring the importance of GHP technologies to the U.S. heating and cooling market. The *GeoVision* analysis concluded that the maximum GHP **market potential** in the BT scenario—resulting from technology breakthroughs and assumptions of the "NREL Optimistic"[91] consumer-adoption rates—is more than 14 times larger than existing capacity. This result is equivalent to heating and cooling solutions for about 28 million homes, compared to the installed GHP capacity equivalent of roughly 2 million homes at the time of the *GeoVision* analysis.[92] This potential represents about 23% of the total residential heating and cooling market share by 2050. From this market potential, total actual capacity deployment in 2050 is projected to be enough to support about 18.6 million U.S. homes.

91 NREL is the National Renewable Energy Laboratory.

92 According to Lund and Boyd (2016), the installed capacity of GHPs in the United States had increased to 16.8 GW_{th} (or about 5 million cooling tons) by 2016. A GHP capacity equivalency of 1.92 million homes was determined on the basis of a calculated average size of residential GHP systems as 2.5 tons (8.75 kilowatts-thermal [kW_{th}]) per household. This average size was derived assuming an average U.S. household floor space of 1,750 square feet and an average U.S. household heating, ventilation, and air-conditioning size of 700 square feet/ton (DOE 2010, Moura et al. 2015).

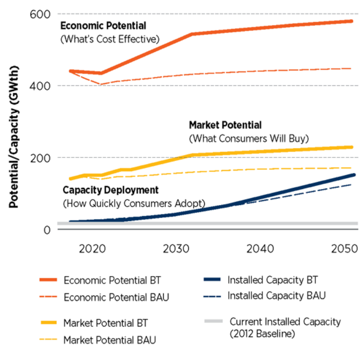


Figure 4-9. Geothermal heat-pump potential under the Business-as-Usual (denoted BAU) and Breakthrough (denoted BT) scenarios assuming the NREL Optimistic consumer-adoption rate

Figure Notes: The chart illustrates that GHP capacity deployment is lower than the economic and market potential because the speed at which deployment occurs is a function of consumer behavior. The reduced rate of increase after 2030 in the economic and market potentials is driven by changes in costs over time. Beyond 2050, the curves of capacity deployment and market potential will eventually meet, driven by consumer-adoption rates. Installed capacity as of 2012 ("2012 Baseline") was used as a baseline for comparison (Navigant 2013). NREL is the National Renewable Energy Laboratory.

The *GeoVision* analysis confirms that technology improvements are a significant factor in advancing GHP deployment. The geothermal industry could also benefit from improved financing and business structures, as well as enhanced collaboration, education, and outreach that help provide consumer knowledge. For GHPs, greater consumer understanding could lead to more and earlier adoption of the technology, converting more economic potential into market potential. Results of the full *GeoVision* analysis for GHPs are detailed in Liu et al. 2019.

4.3 The Market and Technology Nexus

The *GeoVision* analysis indicates that the market for conventional hydrothermal resources and their proven technology applications in electric-power generation have the potential to double in capacity through regulatory reform alone, relative to BAU. In the longer term, EGS resources hold the potential to supply more than 8.5% of the nation's total electric-power generation by 2050. In the *GeoVision* modeling scenario that considers improved technologies (the TI scenario), in combination with the ReEDS Standard Scenario that includes high natural-gas prices, EGS resources have the potential to provide more than 16% of the country's total generation by 2050 (Augustine et al. 2019).

For the heating and cooling sector, the *GeoVision* analysis indicates an opportunity to deploy GHP systems in 28 million homes (versus roughly 2 million residential GHP systems nationwide as of 2016). The *GeoVision* analysis also confirms that, by 2050, about 320 GW_{th} of geothermal direct-use resources are available to be economically deployed through improved technologies that enable EGS development. If deployed as geothermal district heating, these 320 GW_{th} could support as many as 17,500 geothermal district-heating installations across the United States—sufficient to satisfy the demand of about 45 million households.[93]

By identifying deployment opportunities across a range of geothermal applications and end uses that are at varied levels of maturity, the *GeoVision* analysis provides a view of the geothermal industry's nexus of markets and technologies. Figure 4-10 Illustrates the differentiation between the markets for existing, proven technologies and those that require developing technologies and primarily use EGS resources. The *GeoVision* analysis confirms significant growth opportunities for both types, along different pathways. For proven technologies, industry growth to maximum deployment will require stakeholders to collectively address barriers related to project financing, regulatory

93 The Energy Information Administration estimates that there are 118 million homes in the U.S. residential sector (Energy Information Administration 2015). Using this value plus data from the *GeoVision* analysis related to existing GHP market share and installed capacity indicates that 1 GW_{th} can supply heat to about 140,000 homes on average. This value was used to determine the impact of 320 GW_{th} of direct-use capacity on U.S. homes.

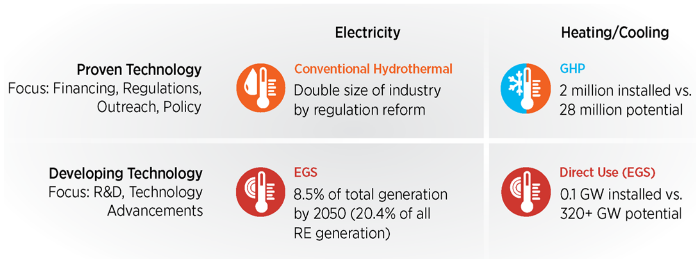


Figure 4-10. The *GeoVision* analysis market-technology nexus

Figure Note: The primary geothermal market sectors are electricity and heating and cooling. The electric sector is served by proven and cost-effective conventional hydrothermal resource technologies and by developing EGS technologies. The heating and cooling sector is served by proven GHP technologies and direct-use applications such as geothermal district heating supported by both conventional hydrothermal resources—and, eventually, EGS technologies. Proven technologies face greater development and implementation obstacles in the areas of financing, regulatory timelines, outreach, and market structures, whereas developing technologies require a focus on research and development to support technology advancements. Installed and potential values under GHP and direct use refer to market potential and economic potential, respectively. As discussed in this chapter, deployment of geothermal district heating based on market potential could not be modeled in the GeoVision analysis.

timelines, outreach and education, and market structures. For *unproven* and *developing* geothermal technologies, deployment growth will be advanced most effectively through research, development, and technology advancement. Actions to advance pathways for both proven and unproven technologies are discussed in the *GeoVision* Roadmap (Chapter 5).

4.4 Impacts of the *GeoVision* Analysis Findings

The *GeoVision* analysis included an assessment of impacts resulting from increased geothermal deployment—jobs and economic development in the domestic geothermal sector as well as water use and air emissions. Most of the impacts were examined at a national scale, with job impacts also evaluated regionally. Sections 4.4.1–4.4.3 summarize the impacts modeling and results, which are based on modeled deployment potentials for the electric and non-electric sectors as described in Sections 4.1–4.3. Impacts were evaluated independently for each sector using the results from the deployment modeling scenarios. Unless otherwise indicated, impacts are expressed as the difference between existing conditions and the various *GeoVision* analysis scenarios. Details of the impacts assessment are in Millstein et al. 2019.

Impacts assessments for power generation in the electric sector correspond to the deployment potential analysis of the Business-as-Usual, Improved Regulatory Timeline, and Technology Improvement scenarios. For the electric sector, impacts were calculated as the difference in specific outcomes (e.g., water consumption) between the BAU scenario and each of the other two scenarios (IRT and TI). For GHPs in the non-electric sector, impacts were calculated as the difference between a 2012 installed-capacity baseline with no additional GHPs (Liu et al. 2019) and the two technology scenarios—BAU and BT—in combination with two market-adoption rates: Navigant Low and NREL Optimistic (Table 3-4).[94]

94 The 2012 Baseline was chosen within the dGeo model framework to allow for assessment of the benefits of the growth in the GHP sector under both the Navigant and NREL adoption rates. This was accomplished by quantifying the benefits vs. the level of GHP deployment at the beginning of the dGeo model run. This initial level of GHP deployment is the "2012 Baseline." NREL is the National Renewable Energy Laboratory.

Modeling impacts for geothermal direct-use applications in district heating differed from electric-sector and GHP modeling due to the nature of the technology. In geothermal district heating, underground heat reservoirs are tapped to provide heating for many—sometimes thousands of—buildings. As such, geothermal district-heating systems have community impacts as well as individual impacts that would likely be substantive if such systems were deployed on a national scale. However, limited data and experience constrain understanding of U.S. market potential for geothermal district heating. As such, full market-potential expansion scenarios could not be modeled for geothermal district-heating systems in the *GeoVision* analysis. Instead, the impacts of a limited number of representative systems were quantified, and those results were used to qualitatively describe the impacts that could be realized from expansion based on economic-potential levels. Projected impacts for district-heating systems are discussed in McCabe et al. 2019 and Millstein et al. 2019.

A flow test on a 7,000-foot geothermal well at Naval Air Station Fallon, Nevada. *Photo credit: Andrew Tiedeman*

4.4.1 Jobs and Economic Development

The *GeoVision* analysis included assessing geothermal industry employment and economic impacts associated with increased deployment. However, specific job numbers are not reported here because the analysis data are gross numbers only and do not evaluate economy-wide net impacts. The assessment used the National Renewable Energy Laboratory's Jobs and Economic Development Impact model, commonly known as JEDI.[95] Details can be found in Millstein et al. 2019.

The majority of jobs in the geothermal electric-power sector depend on the exploration, construction, and deployment of new geothermal installations. As indicated, the employment impacts presented in this chapter represent gross job increases resulting from newly installed capacity in the geothermal electric sector, as opposed to net job impacts in the national economy.[96] Employment impacts are expressed in terms of cumulative expenditures (Table 4-2).[97] For the scenarios studied in the *GeoVision* analysis, job increases in the geothermal electric sector are driven primarily by widespread EGS resource potential that could support electricity demand in large population centers.

Job growth in the geothermal electric sector initially reflects industry growth enabled by improvements in regulatory timelines and technologies. The *GeoVision* analysis indicates that around 2030, technology improvements could reduce EGS costs and enable rapid growth in EGS resource deployment. If results of the TI scenario are achieved, EGS deployments would be responsible for the majority of jobs created and increased rates of job growth toward the end of the analyzed period in 2050.

95 Information on the JEDI model is available on the National Renewable Energy Laboratory's website at https://www.nrel.gov/analysis/jedi/.

96 The *GeoVision* analysis assessed gross job impacts from geothermal deployment compared with BAU scenarios. These gross job impacts represent total jobs needed to fulfill increased geothermal deployment, which may displace other energy generation technologies. The net impacts of this displacement were not calculated in the *GeoVision* analysis; thus, the gross job impacts reported in the *GeoVision* analysis do not represent the impact of geothermal jobs on employment within those other sectors. Assessing such impacts was beyond the scope of the *GeoVision* analysis (Millstein et al. 2019).

97 Cumulative expenditures include capital and O&M spending over the analyzed timeframe that is required to support deployment potential modeled in the *GeoVision* analysis.

Table 4-2 contains cumulative expenditures (millions of dollars) on geothermal electric-sector deployment from 2015 to 2050 by state, in the states where geothermal deploys under the TI scenario (Millstein et al. 2019).

State	Cumulative Expenditures (millions of $)	State	Cumulative Expenditures (millions of $)
CA	79,851	CO	3,008
WV	27,030	MT	976
OR	26,495	TX	222
ID	21,838	WY	208
NV	17,310	PA	110
UT	14,914	VA	51
AZ	13,754	MS	30
NM	13,339	LA	17
Total (millions of $) 219,152			

Table 4-2. Cumulative Expenditures on Geothermal Electricity-Generation Capacity Deployment by State in Millions of Dollars (2015–2050) in the TI Scenario

Table Note: Table contains the states in which geothermal deploys in the TI scenario. Cumulative expenditures include capital and operations and maintenance spending required over the analyzed timeframe to support deployment potential modeled in the GeoVision analysis. Expenditures depend on how the model (ReEDS) builds out generation and transmission at a bulk-grid scale. Expenditures in states such as West Virginia, Oregon, and Arizona are driven upward by a complex function of EGS availability, other generation retirements, and demand, levelized by the least-cost generation option. Expenditures shown are absolute values and not relative to the BAU scenario.

The *GeoVision* analysis indicates that, at a local level, geothermal power plants can provide more than double the long-term jobs per powered household when compared to other utility-scale power-generation technologies considered in the *GeoVision* analysis (Figure 4-11) (Millstein et al. 2019, Young et al. 2019). Long-term geothermal jobs are generally operations and maintenance positions filled mainly by local workers (Figure 4-12). As such, wages generated by these jobs are also more likely to be spent locally. Operations and maintenance spending includes royalties, which are unique to geothermal power plants, as well as property taxes, land-lease payments, and other spending.

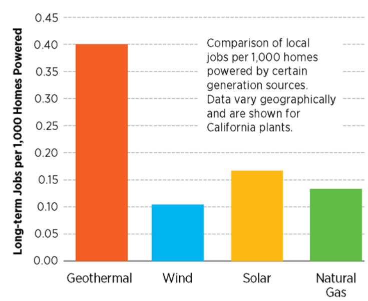


Figure 4-11. Comparison of long-term jobs per 1,000 homes powered, by energy-generation technology

Figure Note: Geothermal can provide more than double the long-term jobs per powered household compared to other electricity-generation technologies considered. As indicated, data shown are for California power plants.

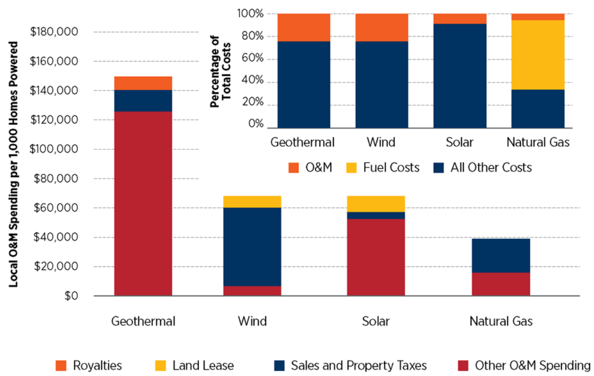


Figure 4-12. Comparison of local operations and maintenance spending per 1,000 homes powered, by energy-generation technology

Figure Note: Data vary geographically and are shown for California power plants.

GHP expenditures can help provide insight on GHP economic impacts and where those impacts might occur. Figure 4-13 illustrates the geographic distributions of gross GHP expenditures in 2030 and 2050 for the BT scenario. Most of the expenditures in 2030 are in Texas and the eastern half of the country. This result is geographically complementary with electric-sector deployment, which occurs mainly in the western United States (Table 4-2). As such, combined electric-sector and GHP economic impacts would be more geographically diverse when compared to each sector individually. GHP expenditures grow from $2.9 billion annually in 2030 to $4.3 billion annually in 2050. From 2030 to 2050, the expenditure increases occur mainly in six states: New Jersey, New York, California, Massachusetts, Michigan, and North Carolina (ranked in order of highest to lowest change).

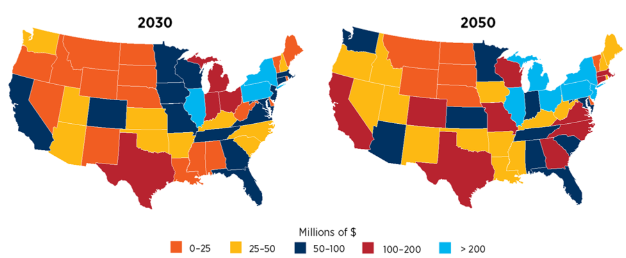


Figure 4-13. Geothermal heat-pump expenditures (in millions of USD) for 2030 (left) and 2050 (right) by state under the Breakthrough scenario

Source: Millstein et al. 2019

Achieving deployment levels identified in the *GeoVision* analysis can increase employment, wages, and economic output in the geothermal electric and non-electric GHP sectors. The analysis also demonstrates that combining geographic trends of development in the geothermal electric and GHP sectors can result in benefits in many U.S. states, particularly the West and Mid-Atlantic regions (Millstein et al. 2019).

4.4.2 Water Use

For the *GeoVision* analysis, water-use impacts were calculated for the electric sector only. This evaluation included two categories of water impacts: 1) water **withdrawal**, which is water removed or diverted from a water source for use, and 2) water **consumption**, which is water evaporated, transpired, or incorporated into products or crops or otherwise removed from the immediate water environment. Water consumption represents a net loss from the local source. For electricity generation, withdrawal is typically water used for cooling and then returned to the source at a slightly elevated temperature, whereas consumption is usually water used for evaporative cooling and not returned directly to the source.

Modeling for water-use impacts focused exclusively on operational water-use requirements, which can vary based on the type of fuel, power plant, and cooling system. Water-use impacts calculated for the *GeoVision* analysis were based on the ReEDS modeling results and extracted directly from the ReEDS model. ReEDS includes water availability in modeling capacity deployment and will restrict deployment of a technology if water resources are not available. Millstein et al. 2019 includes a detailed explanation of the modeling methodology and assumptions for water-use impacts.

Under the *GeoVision* TI scenario, geothermal power generation would represent 8.5% of total national generation in 2050, but only 1.1% of power-sector water withdrawals. Figure 4-14 shows water withdrawals for the TI scenario (Millstein et al. 2019). Because the water-withdrawal percentages for geothermal and other renewable technologies are minor in relative terms, they do not register visibly at full scale in the figure.

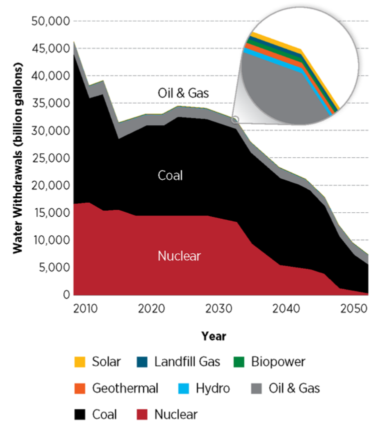


Figure 4-14. Power-sector water-withdrawal impacts in billions of gallons

Source: Millstein et al. 2019

Figure Note: Chart illustrates water-withdrawal impacts from geothermal generation as modeled under the TI scenario. Geothermal, solar, landfill gas, biopower, and hydropower have minimal impact on water withdrawals for the total electric sector; data for these technologies are reflected in the figure but are too small to be seen at full scale. The inset magnifies these data to make them visible.

> Under the *GeoVision* analysis Technology Improvement scenario, geothermal energy could represent 8.5% of total national electricity generation while being accountable for only 1.1% of power-sector water withdrawals. The majority of this growth could be supported using non-freshwater sources.

The *GeoVision* analysis indicates that geothermal power generation under the TI scenario impacts water consumption relative to BAU, representing 7.6% of total power-sector water consumption by 2050, as compared to 8.5% of total generation (Figure 4-15). This percentage of water consumption by geothermal power generation represents a cumulative increase from present day to 2050 of about 230 billion gallons systemwide over the BAU scenario—a small percentage (0.5%) relative to total electric-system-wide consumption (46 trillion gallons cumulatively) over that same time period. Annual water consumption in 2050 in the BAU scenario is about 1.01 trillion gallons, compared with 1.05 trillion gallons under the TI scenario (4% higher). Results are driven by modeling assumptions related to subsurface water loss and the assumed binary, air-cooled configuration for EGS plants (Millstein et al. 2019).

Geothermal technology deployment in the BAU, IRT, and TI scenarios was not restricted on the basis of water quality (i.e., sources being freshwater or non-freshwater). The *GeoVision* analysis evaluated the sensitivity of geothermal growth to restrictions on water sourcing. An alternate sensitivity scenario considered limiting geothermal water use to non-freshwater sources (e.g., brackish groundwater or municipal wastewater). Under the non-freshwater-consumption sensitivity analysis, geothermal deployment could still increase to nearly the same levels as in the freshwater scenario, maintaining about 90% of total projected deployment. The sensitivity analysis results indicate the potential to support almost all of the geothermal energy growth using only non-freshwater resources. This means that geothermal deployment growth could be supported even where access to freshwater is limited. Achieving the deployment results of the *GeoVision* analysis is not expected to materially impact the water needs of the wider electric system.

4.4.3 Air Emissions

The *GeoVision* analysis assessed the impact of increased geothermal deployment on air emissions, including greenhouse gas (GHG) emissions, measured as carbon-dioxide equivalents (CO_2e),[98] as well as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and fine particulate matter ($PM_{2.5}$).[99] Results of the analysis indicate opportunities for reduced emissions and improved U.S. air quality resulting from greater geothermal deployment in both the electric and non-electric sectors.

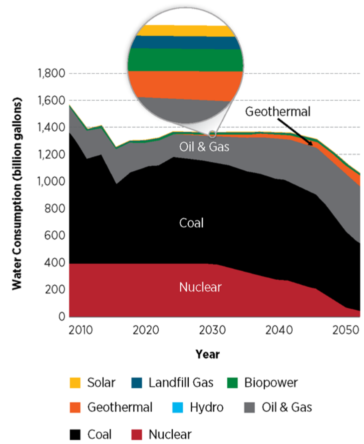


Figure 4-15. Water-consumption impacts from the geothermal power sector (in billions of gallons) under the Technology Improvement scenario

Source: Millstein et al. 2019

Figure Note: Water consumption increases with increasing geothermal power generation, accounting for 7.6% of total power-sector water consumption by 2050 and 8.5% of total generation. Comparatively, however, geothermal accounts for a fraction of the water consumption of coal, natural gas, and nuclear power generation. Solar, landfill gas, biopower, and hydropower are included in systemwide data but represent consumption values that are too low to see at full scale in the figure. The inset magnifies these data to make them visible.

Figure 4-16 illustrates annual life cycle greenhouse gas emissions and annual displaced life cycle greenhouse gas emissions in the entire electric sector under the BAU, IRT, and TI scenarios. In the entire electric sector, geothermal deployment under the TI scenario—particularly from EGS resources—reduces total sector CO_2e emissions by a *cumulative* 516 million metric tons (MMT) from 2015 to 2050, on a life cycle basis relative to a BAU scenario. By the end of the analyzed period (2050), the GHG emissions avoided annually are roughly equal to the annual GHG emissions of 6.4 million cars.[100]

98 Carbon-dioxide equivalents are a summation of the GHG effects of contributing gases (e.g., methane) measured on a carbon-dioxide equivalency basis.

99 $PM_{2.5}$ refers to fine inhalable particulates that are 2.5 microns or less in diameter.

100 Car-emission equivalent calculations assume that a typical U.S. passenger vehicle emits about 4.7 metric tons of CO_2 per year, based on fuel economy of about 21.6 miles per gallon and 11,400 miles of travel per year (Environmental Protection Agency 2014).

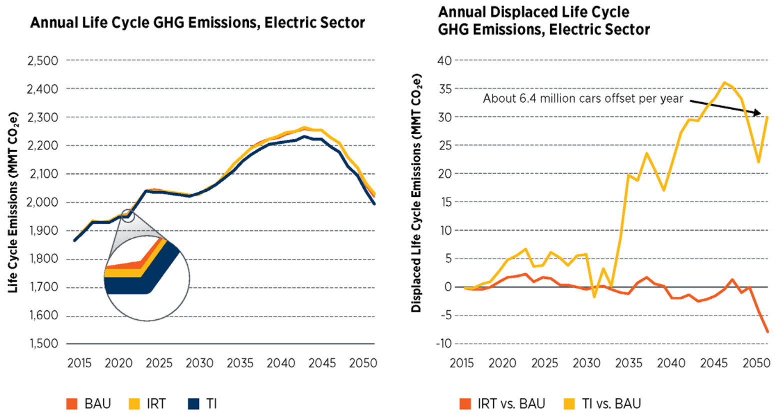


Figure 4-16. Annual life cycle greenhouse gas emissions (left) and annual displaced life cycle greenhouse gas emissions (right) in the entire electric sector under the Improved Regulatory Timeline, Technology Improvement, and Business-as-Usual scenarios

Source: Millstein et al. 2019

Figure Note: For the TI scenario, geothermal deployment in the electric sector results in a cumulative total reduction of 516 MMT of CO_2e from 2015 to 2050, on a life cycle basis relative to a BAU scenario. By the end of the analyzed period, the annual avoided emissions are equivalent to the emissions from about 6.4 million cars. "MMT CO_2e" is million metric tons of CO_2e. Negative impacts (i.e., minor increases in emissions resulting in negative displacement) derive from increases in systemwide emissions, not from geothermal power plants specifically.

Figure 4-17 illustrates annual life cycle greenhouse gas emissions and annual displaced life cycle greenhouse gas emissions in the heating and cooling sector under the BAU and BT scenarios, relative to the 2012 baseline. In the heating and cooling sector, deployment of GHPs in the BT scenario results in as much as ~90 MMT of displaced annual GHG emissions by 2050 relative to the 2012 GHP baseline—the equivalent emissions of about 20 million cars. Given the nature of GHP deployment, GHG emissions reductions from the technology are distributed relatively evenly throughout the contiguous United States, with somewhat higher amounts in the Mid-Atlantic, Midwest, and Great Lakes regions (Millstein et al. 2019).

Assuming the most aggressive technology improvements modeled for both the electric and non-electric sectors, the overall results of the *GeoVision* analysis of air-emissions impacts indicate that—by 2050—geothermal deployment could avoid annual GHG emissions equivalent to removing a total of about 26 million cars from U.S. roads relative to the 2012 baseline. As noted, geothermal deployment in the U.S. electric sector, as modeled in the TI scenario, yields *cumulative* life cycle GHG emissions reductions of 516 MMT of CO_2e through 2050 relative to BAU, whereas GHP deployment in the heating and cooling sector yields *cumulative* life cycle GHG emissions reductions of 1,281 MMT of CO_2e through 2050 relative to the 2012 baseline. Across both the electric and heating and cooling sectors under the most aggressive

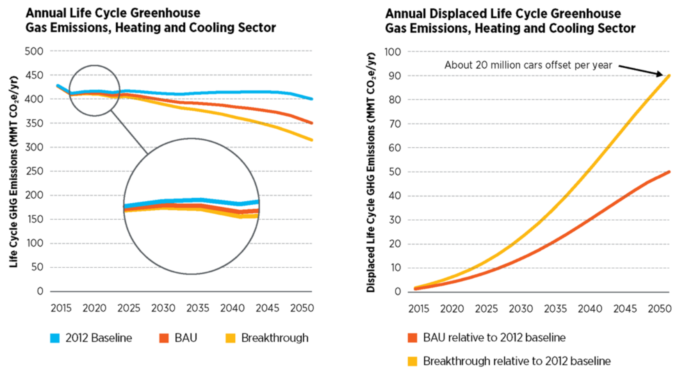


Figure 4-17. Annual life cycle emissions (left) and annual displaced life cycle greenhouse gas emissions (right) in the entire heating and cooling sector under the Breakthrough and Business-as-Usual scenarios, relative to the 2012 GHP baseline

Source: Millstein et al. 2019

technology improvement and growth scenarios, the rate of annual GHG emissions reductions increases through 2050, reaching a combined *annual* reduction of 117 MMT CO_2e by 2050 (Millstein et al. 2019).

By 2050, geothermal deployment in the nation's electric and non-electric sectors could reduce greenhouse gas emissions equivalent to removing 26 million cars from U.S. roads annually.

Results in the *GeoVision* analysis for SO_2, NO_X, and $PM_{2.5}$ emissions also demonstrate improvements in air quality resulting from increased deployment of geothermal technologies. Figure 4-18 illustrates total electric-sector emissions for SO_2, NO_X, and $PM_{2.5}$ and net air-quality impacts (in thousands of metric tons) resulting from the *GeoVision* scenarios compared to the BAU scenario. As with GHG emissions, improvements in SO_2 and NO_X are especially notable for the TI scenario in the electric sector. As illustrated in Figure 4-18, the TI scenario results in greater reductions in SO_2, NO_X, and $PM_{2.5}$ emissions than the IRT scenario. Achieving the TI scenario reduces cumulative emissions of SO_2, NO_X, and $PM_{2.5}$ by 279,000, 417,000, and 54,000 metric tons, respectively, relative to the BAU scenario. These reductions represent about 1% of total emissions in each category and are concentrated in the time period between 2030 and 2050. Reductions of emissions of SO_2, NO_X, and $PM_{2.5}$ are seen in all modeled regions of the country, but are highest in Texas and the southwestern region of the United States. If the nation achieves the large-scale deployment of EGS resources identified in the *GeoVision* analysis TI scenario, then these air-quality benefits are expected to increase around 2030.

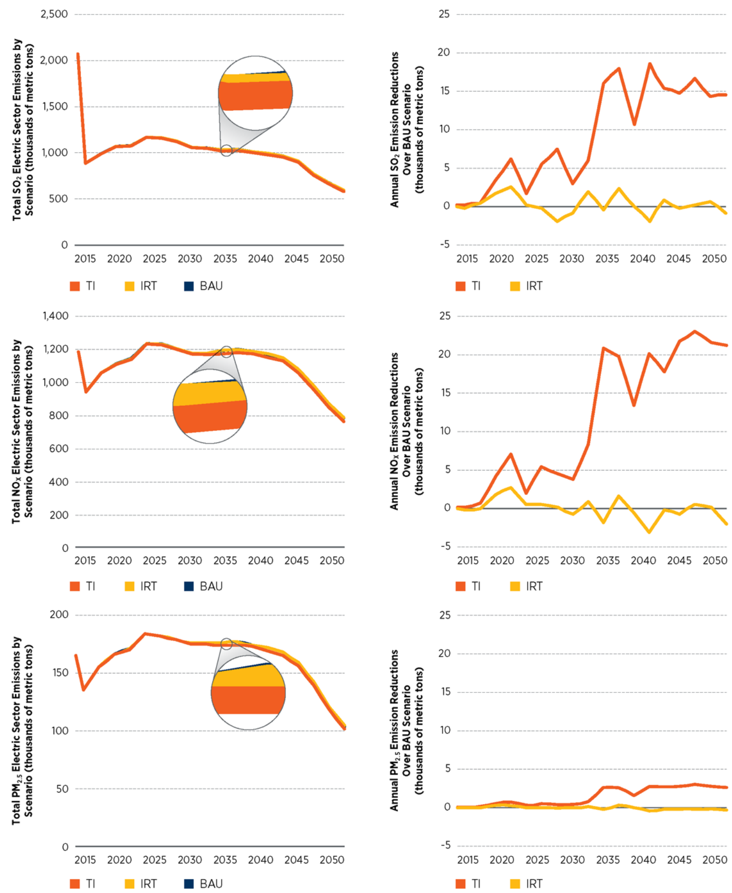


Figure 4-18. Air-quality impacts (SO_2, NO_x, and $PM_{2.5}$ emissions) for the entire electric sector, illustrating total (left) electric-sector emissions and annual (right) emissions reductions impacts from the *GeoVision* scenarios on electric-sector emissions (in thousands of metric tons)

Source: Millstein et al. 2019

Figure Note: Emissions reductions (right) are reported in thousands of metric tons of NO_x, SO_2, or $PM_{2.5}$ emissions removed from the electric sector and attributable to geothermal deployment. The highest emissions reductions in the electric sector result from the TI scenario. Reductions begin in about 2030, when large-scale deployment of EGS resources occurs. Negative impacts (i.e., minor increases in emissions) derive from increases in systemwide emissions, not from geothermal power plants specifically.

In the heating and cooling sector, the decrease in on-site fuel use that results from achieving the BT scenario reduces cumulative emissions (from 2015 to 2050) of SO_2, NO_x, and $PM_{2.5}$ by 232,000, 711,000, and 57,000 metric tons, respectively, relative to the 2012 baseline. These emission reductions are equivalent to double to triple the total single-year SO_2 and NO_x emissions from all residential combustion sources and one-fifth of a single year of $PM_{2.5}$ residential emissions (Environmental Protection Agency 2016). Figure 4-19 illustrates the total GHP heating and cooling sector emissions for SO_2, NO_x, and $PM_{2.5}$ and net air-quality impacts (in thousands of metric tons) resulting from the *GeoVision* BAU and BT scenarios, compared to the 2012 GHP baseline. The emission reductions increase gradually over time. In the case of GHPs, significant benefits are found even in the BAU scenario, with the additional deployment in the BT scenario providing further benefits.

Further details about air-emissions impacts, including a description of methodologies and models, are provided in Millstein et al. 2019.

An evaporative cooling tower at Socrates Geothermal Power Plant (The Geysers, California). *Photo credit: Geothermal Resources Council*

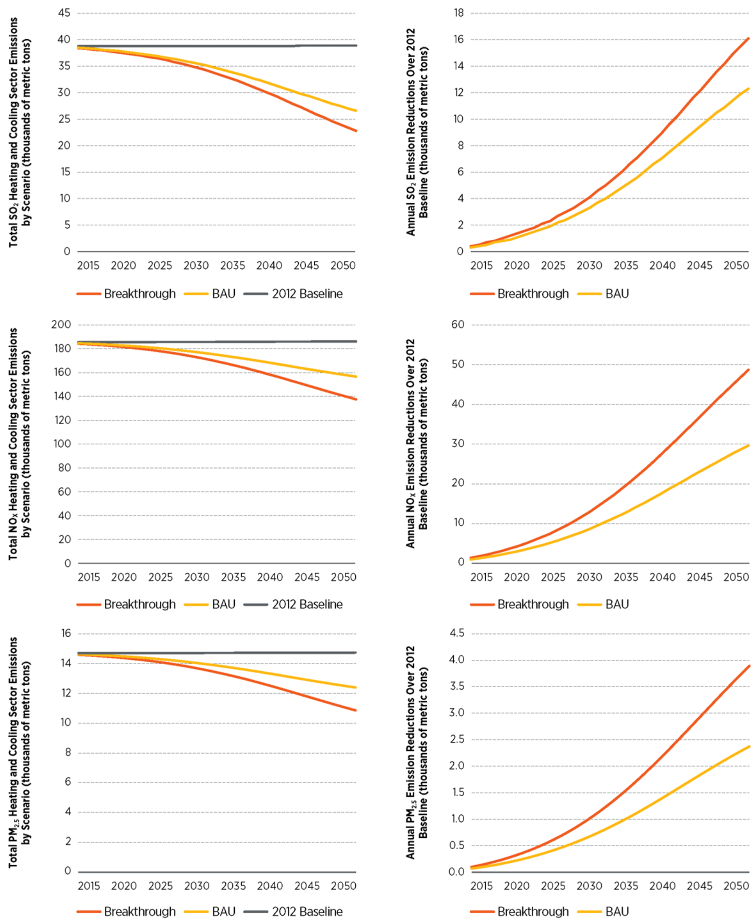


Figure 4-19. Air-quality impacts for the heating and cooling sector, illustrating total sector emissions of SO_2, NO_x, and $PM_{2.5}$ and annual emissions reductions impacts (in thousands of metric tons) from the *GeoVision* scenarios on heating and cooling sector emissions

Source: Millstein et al. 2019

Figure Note: Air-quality impacts reflect reductions (right) in cumulative NO_x, SO_2, or $PM_{2.5}$ emissions resulting from reduced on-site fuel use under the BAU and BT scenarios. These emissions reductions track GHP capacity deployment values and increase gradually over time. "2012 Baseline" refers to the 2012 installed GHP baseline used in the analysis.

The CHAIRMAN. Thank you, Mr. Simmons.

Mr. Spisak, welcome.

STATEMENT OF TIM SPISAK, STATE DIRECTOR FOR NEW MEXICO, OKLAHOMA, TEXAS AND KANSAS, BUREAU OF LAND MANAGEMENT, U.S. DEPARTMENT OF THE INTERIOR

Mr. SPISAK. Chairman Murkowski, Ranking Member Manchin and members of the Committee, I am pleased to join you today to discuss the Bureau of Land Management's role and responsibility in developing the nation's geothermal energy resources.

The Administration is committed to developing a diverse portfolio of energy resources, including oil and gas, coal, and renewable energy such as geothermal, wind and solar, all of which may be developed on America's public lands. This approach supports job creation and strengthens American energy security and infrastructure. Geothermal is an important piece of this strategy.

In Fiscal Year 2018, BLM Administrative resources provided over 40 percent of the nation's total geothermal energy capacity.

The BLM is required to manage the impacts of geothermal operations on public lands under the Federal Land Policy and Management Act and the National Environmental Policy Act. Also, amendments to the Geothermal Steam Act expressly protect certain important geothermal features in national parks like Yellowstone's Old Faithful.

Nearly all of the potential for development of federal geothermal energy is located in 11 Western states and Alaska. The BLM manages more than 240 million acres of public lands open to geothermal leasing which includes 104 million acres of Forest Service-managed lands. The BLM currently manages over 800 geothermal leases, 50 of which are in production. Together these leases have almost 1,900 megawatts of electrical capacity. For comparison, the Hoover Dam provides just over 2,000 megawatts of capacity.

California is by far the largest producer of geothermal energy on BLM-managed public lands. Ongoing rent and royalties from current operations in California generate nearly $8 million per year. Located in northern California, The Geysers is the largest geothermal field in the world hosting 14 power plants producing about 800 megawatts of electricity. Overall, the BLM in California hosts 11 geothermal facilities, including the aforementioned Geysers—Ormesa in Imperial County, Coso in Inyo County, and Casa Diablo in Mono County. Public lands in California have the potential to generate an estimated 4,000 megawatts. The BLM is working to produce, provide leasing for development and expansion across the state and also processing geothermal dominations for leasing in Northwestern California.

In Nevada there has been a notable expansion of geothermal exploration on BLM-managed public lands. Ongoing rent and royalties from current operations on public lands within the state generated over $5 million in 2018 alone. Within Nevada, the BLM hosts 19 geothermal power plants with federal interest, totaling over 600 megawatts of installed capacity, and is in the planning or permitting process for over 400 megawatts of new geothermal power plants. Nevada is also preparing 150 parcels across the state for a lease sale later this year.

Currently, each geothermal project requires separate environmental review under NEPA at both the exploratory phase, as well as when the resource enters the development phase. Under Secretarial Order 3355, the BLM has improved the environmental review process for all energy development projects, including geothermal. Furthermore, the Department of Energy's GeoVision report found that improved regulatory timelines for the drilling of exploratory wells could reduce the administrative costs of geothermal development on public lands and spur new development.

Expanded geothermal energy development carries impressive benefits for the nation. It's the renewable resource that is always on. It diversifies our portfolio and advances the Administration's policy of developing domestic energy resources responsibly.

Thank you for the opportunity to testify, and I'll be happy to answer any questions.

[The prepared statement of Mr. Spisak follows:]

Statement of

Tim Spisak

State Director for New Mexico, Oklahoma, Texas and Kansas

Bureau of Land Management

U.S. Department of the Interior

Senate Committee on Energy and Natural Resources

Hearing on

"Opportunities and Challenges for Advancement of Geothermal Energy in the United States."

June 20, 2019

Chairman Murkowski, Ranking Member Manchin, and Members of the Committee, I am pleased to join you today to discuss the Bureau of Land Management (BLM)'s role in responsibly developing the Nation's geothermal energy resources.

The Administration is committed to developing a diverse portfolio of energy resources, including oil and gas, coal, and renewable energy resources such as wind, geothermal, and solar – all of which may be developed on America's public lands. This approach strengthens American energy security, supports job creation, and strengthens America's energy infrastructure. Geothermal is an important piece of this strategy. Federal resources administered by the BLM provided over 40 percent of the Nation's total geothermal energy capacity in Fiscal Year 2018.

Background

Replenished by heat sources deep within the Earth, geothermal energy is an important energy resource that generates electricity with minimal carbon emissions. Geothermal energy is used to heat buildings, operate greenhouses, and to support aquaculture operations. It is an abundant resource, especially in the western United States. Geothermal energy was the first form of renewable energy that the BLM approved for production on public lands, with 2018 marking four decades since the first approved geothermal project in 1978.

Existing Regulatory Framework

Until the passage of the Geothermal Steam Act of 1970 (30 U.S.C. 1001), geothermal energy was regarded legally as a groundwater resource. The law defined geothermal resources as steam, hot water, and hot brines, indigenous to the geology or generated from introduced fluids, associated heat energy, and any byproducts. It also authorized the Secretary of the Interior to issue leases for the development and utilization of geothermal resources on lands managed by the Department of the Interior and the U.S. Forest Service. These leases were only competitive within "known geothermal resource areas." This placed geothermal in the context of Federal mineral leasing, like oil and gas, though some States still regard geothermal energy as a water resource. Amendments to this regulatory system were made in the 1980s and the 2000s. Of particular note, the Energy Policy Act of 2005 directed that revenues from geothermal electricity generation on Federal public lands would be shared, with 50 percent going to the State, 25 percent going to the county, and the remainder to the U.S. Treasury. The President's Fiscal Year 2020 Budget proposes repealing the 25 percent earmarked for counties, returning $40 million over ten years to the Treasury.

The BLM is required to manage the impacts of geothermal operations on public lands under the Federal Land Policy and Management Act and the National Environmental Policy Act (NEPA). Also, amendments to the Geothermal Steam Act expressly protect certain important geothermal features, like Old Faithful, in National Parks, including: Yellowstone, Mount Rainier, Crater Lake, the John D. Rockefeller, Jr. Memorial Parkway, Hot Springs, and Hawai'i Volcanoes. The BLM must ensure that proposed geothermal development does not harm these features.

Geothermal Operations on Public Lands

Nearly all of the potential for development of Federal geothermal energy is located in 11 western States and Alaska. Technologies currently being researched, such as Enhanced Geothermal Systems and closed-loop deep geothermal, would allow for the responsible development of geothermal almost anywhere. The BLM manages more than 240 million acres of public lands open to geothermal leasing, including 104 million acres of Forest Service-managed lands. The BLM currently manages over 800 geothermal leases, 50 of which are in production. Together these leases generate almost 1,900 megawatts of electrical capacity, representing about 40 percent of the total U.S. geothermal energy generated. For comparison, Hoover Dam has just over 2,000 megawatts of capacity.

California is by far the largest producer of geothermal energy on BLM-managed public lands. Ongoing rent and royalties from current operations in California generate $7.85 million per year. Located in northern California, The Geysers is the largest geothermal field in the world, hosting a complex of power plants producing approximately 800 megawatts of electricity. The Geysers also provides hundreds of full-time jobs. Overall, the BLM in California hosts 11 geothermal power plants, including The Geysers in Lake, Colusa, and Sonoma counties, Ormesa in Imperial County, Coso in Inyo County, and Casa Diablo in Mono County. Public lands in California have the potential to generate an estimated 4,000 megawatts of electricity from geothermal development. The BLM is working to provide leasing in the Haiwee area in Inyo County, for an additional power plant at Casa Diablo, and in the Truckhaven area of Imperial County. The BLM is also processing geothermal nominations for leasing in Modoc, Shasta, and Siskiyou counties.

There has also been a notable expansion of geothermal exploration on public lands in Nevada. As a result, Nevada has the most leased acreage and has generated the most bonus bids for the

U.S. taxpayer – over $50 million between 2007 and 2018. Notably, ongoing rent and royalties from current operations on public lands within the State of Nevada generated $5.2 million in 2018 alone. Within Nevada, the BLM administers 19 geothermal power plants with Federal interest, totaling over 600 megawatts of installed capacity, and is in the planning or permitting process for over 400 megawatts of new geothermal power plants. Nevada is also preparing 150 parcels across the state for an upcoming competitive geothermal lease sale.

Regulatory Streamlining

Currently, each geothermal project requires separate environmental review under NEPA at both the exploratory phase, as well as when the resource is to be utilized. Under Secretarial Order 3355, *Streamlining National Environmental Policy Reviews*, the BLM has improved the environmental review process for all energy development projects, including geothermal. The Department of Energy's GeoVision report has also found that improved regulatory timelines for the drilling of exploratory wells could reduce the administrative costs of geothermal development on public lands and spur new development. Drilling exploratory wells is expensive and more technically demanding than conventional oil and gas wells, and exploration necessarily carries financial risk for the driller. Offsetting administrative costs from this phase has the potential to expand the development of current leases and encourage bidding on new leases. BLM is exploring opportunities to further streamline NEPA reviews and other permitting processes to facilitate greater use of these important resources.

Conclusion

Expanded geothermal energy development carries impressive benefits for the Nation. It would diversify our overall energy portfolio, reduce carbon dioxide emissions, and advance the Administration's policy of developing domestic energy resources responsibly. Thank you for the opportunity to testify today. I would be happy to answer any questions.

The CHAIRMAN. Mr. Spisak, thank you.

Ms. Young, welcome.

STATEMENT OF KATHERINE R. YOUNG, GEOTHERMAL PROGRAM MANAGER, NATIONAL RENEWABLE ENERGY LABORATORY

Ms. YOUNG. Thank you.

Chairman Murkowski, Ranking Member Manchin, members of the Subcommittee, thank you for the invitation to discuss the benefits of geothermal that can offer our nation the opportunities to advance technologies for accessing this incredible resource.

My name is Katherine Young. I am the Geothermal Program Manager at the National Renewable Energy Lab, and I'm also a Director on the Geothermal Resources Council. I've spent more than a decade at NREL focused on the advancement of geothermal technologies.

Geothermal is good for the environment. It is renewable, has no emissions, and uses significantly less land than other power technologies. It's good for the grid as Senator Murkowski mentioned, it's always available, and provides much needed reliability, flexibility, resiliency and security.

Geothermal is good for the economy. It creates long-term, wage-earning jobs, provides royalties, creates local spending and delivers stable, affordable consumer energy prices. Additionally, geothermal brines carry valuable minerals like lithium that can provide a reliable domestic supply for our nation. Despite these remarkable characteristics, there is still much that remains to be done.

The U.S. is a global leader in geothermal deployment and is also home to the world's largest geothermal power plant. But the resource remains underutilized.

The recent GeoVision study outlined scenarios that could increase geothermal nearly 26 times by 2050.

Three key improvements that could revolutionize the industry are research that lowers the cost of wells, technologies that enable geothermal anywhere, and the streamlining of geothermal permitting.

First, about half the cost of geothermal development is in drilling and well construction. But reducing these costs is feasible with research investment. Target research areas include drilling efficiency, including development of low-cost, high-temperature power electronics, technologies that reduce drilling rates, such as energy drilling technologies, and low-cost materials for well construction.

The second area of research is focused on accessing geothermal anywhere. Heat exists everywhere below the surface of the earth, even below where you're sitting right now. Today geothermal projects are developed at locations where a natural heat exchanger exists, including both fractures and fluid to transport that heat to the surface. There are two challenges to this model, however. First, the systems exist in a limited number of places and in the U.S., mostly in the West. Second, finding these sites requires sophisticated exploration techniques which are sometimes still unsuccessful.

GeoVision suggests that shifting this paradigm is the key to unlocking vast geothermal potential. If, instead of looking for natural heat exchangers, new technologies instead allow us to create our own, we remove not only the limited nature of the resource, but also, many of the challenges associated with exploration. EGS research, such as that being conducted by DOE at their Utah FORGE site, focuses on stimulating the subsurface to open the natural fractures in the rock. Other technologies use horizontal drilling techniques to drill boreholes between wells and circulate fluid. Advancing these technologies to commercial feasibility, understanding their scalability, and reducing deployment costs are critical to advancing the geothermal anywhere goal.

And finally, the DOE and BLM contracted NREL for technical environmental analysis related to geothermal permitting. These analyses show first, that geothermal has protracted regulatory timelines, and second, that reducing these timelines alone can double geothermal deployment. One way to reduce both project risk and timeframes is through the use of categorical exclusions for resource confirmation.

Our technical analysis showed that confirming a geothermal resource requires drilling at least two wells. Currently, this requires an environmental assessment which can cost hundreds of thousands of dollars and 6 to 12 months of time prior to permit authorization.

Our environmental analysis showed that geothermal resource confirmation drilling has not had a significant impact on the environment. Furthermore, under EPACT 2005 oil and gas, using similar rigs and drilling to similar depths, received a legislative categorical exclusion from Congress for similar activities.

In conclusion, the U.S. has some of the best geothermal resources in the world, but they remain underutilized. To realize this potential, investment in new technologies to lower cost and allow for geothermal anywhere are required. Streamlining of permitting would also be immediately impactful.

Today we sit at a critical juncture. If we appropriately invest in new, early-stage research and in-depth analysis and partner with industry to commercialize these new technologies, American businesses and consumers will benefit significantly from these advancements improving our country's energy security, economic prosperity, and scientific leadership.

Thank you for your interest in advancing geothermal in the U.S., and I look forward to your questions.

[The prepared statement of Ms. Young follows:]

Prepared Statement of Katherine R. Young
Geothermal Program Manager
National Renewable Energy Laboratory
For the U.S. Senate Committee on Energy and Natural Resources
Hearing on: "Opportunities and Challenges for Advanced Geothermal Energy Development in the United States"

June 20, 2019

Chairman Murkowski, Ranking Member Manchin, members of the Committee, thank you for this opportunity to address the future research opportunities for geothermal energy, the many benefits that advanced geothermal technologies can deliver for our nation, and the value they provide to our country's security, economic prosperity, and scientific leadership.

My name is Katherine Young, and I am the Laboratory Program Manager of Geothermal Research at the National Renewable Energy Laboratory (NREL) in Colorado. I am also a director of the Geothermal Resources Council. I have spent more than a decade at NREL focused on the advancement of geothermal technologies, so they can continue to provide a cost-effective, viable option for clean energy and job creation. As an engineer, I have led research projects on geothermal exploration, drilling, regulations, thermal applications, and resources engineering, most recently supporting the Department of Energy's (DOE) *GeoVision* study. Before joining NREL, I was a water rights engineer, a software developer, and a professional in hydrocarbon cementing and fracturing. My entire career has been about leveraging science in new ways to create practical, cost-effective solutions. This experience has given me a deep understanding of and profound appreciation for the role that federally supported scientific research can play in maintaining our nation's leadership in science and innovation, and also, how those accomplishments can drive U.S. competitiveness, autonomy, and security.

Benefits to the Nation

In my view, the subject of today's hearing is timely and especially important to the energy future of our country. Often when people discuss renewable energy, the environmental impact is at the forefront of the conversation. Geothermal meets these requirements with new plants that have little to no emissions, little water use, and a significantly lower land-use footprint than other energy technologies.

The economic benefits are equally impactful. Geothermal creates more local long-term, wage-earning jobs, includes more local spending during construction and operations than other power technologies, and provides more affordable, less volatile consumer energy prices nationwide. Geothermal technology's always-available characteristic provides much-needed reliability for both electricity and heating, and is accessible across the country. Geothermal plants also offer grid reliability, resiliency, and security to our nation's changing grid challenges through traditional services, such as regulation reserve, frequency response, and contingency reserves (spinning and nonspinning) to more nontraditional services, such as flexible capacity, voltage control, inertia, and black start capabilities. Additionally, geothermal brines carry valuable minerals such as lithium to the surface that could create a reliable domestic supply for our nation.

Despite these remarkable characteristics, there is still much more that remains to be done. Geothermal technology has great unmet potential. But to reach that potential, foundational scientific R&D and the breakthroughs it can produce are needed to accomplish the goals for a competitive, geothermal-anywhere U.S. market.

Geothermal Potential

The United States is a global leader in geothermal deployment, with 3.6 gigawatts of deployed power, and is home to the world's largest geothermal power plant, The Geysers, in California. Geothermal energy accounts for 2.3% of U.S. electrical renewable generation today[1], but has tremendous longer-term potential. Heat exists everywhere below the surface of the Earth—even below where you are seated reading this document. The Earth is continuously radiating heat out from its core and will continue to do so for billions of years. It is an underutilized, renewable, domestic resource.

The recent 2019 DOE *GeoVision* report outlines specific improvement scenarios that could increase geothermal use nearly 26-fold from today—representing 60 gigawatts of installed geothermal capacity across the U.S. by 2050 (8.5% of total generation), as shown in Figure 1. Geothermal power could provide about 57% of the baseload renewable generation portfolio by 2050 (20.4% of all renewable generation).

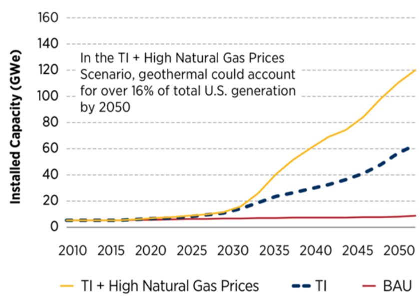


Figure 1. Installed geothermal capacity for GeoVision's *Technology Improvement (TI) scenario compared to a combined scenario and Business-as-Usual (BAU). The combined scenario considers the TI scenario in combination with the U.S. Energy Information Administration's High Natural Gas Prices. At the end of the analyzed period (2050), total geothermal deployment in the TI scenario is more than 60 gigawatts-electric. In the TI scenario, geothermal could support up to 8.5% of total national generation by 2050, compared to the 0.4% share of total contributed as of 2017.*

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

The report also presents a compelling case for geothermal to provide heating and cooling solutions to American residential and commercial consumers through direct-use and heat-pump technologies. According to ENERGY STAR®[2], geothermal heat pumps are the most efficient, quiet, and comfortable heating and cooling option on the market. Geothermal installations for heating and cooling already stretch nationwide. DOE estimates an average of 50,000 new geothermal heat-pump installations in the United States each year[3]. District heating systems, such as the one in Klamath Falls, Oregon, are rapidly being installed globally, particularly in areas with high heating costs, such as Europe[4]. *GeoVision* showed that the economic potential for geothermal district heating systems is more than 17,500 installations nationwide.

Target Areas of Improvement

Because of NREL's work, and the DOE programs that support it, previously small industries like wind and solar have become major American economic successes. R&D, much of it federally supported, has been crucial in these success stories, as have policies and incentives that drive industry participation. The R&D conducted at NREL has similar goals for each key technology: to bring the return on investment to the point where private industry and private financing take over and commercialize that technology.

The nationally beneficial geothermal resource will never fulfill its potential without needed development of new technologies to tap it. NREL has looked at the future of geothermal energy from every relevant perspective, from needed basic science to (at the request of other federal resource agencies) analyzing the impact of regulatory and permitting reforms to accelerate the deployment of new technologies. This research and analysis has given us confidence that geothermal can deliver on its potential benefits and has provided us with a roadmap to achieve that. Three key research areas (Figure 2) that could revolutionize the prospects for geothermal are: technologies that lower the cost of wells, technologies that enable geothermal anywhere, and technologies that recovery lithium from brines. Streamlining permitting and leasing can also significantly increase deployment.

[2] https://www.energystar.gov/products/energy_star_most_efficient_2019/geothermal_heat_pumps
[3] https://www.energy.gov/energysaver/heat-and-cool/heat-pump-systems/geothermal-heat-pumps
[4] Snyder, D., K. Beckers and K. Young, 2017. *Update on Geothermal Direct-Use Installations in the United States.* Proceedings, 42nd Workshop on Geothermal Reservoir Engineering. Stanford University https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2017/Snyder.pdf

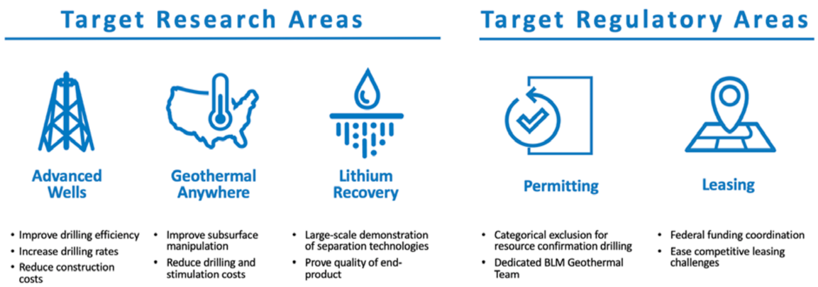


Figure 2. Target research and regulatory improvements that can help catapult the geothermal industry in the United States.

Lowering Costs Through Advanced Wells

The cost of geothermal development is about 50% on the surface (e.g., power plants, piping) and 50% below ground (e.g., drilling and well construction costs). Many of the below-ground costs are borne at the front end of the project development, which can make project financing challenging. And though drilling and well construction activities are present in many industries, time and costs are significantly higher for geothermal. Geothermal drilling averages about 150–200 feet per day, compared to oil and gas wells that that average more than 750 feet per day, and sometimes are as fast as a mile a day (a.k.a. "MAD" wells). The oil and gas industry has seen well drilling rates more than double in the last 10 years[5] while geothermal drilling rates have remained constant. This is in part because of the large volume of oil and gas wells drilled; however, it suggests that reducing geothermal drilling time and costs is feasible. Advancements in oil and gas development have made possible things that once seemed impossible—producing gas from shale and developing deep offshore resources—in a relatively short period of time. We believe these same types of dramatic improvements are possible for geothermal drilling, if, and only if, support is provided for needed research.

Drilling in geothermal rocks is slower for many reasons—wells are typically drilled in harder, hotter rocks, with more lost circulation, and the industry has been slower to adopt new technologies, sometimes because of cost. Drilling rates are important because drill rigs and equipment have expensive daily rental rates; each extra day spent on the rig significantly increases well costs. Target areas for research and industry adoption include increasing drilling efficiency, increasing drilling speed, and reducing construction costs. These advances have uses for multiple industries, making R&D investment even more impactful.

[5] https://www.eia.gov/analysis/studies/drilling/pdf/upstream.pdf

Increase Drilling Efficiency

Improving drilling efficiency is a near-term research effort that can have a big impact on drilling rates; the oil and gas industry reports drilling as much as 50% faster through efficiency improvements alone. The oil and gas industry uses downhole tools to measure drilling mechanics data that help make real-time efficiency decisions. But these tools are not rated for high-temperature geothermal environments, and the risk of burning up a tool makes the use of these tools too costly for geothermal developers to gamble on. Research into low-cost, high-temperature power and sensing electronics for extreme environments would not only help the geothermal industry, it would also benefit other industries, including vehicle technology, aviation, and manufacturing (e.g., metal forging and chemical industries). Additional research that would benefit geothermal and all other well-drilling industries includes advanced data analytics, machine learning, and mitigation of lost circulation events.

Increase Drilling Rates

Some rocks are harder than others; the harder the rock, the more energy it takes to crush and the longer it takes to drill through. In general, the sedimentary rocks drilled to access oil and gas rocks are softer, making it easier and faster to drill. Advances in rotary bit drilling, such as the development of the polycrystalline diamond bit, have made some progress in increasing drilling rates in harder rocks, but challenges still exist. Early-stage energy drilling technologies such as electronic pulse drilling, laser drilling, and projectile drilling show promise in significantly advancing drilling rates and reducing downtime during drilling. Testing of these energy drilling technologies are reported to advance drilling rates by 10 times over traditional rotary rates—translating to a significant potential for cost savings. Research into these types of technologies to more quickly drill through harder rock will support not only the geothermal industry, but also support accessing the nation’s mineral resources and harder-rock oil and gas plays.

Reduce Construction Costs

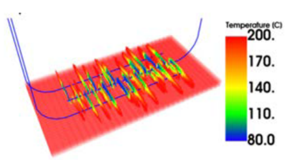
Well construction is a significantly high cost of developing a geothermal well field. Geothermal wells are larger, with a typical hole diameter more than twice the size of oil and gas wells, requiring more casing and cement to be used in construction. Additionally, because of the harsh environment, geothermal wells often need more expensive metal alloys containing significant concentrations of chromium, manganese, cobalt, and titanium to manage the high temperatures and thermal cycling that occur during operations. Research into low-cost materials for well construction can have significant benefits not only in geothermal, but also for other industries, such as chemical plants and vehicles. The use of computational materials design is a key U.S. opportunity in the development of new functional alloys using raw materials that are abundant in the United States.

Expanding Impact Through Geothermal Anywhere

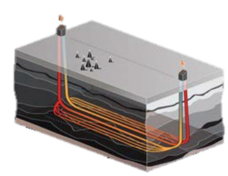
Traditional hydrothermal sites have focused on developing projects at locations where a natural heat exchanger exists in the subsurface, usually in the form of a fracture network, and where fluid exists to transport the heat to the surface. There are two challenges to this model, however. First, these types of systems exist in a limited number of places—and all in the western United States. Second, finding these sites often requires sophisticated exploration techniques, which are still sometimes unsuccessful in finding these "needles in a haystack."

The *GeoVision* study suggests that shifting this paradigm is the key to unlocking the vast geothermal potential in the United States. If instead of looking for natural heat exchangers, advanced technologies allow us to create our own, we remove not only the limited nature of the resource potential, but also the challenges associated with exploring for these needles in a haystack.

Two of the leading technologies being explored today to create geothermal anywhere are enhanced geothermal systems (EGS) and advanced geothermal systems (AGS) technologies. Enhanced geothermal systems research and development, such as that being conducted by the DOE Geothermal Technologies Office (in partnership with industry and the national labs) at their Frontier Observatory for Research in Geothermal Energy (FORGE) site in Milford, Utah, focuses on stimulating the subsurface to open the natural fractures in the rock, allowing for the circulation of water and the recovery of the heat to the surface. Advanced geothermal system technologies focus on using horizontal drilling techniques borrowed from the oil and gas sector to drill small, sealed horizontal boreholes between wells to allow for circulation of fluids that bring the heat to the surface. Modeling suggests this can be done feasibly with temperatures as low as 150°C. Examples of each of these technologies are shown in Figure 3. Advancing these technologies to commercial feasibility, understanding their scalability, and reducing deployment costs are critical to advancing the geothermal-anywhere goal.



Enhanced Geothermal Systems (EGS):
Use stimulation to enhance fracture network
(Example shown: Fervo Energy design)



Advanced Geothermal Systems (AGS):
Use horizontal well drilling to create small pathways
(Example shown: Eavor Technologies design)

Figure 3. Example technologies that could enable geothermal anywhere.

Mineral Recovery from Geothermal Brines

Geothermal power plants produce a large volume of brine, which contains dissolved chemical components, including critical and strategic minerals (e.g., lithium, manganese, copper, silver, gold) in various locales, at various concentrations[6]. Thus, significant quantities of valuable minerals could be recovered as a by-product of geothermal power plants.

For example, lithium extraction from geothermal brines offers the potential to provide the United States with a secure, strategic domestic supply of lithium for increasing energy storage and electric vehicle demands, and for other end-use applications. As of 2018, 35% of the lithium end-use was for lithium batteries and the automotive lithium-battery market is expected to grow, reaching a demand of 39 gigawatt-hours by 2020, with a market value of $14.3 billion[7]. The United States is expected to remain one of the largest markets for electric vehicle lithium batteries until at least 2020[8]. Lithium, as needed for the lithium-battery market alone, is a significant driver for investment in technologies to recover this mineral from geothermal brines and it is vital for the United States to position itself in this growing global market.

The large lithium resources available in geothermal brines in the United States, if recovered and processed economically, could position the United States to be become a global supplier of recovered lithium. Active geothermal plants in the Salton Sea in California alone have reported potential to produce nearly 90,000 metric tons per year of lithium. Currently, there is a plethora of potential lithium recovery processes with little confirmation of their bankability, economics, and experience operating in realistic conditions. Research dollars are needed to advance the technologies beyond early-phase testing to large-scale demonstrations to prove and test the mined resource as well as garner investor and consumer interest in full-scale deployment.

Streamlining Geothermal Permitting

The DOE Geothermal Technologies Office and the Bureau of Land Management (BLM) contracted with NREL for technical analysis related to geothermal leasing, permitting, and regulation. With regard to permitting, these analyses have shown:

1. **Geothermal has protracted regulatory timelines.** The extensive timeframes needed for geothermal are because of the series, rather than parallel nature of geothermal permitting and project development as well as the disparity between geothermal permitting requirements (Figure 4) versus those for similar activities for other industries. Because of the current regulatory scheme and the phased development approach used by most geothermal project proponents, projects may require compliance with the National Environmental Policy Act of 1969 (NEPA) numerous times over the course of project development (e.g., during land use planning, leasing, exploration, well field development, power plant and transmission siting, and project enhancement/expansion)[9]. Historically, depending on the level of NEPA analysis required (Determination of NEPA Adequacy, Categorical Exclusion, Environmental Assessment, Environmental Impact Statement) the

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[6] Neupane, G. and D. Wendt. 2017. *Assessment of Mineral Resources in Geothermal Brines in the US*. Proceedings, 42nd Workshop on Geothermal Reservoir Engineering. Stanford University. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2017/Neupane2.pdf
[7] CEMAC 2015. https://www.nrel.gov/docs/fy16osti/65312.pdf
[8] Chung, Elgqvist, and Santhanagopalan 2015. https://www.nrel.gov/docs/fy16osti/66086.pdf
[9] Young, K., K. Witherbee, A. Levine, A. Keller, J. Balu, and M. Bennett. 2014. *Geothermal Permitting and NEPA Timelines*. GRC Transactions, Vol. 38, 2014. http://pubs.geothermal-library.org/lib/grc/1033639.pdf

review may take between 1 month and 3 or more years. As a result, under the current approach, a geothermal project may take 8 years to develop[10].

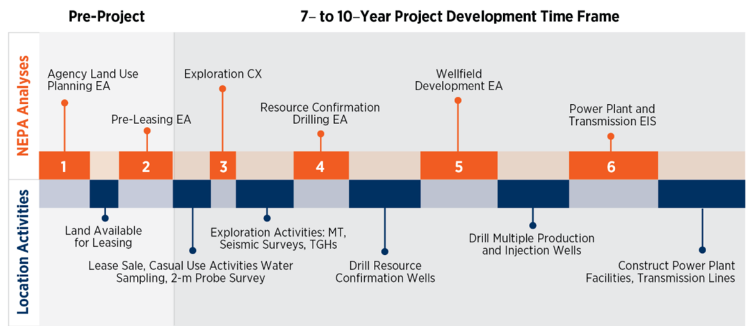

Figure 4. Example timeline of a geothermal project on federal lands, illustrating that a single location could trigger NEPA analyses six separate times. (Source: Young el al. 2014). EA = Environmental Assessment, EIS = Environmental Impact Statement, CX = Categorical Exclusions, MT = magnetotelluric, TGH = temperature gradient hole

2. **Reducing these timeframes alone can double geothermal deployment by 2050 without any new technology.** NREL's *GeoVision Analysis Supporting Task Force Report: Barriers* analyzed nontechnical barriers to geothermal deployment and potential improvement scenarios. In part, this report highlighted that reducing project development timelines from 8 years to 4 years can increase resource discovery and (primarily because of improved financing costs) more than double geothermal deployment over the Business-as-Usual scenario by 2050, resulting in an additional 6.7 gigawatts of geothermal deployment[11], as shown in Figure 5. Two mechanisms were identified to help meet this reduction in regulatory timeframes, including the expanded use of categorical exclusions for resource confirmation and a dedicated geothermal team (e.g., a dedicated strike team of BLM resource specialists)[12]. Each is described briefly in the following sections.

[10] Young, K., A. Levine, J. Cook, D. Heimiller, and J. Ho. 2019. *GeoVision Analysis Supporting Task Force Report: Barriers. An Analysis of Non-Technical Barriers to Geothermal Deployment and Potential Improvement Scenarios*. NREL/TP-6A20-7164. https://www.nrel.gov/docs/fy19osti/71641.pdf

[11] Young, K., A. Levine, J. Cook, D. Heimiller, and J. Ho. 2019. *GeoVision Analysis Supporting Task Force Report: Barriers. An Analysis of Non-Technical Barriers to Geothermal Deployment and Potential Improvement Scenarios*. NREL/TP-6A20-7164. https://www.nrel.gov/docs/fy19osti/71641.pdf

[12] Similar to the EPAct Section 365 Pilot Project to Improve Federal Permit Coordination for oil and gas permit processing.

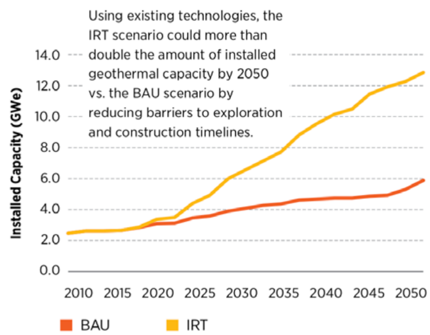

Figure 5. GeoVision's *Improved Regulatory Timeline (IRT) scenario results and comparison to the Business-as-Usual (BAU) scenario for conventional hydrothermal resources. The IRT scenario modeled the impact of 4-year regulatory timelines against the current average BAU regulatory timeline of 8 years and shows total deployment would reach nearly 13 gigawatts-electric by 2050.*

Categorical Exclusions for Resource Confirmation

Proving a resource is relatively inexpensive for other renewable technologies like solar and wind. However, proving a geothermal resource with sufficient certainty to obtain project financing requires drilling two or more resource confirmation wells, which is expensive and time consuming. This, as shown in Figure 4, requires an Environmental Assessment, which can cost companies potentially hundreds of thousands of dollars and 6–12 months or more of environmental review prior to permit authorization.

Geothermal resource confirmation drilling can be defined as "obtaining sufficient subsurface information that proves with high probability that a resource of a certain magnitude can be developed." When a developer has confirmed a resource, financial institutions are more willing to provide financing for further phases of project development, including the well field and power plant. The resource confirmation phase is distinct from and follows the resource exploration phase. Geothermal exploration uses various techniques—such as interpreting geologic maps, conducting seismic and resistivity surveys, and drilling core holes and shallow temperature-gradient wells—to find geothermal resources[13]. Per regulations, these small-diameter wells may not touch the target reservoir. Once a promising region has been identified, larger-size wells are drilled into the reservoir, and additional tests are conducted to confirm the resource.

[13] 43 CFR § 3250 et seq.

Technical analysis has shown that geothermal resource confirmation generally requires drilling at least two (preferably three) successful wells (6–8 inches in bottom-hole diameter) into the resource to conduct the necessary tests, including an interference test[14].

At BLM's request, NREL also analyzed environmental considerations related to geothermal resource confirmation drilling. The NEPA document review and related discussions with geothermal stakeholders resulted in a finding that geothermal resource confirmation drilling does not have a significant impact on the environment[15].

At the administrative level, current BLM regulations include one categorical exclusion specific to geothermal exploration, which allows for geophysical exploration[16] when no temporary or new road construction or (other surface disturbance) is required[17]. The categorical exclusion does not allow for resource confirmation activities, such as direct testing of the geothermal resource[18]. However, under EPAct 2005 Section 390, oil and gas operations using similar drill rigs and drilling to similar depths received a statutory categorical exclusion from Congress for activities similar to resource confirmation.

One noted benefit of statutorily established categorical exclusions is the ability to apply these across multiple federal departments (e.g., Department of the Interior and Department of Agriculture), whereas administrative categorical exclusions established at the departmental level may lack consistency across departments/agencies.

Dedicated BLM Geothermal Team

BLM manages all geothermal development on BLM-managed mineral estates in the United States. However, because not all regions of BLM-managed land have staff-level expertise in geothermal, projects in certain areas may face delays resulting from a lack of local staff knowledge. One mechanism to address this would be the creation of a dedicated geothermal team to provide support—for example, through improved training, guidance, standard operating procedures, and access to requisite data—to local BLM field offices where needed. This approach has the potential to save time and add greater continuity, consistency, rigor, and safety into the geothermal permit review process.

Geothermal Leasing

Geothermal leasing on federal lands, predominately administered by BLM and the U.S. Forest Service, requires compliance with both land use planning provisions (BLM's Resource Management Plans, Forest Service's Forest Plans) identifying geothermal development as a permissible use and approval of a lease nomination prior to placing the parcel up for

[14] For more information about technical needs for resource confirmation, see Beckers, K. and K. Young. 2018. *Technical Requirements for Geothermal Resource Confirmation.* GRC Transactions, Vol. 42, 2018. (attached)
[15] Levine, A., N. Taverna, and K. Young. 2018. *Environmental Concerns and Mitigation Associated with Geothermal Resource Confirmation Drilling Activities.* GRC Transactions, Vol. 42, 2018. https://www.geothermal-library.org/index.php?mode=pubs&action=view&record=1033934
[16] 43 CFR § 3250
[17] 516 DM 11 (6)
[18] See 43 CFR §§3200.1 and 252.12

competitive lease sale (via the default competitive leasing process established under EPAct 2005 Section 222). Two challenges with leasing involve federal funding coordination and competitive leasing:

Federal Funding Coordination

The geothermal lease nomination process requires BLM (and the Forest Service if on National Forest System land) to conduct preleasing analysis, including a NEPA environmental review and establishment of lease stipulations[19]. In the past, particularly on Forest Service land, the Forest Service has experienced a backlog of geothermal lease nominations awaiting processing, delaying projects by years. EPAct 2005 Section 225 temporarily addressed this issue by requiring a program to reduce the backlog of geothermal lease nomination applications on Forest Service land by 90% within 5 years of enactment. While EPAct 2005 Section 225 temporarily increased funding dedicated to geothermal lease nomination processing on Forest Service land, the funding provision is no longer active—meaning that lease nominations on Forest Service land may once again face processing constraints unless something is changed from pre-EPAct 2005 practices[20].

Competitive Leasing Requirement

The competitive leasing process established under EPAct 2005 Section 222 requires that all parcels initially nominated for a geothermal lease must be sold competitively to the highest responsible qualified bidder and only where the parcel does not receive any bids is it available for a noncompetitive lease for two years following the lease sale[21]. While EPAct 2005 Section 222 established a default competitive leasing process, EPAct 2005 did not alter the ability of a project proponent to explore unleased parcels upon receiving approval under a Notice of Intent[22]. As a result, any exploration activities on unleased land would still require the exploration project proponent to submit a lease nomination application and outbid other entities via a competitive lease sale to develop the resource—creating a disincentive for private industry to explore for additional geothermal resources on unleased federally managed lands.

In Conclusion

The United States has some of the best geothermal resources in the world, but they remain underutilized. To realize this potential, investment in new technologies to lower cost and allow for geothermal anywhere are required. Streamlining permitting would immediately be impactful.

Today we sit at a critical juncture. If we seize the opportunities before us, capitalize on our prior work, and appropriately invest in new early-stage research and in-depth analysis, American

[19] On National Forest System Lands, the U.S. Forest Service has principal responsibility to manage use of the surface resources and ensure land are reclaimed to support on-going land uses. As a result, the Forest Service must provide their consent to the BLM prior to placing the parcel up for lease sale.

[20] Witherbee, K., K. Young, and A. Levine. 2013. *Funding Mechanisms for Federal Geothermal Permitting.* GRC *Transactions*, Vol. 37, 2013. http://pubs.geothermal-library.org/lib/grc/1030638.pdf

[21] Prior to EPAct Section 222, the BLM was authorized to issue noncompetitive leases for areas outside of known geothermal resource areas.

[22] Notice of Intent to Conduct Geothermal Resource Exploration Operations

businesses and consumers will benefit significantly from major advancements in geothermal technologies. There is still important research we must do to improve cost, performance, reliability, and integration of geothermal energy. I know that researchers at NREL and other institutions are prepared to tackle these challenges, allowing geothermal energy to meet its potential for our energy future.

NREL, along with our partner laboratories across the DOE family and with university and industry collaborators, will continue to help our country succeed in an increasingly competitive global economy. Our country needs to leverage the progress science can deliver to remain leaders in this important growing industry.

Thank you for your interest in advancing geothermal research and technologies.

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Technical Requirements for Geothermal Resource Confirmation

Koenraad F. Beckers and Katherine R. Young

National Renewable Energy Laboratory
***corresponding author: koenraad.beckers@nrel.gov**

Keywords

Geothermal resource confirmation, geothermal wells, well pads, surface disturbance, well tests

ABSTRACT

In 2017–2018, the Bureau of Land Management's Renewable Energy Coordination Office, through its Geothermal Program, funded the National Renewable Energy Laboratory (NREL) to analyze technical and environmental considerations related to geothermal resource confirmation drilling. NREL solicited input from a group of technical and environmental experts in the geothermal industry, along with analyzing National Environmental Policy Act of 1969 (NEPA) documentation for previously approved projects. The collected data and analysis will be used by the Bureau of Land Management to examine the possibility of developing a new classification of wells and/or expediting the NEPA compliance process, which could potentially reduce permitting and regulatory compliance timelines when compared to the current process for obtaining a geothermal drilling permit for resource confirmation drilling activities.

This paper provides a summary of the technical requirements for confirming a geothermal resource. The analysis showed that confirming a geothermal resource requires confirming reservoir temperature, chemistry, permeability, and flow rate. Obtaining these data requires drilling at least two—preferably three—successful wells into the resource to conduct the necessary tests, including an interference test. Bottom-hole well diameters of at least 6" to 8" (0.15 to 0.2 m) are needed to limit the wellbore frictional pressure drop to effectively perform well flow and interference tests. Drilling these wells requires a drill rig with a mud pump and derrick capable of holding three drill pipes. This type of rig requires a minimum well-pad size of 2.5 acres (10^4 m^2) including surface area for a 1 million-gallon (3.8 million-liter) pit. Up to 15 acres (5×10^4 m^2) of total surface disturbance are needed for developing access roads and well pads to drill a total of three to five wells.

1. Introduction

The Bureau of Land Management's Renewable Energy Coordination Office, through its Geothermal Program, has funded the National Renewable Energy Laboratory (NREL) to analyze technical and environmental topics related to geothermal resource confirmation. Geothermal drilling has high up-front costs and high potential risk of unsuccessful exploration efforts, making it difficult to secure financing for these projects before the resource has been confirmed. This analysis looks at the possibility of developing a new classification of wells and/or expediting National Environmental Policy Act of 1969 (NEPA) compliance that could potentially be permitted more quickly than the current process for obtaining a geothermal drilling permit (GDP) for resource confirmation drilling activities.

Confirming a geothermal resource is defined as obtaining sufficient subsurface information that proves with high probability that a resource of certain magnitude can be developed. When a resource has been confirmed, banks are willing to provide financing for further project development. The resource confirmation phase follows the resource exploration phase. Geothermal exploration uses various techniques—such as interpreting geologic maps, analyzing surface manifestations, conducting seismic and resistivity surveys, and drilling core holes—to find promising geothermal resources (Stober and Bucher, 2013; Glassley, 2014). Once a promising region has been identified, larger-size wells are drilled, and additional tests are conducted (as discussed in Section 4) to confirm the resource.

This paper summarizes the technical interviews, monthly calls, and in-person workshop dedicated to technical requirements. Section 2 provides the methodology for this project. Section 3 provides an overview of the different types of geothermal wells and discusses which ones are used during the resource confirmation phase. Section 4 lists the resource confirmation tests conducted; well, well pad, and surface disturbance technical requirements; and project time needed for the confirmation phase. A conclusion of the results is included in Section 5. A parallel paper focusing on environmental concerns and mitigation strategies related to geothermal resource confirmation is presented at this conference by Levine et al. (2018).

2. Methodology

NREL conducted a series of technical and environmental interviews with geothermal stakeholders (i.e., Geothermal Expert Team) to understand the minimum technical requirements for confirming a geothermal resource, the associated potential environmental concerns, and measures to mitigate these concerns. As a follow-up to the one-on-one interviews with geothermal stakeholders, NREL organized a series of monthly calls with the Geothermal Expert Team to gain consensus on the feedback documented as part of the one-on-one interviews. In addition, NREL held an in-person workshop open to the public in February 2018, inviting a broader industry audience, during the Stanford Geothermal Workshop in Palo Alto, CA. The "technical experts" on the Geothermal Expert Team had backgrounds in geothermal exploration, geothermal drilling, well design, reservoir engineering, and project development (see Section Acknowledgments).

Table 1. Comparison of different geothermal well types. (T = temperature, P = pressure, and OD = outer diameter)

Well Type	1	2	3	4	5
Well Name	Temperature-Gradient Hole (TGH)	Core Hole *(into reservoir)*	Slim Hole *(into reservoir)*	Standard-Completion Confirmation Well	Standard-Completion Production/ Injection Well
Main Objective	Measure shallow temperature-by-depth profile	Obtain subsurface core samples	Penetrate reservoir to assess T/P, chemistry and geology	Conduct flow and interference test	Regular production/ injection
Data Obtained	T gradient, geology	T/P, chemistry, limited flow test, geology	T/P, chemistry, limited flow test, geology	T/P, chemistry, flow test, interference test, geology	T/P profiles, flow test, interference test, chemistry, geology
Range of Typical Measured Depth	150 to 500 ft (46 to 152 m) (up to 1,500 ft [457 m] in some areas)	1,500 to 5,000 ft (457 to 1,524 m)	1,500 to 5,000 ft (457 to 1,524 m)	up to 12,000 ft (up to 3,658 m)	up to 12,000 ft (up to 3,658 m)
Conductor Size	Typically N/A	Hole Diameter: 15–20″ (0.38–0.51 m) Casing OD: 9–14″ (0.23–0.36 m)	Hole Diameter: 15–20″ (0.38–0.51 m) Casing OD: 9–14″ (0.23–0.36 m)	Hole Diameter: 22–24″ (0.56–0.61 m) Casing OD: 16–20″ (0.41–0.51 m)	Hole Diameter: 30–40″ (0.76–1.0 m) Casing OD: 20–30″ (0.51–0.76 m)
Surface String Size	Typically N/A	Hole Diameter: 10–15″ (0.25–0.38 m) Casing OD: 6–10″ (0.15–0.25 m)	Hole Diameter: 10–15″ (0.25–0.4 m) Casing OD: 6–10″ (0.15–0.25 m)	Hole Diameter: 16–18″ (0.41–0.46 m) Casing OD: 13–16″ (0.33–0.41 m)	Hole Diameter: 20–30″ (0.51–0.76 m) Casing OD: 18–22″ (0.46–0.56 m)
Size of Final Cemented String	None (2″ [0.05 m]) blind tubing)	4–6″ (0.10–0.15 m)	4–6″ (0.10–0.15 m)	6–10″ (0.15–0.25 m)	8–18″ (0.20–0.46 m); most common: 9-5/8″ (0.24 m) and 13-5/8″ (0.35 m)
Final Hole Size	3–6″ (0.08–0.15 m)	<6″ (<0.15 m)	<6″ (<0.15 m)	6–10″ (0.15–0.25 m)	8–12″ (0.20–0.30 m)
Drilling Time	1–5 days	15–45 days	15–45 days	30–60 days	30–70 days
Cost Range ($US)	$20–150K	$0.5–2M	$0.5–2M	$2–6M	$3–10M
MW_e Potential	0	<2 MW_e	<2 MW_e	< 5MW_e	< 20 MW_e
Lead Time (Designing and Permitting)	1–3 months	4–8 months	4–8 months	5–10 months	9–12 months

3. Types of Geothermal Wells

Various types of geothermal wells exist, which are drilled for different purposes in a geothermal project, and they include different designs, dimensions, drilling times, drilling costs, and more. In collaboration with the Geothermal Expert Team, five main categories of geothermal wells were identified, based on the (original) objective of the well (see Table 1). Other classifications and labels exist—for example, an "observation well," which could fall under any of the well types 2 to 5 in our classification—but are not discussed further here. At a specific geothermal site, typically at least one of each of these well types are drilled: temperature-gradient holes and core holes during initial exploration, slim holes for obtaining additional subsurface data, standard-completion confirmation wells for well and interference tests to further characterize and confirm the resource, and eventually, standard-completion production and injection wells used for regular geothermal plant operation. As discussed in Section 4, the geothermal wells needed for geothermal resource confirmation need to have sufficiently large bottom-hole diameter—at least 6” to 8” (0.15 m to 0.20 m)—to allow reliable flow and interference tests. These wells are of type 4 or 5.

4. Results

The Geothermal Expert Team stated that to confirm a geothermal resource, various tests are required (Section 4.1) to confirm temperature, pressure, flow rates, and more. To effectively execute the well flow and interference tests, a minimum number of wells of sufficiently large bottom-hole diameter is required (Section 4.2). Drilling these types of wells requires surface disturbance for access roads and well pads (Section 4.3) as well as a large enough drill rig and surface fluid storage (Section 4.4). The resource confirmation timeframe (Section 4.5) should be long enough to conduct all on-site activities (e.g., drilling, testing) and account for delays (e.g., securing financing, snow fall, species breeding season).

4.1 Tests

Confirming a geothermal resource requires conducting tests to confirm temperature, pressure, chemistry, flow rate, and near-wellbore and overall reservoir permeability. These tests include:

- **Pressure/Temperature (P/T) or Pressure/Temperature/Spinner (P/T/S) survey:** Gives pressure and temperature (the S – or “spinner” – can be used to identify reservoir feed zones).
- **Chemical analysis test:** Conducted on fluid samples to estimate corrosion, theoretical reservoir temperature, and presence of non-condensable gases.
- **Well flow test:** Provides flow rate (after steady-state condition is obtained) and, when combined with pressure, provides productivity index/injectivity index. This test typically takes two to seven days. In case of two-phase flow for flash plants, the individual gas and liquid volume rates are measured to estimate the vapor fraction. Data obtained from a well flow test give developers an initial indication of reservoir transmissivity and allow for assessing the drilling-mud damage to the formation (also called skin factor). Banks generally require developers to demonstrate that a certain percentage (in the United States, typically 50%) of the target production flow rate is obtained during the confirmation phase. Depending on the size of the plant considered, fulfilling this criterion requires drilling a certain number of wells (see Section 4.2.1).
- **Interference tests:** Provides average reservoir permeability and can take four to eight weeks. Fluid is produced from one well and reinjected into another well to measure connectivity between the two wells. Preferably, a third well is instrumented to obtain additional transient pressure data.

4.2 Wells

4.2.1 Number of Wells

One well penetrating the reservoir would be sufficient to obtain data on reservoir temperature, pressure, and chemistry. However, multiple wells are needed to conduct well flow and interference tests:

- **To conduct interference test:** An interference test is conducted to estimate overall reservoir permeability. For this test, a minimum of two—preferably three—flowing wells are needed. One well can only provide information on near-wellbore permeability.
- **To conduct well tests:** A percentage (typically 50% in the United States) of the total target production flow rate should be demonstrated during the resource confirmation phase. For example, considering a 20 MW_e plant, and sizing wells for a 5 MW_e power output per well, two flowing production wells would be required. The percentage required can be 70% to 80% for other countries such as Chile, Peru, and Uganda.

Several project-dependent factors impact the final number of wells that are required for well and interference tests to confirm a geothermal resource:

- **Field history:** An established geothermal region (e.g., Iceland) or a brownfield with prior development may need fewer wells to confirm a resource than new regions (e.g., Cascades) and greenfields.
- **Project size:** For the same geothermal resource, a 50 MW_e plant would need more wells than a 10 MW_e plant.
- **Resource quality:** For the same plant size, a high-enthalpy resource (e.g., high-temperature two-phase liquid/vapor) would need fewer wells than a low-enthalpy resource (e.g., low-temperature single-phase liquid).
- **Company history:** Smaller, less established companies may need more wells to convince a bank that a resource has been confirmed than larger, more established companies.

4.2.2 Diameter of Wells

Sufficiently large wellbore diameters are required to limit the wellbore frictional pressure drops to effectively run well flow and interference tests. These tests depend on several parameters including well depth, resource temperature and pressure, and target plant size; but, in general, a bottom-hole diameter of 6" (0.15 m) or larger is desired.

A slim-hole well with 4.5" (0.11 m) bottom-hole diameter allows for collecting fluid samples for chemical analysis, measurements of resource temperature and pressure, and for conducting initial transient pressure tests. However, this diameter is normally too small to effectively flow fluid during well flow and interference tests. Some developers may use a slim-hole well as a monitoring well in combination with two other wells with larger-diameter holes for interference tests.

If large flow rates are targeted, a 6" (0.15 m) bottom-hole diameter may be too small for the criterion of a 50% target flow rate. However, this well can still be used to obtain data on near-wellbore reservoir permeability with a well flow test and overall reservoir permeability with an interference test. In the latter test, this well is likely used as an injection well with a larger bottom-hole diameter (e.g., 8.5") serving as a production well.

If developers have enough confidence in the resource, they may choose to drill full-size production and injection wells with bottom-hole diameters of 8" (0.2 m) or larger during the resource confirmation phase. These wells will eventually be used for fluid production and injection during regular plant operation. In some regions, 20 MW_e wells have been drilled with bottom-hole diameters larger than 10" (0.25 m), but this is not likely for most U.S. resources. If the well must be pumped, the well should be sized appropriately to fit the pump in the well. For example, installing a 12" (0.30 m) pump requires at least 13-3/8" (0.34 m) casing.

4.2.3 Fate of Standard-Completion Confirmation Wells

Standard-completion confirmation wells with sufficiently large bottom-hole diameter (generally 8" [0.20 m] or larger) can be used as regular production or injection wells during plant operation. If the bottom-hole diameter is only 6" (0.15 m), in some circumstances—e.g., the well is right next to a power plant and intersects a fracture—the well can be used as an injection or even a production well. However, in most cases, these wells serve as observation wells and the developer may drill a new larger-diameter production or injection well from the same well pad.

4.3 Surface Disturbance

Developers need about 15 acres (5×10^4 m^2) of surface disturbance to confirm a geothermal resource. Developers use this acreage for three to five well pads and access roads.

4.3.1 Size of Well Pad

The minimum well-pad size for drilling standard-completion confirmation or production/injection wells is 2.5 acres (10^4 m^2). This acreage is distributed as follows:

- **Drill rig and equipment:** 1.3 acres (5.3×10^3 m^2).
- **Sump:** 0.6 acres (2.4×10^3 m^2). This assumes a 1 million-gallon (3.8 million-liter) sump at 5 ft (1.5 m) depth. However, depth will depend on location (e.g., in Nevada, typically a shallow sump depth is required because of a shallow water table). Experts stated that sumps up to 10 ft (3.0 m) deep are not uncommon. This includes 1 to 2 ft (0.3 to 0.6 m) of freeboard required to prevent spills.
- **Equipment moving:** 0.5 acres (2.0×10^3 m^2).

4.3.2 Number of Well Pads

Wells need to be spaced a significant distance apart to effectively run an interference test. A minimum distance of 1,000 ft (305 m) has been put forward by the expert team, measured from where the wells touch the reservoir. Depending on how much deviation from drilling vertically, the surface spacing may be slightly different. Directional drilling is not common for early-phase exploration wells. Hence, for drilling three wells, three well pads are needed (for a total acreage of about 7.5 acres). Developers may only know after drilling each well where they want to locate the next well pad.

4.3.3 Access Roads

The ability to construct access roads is desirable to have freedom in selecting the drill sites. Access road dimensional requirements are as follows:

- **Minimum width:** 18 ft (5.5 m)
- **Average length:** 0.25 miles (0.4 km). One access road of 0.25 mile (0.4 km) length and 18 ft (5.5 m) width has an area of about 0.5 acres (2.0×10^3 m^2).

- **Strength:** Sufficient road strength to allow a semi tractor-trailer load that is overweight highway permittable.
- **Turnouts:** Periodic (every 0.25 mile [0.4 km]) turnouts to allow 2-way traffic are desirable. In theory, an 18-ft-wide road would not require turnouts, but they are still preferred by developers to facilitate two large semi-trucks coming from opposite direction to pass each other.

Rubber mats can be used on access roads in muddy/swampy environments as a base for the first layer to keep that layer from sinking. However, the expense can go up quickly when placing mats on access roads, so they are rarely used.

4.4. Well Pad Components

4.4.1 Drill Rig

To drill a standard-completion confirmation or production/injection well—with bottom-hole well diameter of 6" to 8" (0.15 m to 0.2 m) or larger, and typical depth of 5,000 ft (1,524 m) or deeper—a drill rig is required that uses a mud pump and has a derrick capable of holding three drill pipes. This type of drill rig is not mobile and cannot be mounted on a truck. Instead, this drill rig is usually deconstructed into 20 to 40 truckloads (overweight highway permittable) and requires a sufficiently large well pad (see Section 4.3.1) and sufficiently wide and strong access roads (see Section 4.3.3). A helicopter drill rig can be used for drilling core-hole and slim-hole wells, but not for confirmation and production/injection wells.

4.4.2 Fluid Storage

Surface fluid storage is needed during drilling and for well flow and interference tests. A 1 million-gallon (3.8 million-liter) open pit is preferred. Pits are typically clay-lined. Surface fluid storage can also be obtained with temporary tanks (e.g., Baker tanks). However, tanks are more expensive, typically have less total volume, lines can freeze in winter, and they can be difficult to clean out. Tanks are generally only used in an emergency or when no pit excavation is possible or allowed.

During a long-term interference test, the pit acts as a storage buffer. All fluid produced from one well gets reinjected into the other well. Fluid is not being stored from several weeks of production, but rather, only from a few hours or days maximum. A 1 million-gallon (3.8 million-liter) pit can store 12 hours of produced fluid flowing at 1,360 gpm (86 L/s).

4.5 Timeline

The resource confirmation timeframe can take up to 5 years. The clock starts ticking when "a rock gets kicked," i.e., when the first access road or well pad starts getting built.

This timeframe encompasses:

- On-site activities: Up to 1.5 years
    - 60 to 100 days for preparing roads

  - 30 to 75 days per well for well drilling and well tests. The decision to drill each consecutive well is made after evaluating data from previous wells (i.e., wells are not drilled concurrently).
  - 1 to 2 months for interference test.
- Account for delays due to securing additional financing, negotiating power purchase agreement, avoiding species breeding season, snowfall, and more: Up to 3.5 years[1]

5. Conclusions

The results presented in Section 4 provide typical technical requirements for confirming a geothermal resource with focus on average-sized hydrothermal systems in the United States developed by established companies. Requirements may vary in other countries, for different companies, for different-type geothermal resources, and for different-size geothermal systems. The technical requirements are heavily governed by the need for performing effective well flow and interference tests. These tests require two to three wells penetrating the reservoir with large enough bottom-hole diameter. Drilling these wells requires large enough drill rigs and fluid storage, which translates into requiring access roads, large enough well pads, and a long enough timeframe.

For this study, geothermal resource confirmation was defined as obtaining sufficient subsurface data to state with high probability—e.g., with 90% confidence level (Sanyal and Morrow, 2010)—that a resource of certain magnitude (in MW_e) can be developed. At this point, banks are willing to provide financing for further project development. An exploration phase (using data obtained, for example, from geologic maps, seismic surveys, and core-hole drilling) precedes the confirmation phase. The data collected during both phases become input in geothermal reservoir and geothermal resource assessment models to quantify the developable resource size (Glassley, 2011; Grant, 2011). Other terminology has been used in the literature to describe the geothermal resource confirmation activities, e.g., production testing (Grant and Bixley, 2011), resource confirmation testing (Glasspey et al., 2008), test drilling (Gehringer and Loksha, 2012), and confirmation drilling (Sanyal and Morrow, 2010).

The conclusions of the analysis on technical requirements for geothermal resource confirmation are as follows (typical requirements with focus on the United States):

- **Tests:** Tests are conducted to confirm temperature, pressure, chemistry, permeability (near wellbore and overall reservoir), and flow rates.
- **Wells:** Up to three successful wells are required that penetrate the reservoir with bottom-hole diameter of at least 6”–8” (0.15–0.20 m). A large enough wellbore diameter is needed to effectively run well flow and interference tests.

[1] Note: This includes additional time for smaller companies that may be slower in developing wells than more established companies.

- **Well pad components:** A drill rig with mud pump and derrick capable of holding three drill pipes is required. A sump with typical size of 1 million gallons (3.8 million liters) is required to store fluid during drilling and tests.
- **Surface disturbance:** Up to 15 acres (5×10^4 m^2) of surface disturbance are required for developing access roads and well pads. The type of rig needed requires a well-pad size of 2.5 acres (10^4 m^2).
- **Timeframe:** A resource confirmation timeframe of up to five years may be required to conduct all on-site activities (e.g., drilling, testing) and account for delays (e.g., securing financing, snow fall, species breeding season).

Acknowledgments

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The CHAIRMAN. Thank you, Ms. Young.

Mr. Latimer, welcome.

STATEMENT OF TIM LATIMER, CEO, FERVO ENERGY

Mr. LATIMER. Thank you.

Chairman Murkowski, Ranking Member Manchin and members of the Committee, thank you for this opportunity to join the important discussion on advanced geothermal energy development.

This is an important time for geothermal energy. The DOE just released the landmark GeoVision study which outlined the opportunity for geothermal to power up to 16 percent of the U.S. electric grid and heat up to 45 million homes by 2050.

Geothermal is a unique energy resource. It's versatile, renewable, and has 24/7 reliability. So this is a major prize worth pursuing. Currently, geothermal makes up only 0.4 percent of U.S. electricity, its growth lagging significantly behind both wind and solar.

My testimony today is about this gap between our current state and the potential future in the GeoVision study and what I believe it will take to get there.

First, let me introduce myself. I am the co-founder and CEO of Fervo Energy where our mission is to leverage innovation in geoscience to advance the clean energy future. Five years ago, I was a well site supervisor in the heart of the oil boom in the Permian Basin. I was able to witness firsthand one of the fastest paced and most innovative energy booms ever. But like many people my age, the more I learned about climate change, the more I felt a sense of urgency to change my career to address its looming threats. Since my primary experience involved drilling deep wells, geothermal seemed like a natural place to apply my skills and I saw a major opportunity for technology transfer from oil and gas.

I left my oil job to study energy in the environment at Stanford University where I met Dr. Jack Norbeck. At the time, he was using advanced computational models to research fundamentally new ways of producing geothermal energy. Together we launched Fervo Energy in 2017. Fervo's vision is to use novel horizontal drilling and production techniques to unlock the 120-gigawatt potential for geothermal outlined in the GeoVision study. To date we have benefited tremendously from the early stage, public-private innovation ecosystem this Committee has been instrumental in creating. We are supported through grant awards from both the Geothermal Technologies Office and ARPA-E. We are embedded with world-class, geoscience researchers at the Lawrence Berkeley National Lab through the Cyclotron Road Entrepreneurial Fellowship program. We've also obtained venture capital investment including from Breakthrough Energy Ventures, a billion-dollar clean energy fund backed by Bill Gates and others dedicated to tackling climate change.

I'm encouraged by our progress so far, but the most challenging point for any geothermal technology occurs at the scale-up from the lab to the field. And I'd like to offer a few thoughts on how we can accelerate this transition.

Although geothermal is quite different from oil and gas, it can serve as a useful analog on how new subsurface technologies can be deployed. Part of my confidence in the ability of technology and innovation to drastically improve productivity in geothermal comes from my firsthand experience in the oil industry. I have personally witnessed my team's learning, tweaking, developing new methods, and driving productivity at a rapid pace, month after month. This innovation led to dramatic results.

In every major shale basin in the U.S. productivity has increased by a factor of ten in the last decade alone. It's clear that subsurface industries exhibit rapid learning at scale, but getting to scale is very challenging.

For oil and gas, launching the shale revolution took years of fundamental research support from the Department of Energy helping to develop vital technologies like seismic mapping and the PDC drilling bit. It also took a private sector leader, Mitchell Energy, to pick up these technologies and lead the field level testing to make them commercially viable.

It's fascinating to consider in hindsight the shale revolution, which has led the U.S. to become the largest oil producer in the world, may never have happened if Mitchell Energy hadn't been willing to try all new technology on a couple dozen wells in the late '90s.

Geothermal has similar potential for both innovation and scale but will require the same kind of early support. We face a major challenge in crossing the so-called "valley of death" from the lab-scale to the field-scale where investment costs are much higher and you must deal with the complexity and harsh conditions of the subsurface.

A few actions could provide that early support and greatly accelerate development of geothermal technology. These include potentially restoration of the investment tax credit to be on par with other renewable energy resources, use of appropriate categorical exclusions to accelerate permitting, and increasing funding to the Geothermal Technologies Office.

The Geothermal Technologies Office is currently leading the Field Observatory for Research in Geothermal Energy, or the FORGE project, an unprecedented and promising geothermal energy test bed. Increased funding to ensure technologies developed there have a roadmap to commercialization and a focus on public-private partnership to identify wells of opportunity from new technology deployment could have a transformative impact on crossing the innovation "valley of death."

This is a critical time for geothermal energy. The FORGE project is a unique and exciting research effort. The urgency of climate change is both rapidly changing electricity markets and driving interest from the oil and gas industry to look at alternatives. Geothermal energy can be a critical part of the clean energy future in the United States with the right technology, policy, and markets, and is a prize worth pursuing.

I want to thank the Committee for your time, and I look forward to a lively discussion.

[The prepared statement of Mr. Latimer follows:]

FERVO ENERGY

Written Testimony
Tim Latimer, CEO, Fervo Energy
June 20, 2019
Before the United States Senate Committee on Energy and Natural Resources

Chairman Murkowski, Ranking Member Manchin, and members of the Committee, thank you for the opportunity to join this important discussion on advanced geothermal energy development in the United States.

This discussion happens at a critical juncture for geothermal energy. **The Department of Energy recently released an important report, the GeoVision study, outlining the opportunity to power up to 16% of the United States electric grid and heat up to 45 million homes from geothermal energy by 2050.** Because of geothermal's unique attributes as an energy source, firm, low carbon, with 24/7 reliability, this is a major prize worth pursuing from the private and public sector alike. Additionally, many forces are coming together to make this the right time to develop more geothermal energy. First, increasing attention for climate change has led many states to target ambitious clean energy standards that go well beyond historic targets. Next, the Department of Energy Field Observatory for Research in Geothermal Energy (FORGE) is underway, the largest and most sophisticated advanced geothermal test bed ever created. Finally, oil and gas technology has advanced at a lightning pace this decade, and oil and gas operators are increasingly looking at new energy options as climate change puts pressure on their traditional businesses, so the time for technology transfer from the oil and gas industry has never been better.

However, geothermal energy today constitutes just 0.4% of current US electricity, and in recent years, growth has lagged significantly behind other renewable resources like wind and solar. My testimony today will focus on challenges and opportunities to geothermal energy development, drawing on my experience as the Co-Founder and CEO of Fervo Energy, where our mission is to leverage innovation in geoscience to advance the clean energy future.

If you would have found me five years ago, I was in my old job, as a wellsite supervisor in the heart of the oil boom in the Permian Basin in West Texas. In this role, I witnessed first-hand the revolution in oil and gas production from unconventional resources, catalyzed in large part from technologies supported by the Department of Energy such as horizontal drilling and distributed fiber optic sensing. While I found this job dynamic and interesting, like many people my age, with an increasing understanding of the urgency of climate change, I felt drawn to the burgeoning clean energy economy. As a drilling engineer, geothermal energy seemed like a perfect fit, and the more I learned about the huge untapped potential of geothermal, the more excited I became about applying my skills in this field. I left my oil job to study energy and the environment at Stanford University, where I met my co-founder and launched Fervo Energy in 2017.

Fervo Energy was founded to leverage recent subsurface technology advancements, such as horizontal drilling and distributed fiber optic sensing, to lower the development cost and increase the resource base of geothermal energy. To date, Fervo Energy has benefited tremendously from the early stage public-private innovation ecosystem this Committee has been instrumental in creating. We are supported through grant awards from both the Geothermal Technology Office and ARPA-E. We are currently embedded with world class geoscience researchers at the Lawrence Berkeley National Lab through the DOE-supported Cyclotron Road entrepreneurial fellowship program. From the private sector, we are backed through venture capital investments including Breakthrough Energy Ventures, a billion-dollar clean energy fund dedicated to supporting breakthrough technology companies tackling climate change. This support has been critical to our success so far, but the greatest difficulty in scaling geothermal technology comes at the valley-of-death between the lab-scale and field-scale. I'd like to offer a few thoughts on how to accelerate this scale up for both Fervo and any other technology-enabled geothermal company.

Geothermal energy has many unique and valuable benefits

<u>The recent GeoVision Study highlighted the immense potential and significant positive environmental, economic, and security impact of geothermal energy development in the United States</u>. Geothermal energy:

- Is a clean, renewable, and fuel-secure resource. Increased development would lead to significant reductions in CO_2, SO_2, and NO_x emissions in the United States.
- Is a firm, always-on resource. Recent research has shown the benefit of including firm, low carbon resources in the electricity mix, reducing costs to decarbonizing by 10-62%.[1]
- Is a versatile energy resource, with the ability to provide everything from large-scale utility generation to residential heating and cooling options throughout the US.
- Leverages unique US expertise in subsurface development and geoscience. Both US public and private sector entities have been active in projects around the world, such as in Kenya, where geothermal provides 47% of electricity generation[2], and Indonesia, which holds up to 40% of the world's geothermal resources.
- Has enormous untapped potential, with NREL estimating the United States contains over 5,157 GW_e of electricity generation resource potential. The GeoVision study shows in certain scenarios generation could reach 120 GW_e by 2050, capable of providing 16% of US generation.
- Is often found on public lands, which means federal policy could have an outsized impact on accelerating development. The GeoVision study found that improving regulatory timelines alone through use of standardization and tools such as categorical exclusions could increase geothermal development 5-fold by 2050[3].

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[1] Sepulveda et al., The Role of Firm Low-Carbon Resources in Deep Decarbonization of Power Generation, Joule (2018), https://doi.org/10.1016/j.joule.2018.08.006

[2] Annual Report, Kenya Power and Lighting Company, 2018.

[3] GeoVision: Harnessing the Heat Beneath Our Feet. Department of Energy. 2019.

Despite all these benefits, geothermal must overcome significant technical and non-technical barriers to become a major energy resource. Subsurface exploration is an inherently risky activity and new technology and business models must be developed to tackle this risk. Projects can have extended development timelines, challenging economics. Importantly, the jump between lab-scale innovation and field-scale deployment is significant, with many promising new technologies never successfully crossing this challenging valley. Many of the important research and development questions in geothermal energy can only be answered at the field scale, so it is imperative that a robust innovation ecosystem addresses this critical gap.

Supporting technology scale up

Restoration of the Investment Tax Credit to achieve parity with other clean energy resources would catalyze new geothermal development. Subsurface industries demonstrate a strong learning effect, growing far more efficient over time[4], but must be supported in early days in order to start the virtuous cycle of cost reduction. As an analogue, we can look to the pace of innovation in shale oil and gas boom. It should be noted that there are many differences between oil and gas, which is focused on extraction of hydrocarbons, and geothermal, which is principally focused on circulation of water through closed loop reservoirs to mine heat, but it can still serve as a useful analog.

Horizontal drilling first became commercially deployed in the late 1990s to develop shale resources. Early commercialization was supported directly through DOE-funded research into technologies such as horizontal drilling and advanced drill bit technology. In the last decade alone, productivity across the major shale basins in the United States has increased by a factor of 10X (see Figure 1). This has led to an unprecedented resurgence of oil and gas production. The US in 2018 recorded the highest oil and gas output in a single year for any country in history[5]. This multi-decade increase in productivity and output could never have occurred had the industry not had support in early days to develop the first-of-a-kind commercial projects. New technology deployments in subsurface industries always show a strong learning effect, but because of the capital intensity of new projects, initial deployment of a new technology before it reaches the learning phase is challenging.

[4] "Use of the Experience Curve to Understand Economics for At-Scale EGS Projects". Proceedings, 42nd Workshop on Geothermal Reservoir Engineering, Stanford University. Latimer and Meier. 2017.
[5] "U.S Oil and Gas Output Surges the Most Ever for a Single Country", Bloomberg, 2019. https://www.bloomberg.com/news/articles/2019-06-11/u-s-oil-gas-output-surges-the-most-ever-for-a-single-country

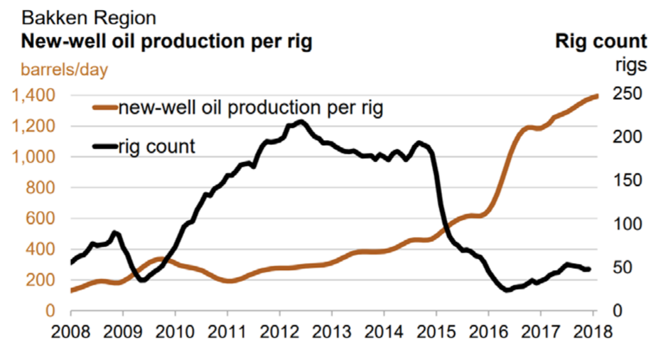

Figure 1: US Energy Information Agency Drilling Productivity Report. 2018.

Geothermal energy has the potential to have similar large-scale efficiency and productivity improvements, but needs similar early-stage support to deploy the earliest, higher cost initial projects. Because of rapid innovation in the oil and gas sector, technology transfer opportunities could lead geothermal to have an even faster commercialization cycle. While geothermal is quite different from oil and gas, targeting harder, hotter rocks, and focusing on closed loop circulation, there are still areas where recent innovation from oil and gas can be applied, such as seismic mapping or advanced directional drilling techniques. However, despite the fact the United States has now drilled over 300,000 horizontal wells for oil and gas production, horizontal drilling had never been systemically developed for geothermal energy. This is due in part to very unfortunate timing. In recent years, just when advanced drilling technology was reaching a maturity level that could make it very attractive, geothermal energy has had access to only a 10% Investment Tax Credit, while other resources such as solar energy receive a 30% Investment Tax Credit. In a hyper-competitive market like power generation, with low project margins, starting this deeply behind other resource classes makes even traditional project development challenging, and presents an incredible barrier to project development with any new technology approach. In order to send a clear enough signal to the market and investors, it is important that the ITC be installed for a meaningful and clear period-of-time to align with geothermal development cycles, such as a 5-year target.

The GeoVision study highlights numerous benefits for geothermal development, including generating 16% of US electricity, catalyzing over $200 billion in new investment, and significant reductions in emissions of CO_2, SO_2, and NO_x. A near-term restoration of the ITC to be comparable to the ITC received by other energy resources would be key to unlocking $200+ billion of new private sector investment over the next decades.

Supporting technology innovation

Increased funding to promising initiatives currently run by the Geothermal Technology Office (GTO) and the Advanced Research Projects Agency-Energy (ARPA-E) could dramatically accelerate early-stage technology innovation and adoption. The most challenging area for geothermal technology development is through the "valley of death" from the lab-scale to the field-scale. To address this point, the Department of Energy launched the FORGE program, beginning with a competitive site selection process in 2014, to establish a field test bed for the deployment of new technologies. FORGE has now completed the site selection phase and is moving forward with a multi-year R&D program at a site in Milford, Utah operated by a team for the University of Utah. This project is unprecedented and will enable the subsurface research community to develop, test, and improve new technologies in a well characterized and instrumented site. Similarly, ARPA-E recently initiated a program focused on unlocking the potential of geothermal through a funding announcement on "Innovating Through Unconventional Ideas"[6]. ARPA-E awarded projects focused on geothermal tools, including one to Fervo Energy, and announced that "topics explored under this opportunity are not part of existing ARPA-E programs, but if successful could establish new program areas for ARPA-E to explore." It is an exciting time for geothermal R&D with innovative projects underway from both the GTO and ARPA-E.

However, because of the high cost of testing new technology at the field scale, even these innovative programs will have limited opportunities for new technology deployment. Currently, due to drilling costs, only a limited number of wells will be developed for new technology evaluation at FORGE. Increased funding to the GTO could enable multiple more technologies and wells to be developed at the FORGE site and create opportunities for continued technology development beyond FORGE. With ARPA-E's unique focus on commercialization of breakthrough technology, additional funding for novel downhole tools, electronics, and sensors would help to unlock the prize for geothermal. Additionally, there are opportunities for innovative public-private partnerships for technology scale up at existing or new geothermal sites throughout the US that would greatly accelerate deployment. These collaborations could identify "Wells of Opportunity" or promising, but sub-commercial, geothermal reservoirs as low-cost, low-risk areas for geothermal technology deployment. These currently sub-commercial reservoirs, referred to as "In-Field" and "Near-Field" in the GeoVision study, would be ideal candidates for public-private partnership for new geothermal technology deployment and an important intermediate step for unlocking the full potential for geothermal energy (see Figure 2).

[6] ARPA-E: Innovating Through Unconventional Ideas. https://arpa-e.energy.gov/?q=news-item/arpa-e-innovating-through-unconventional-ideas

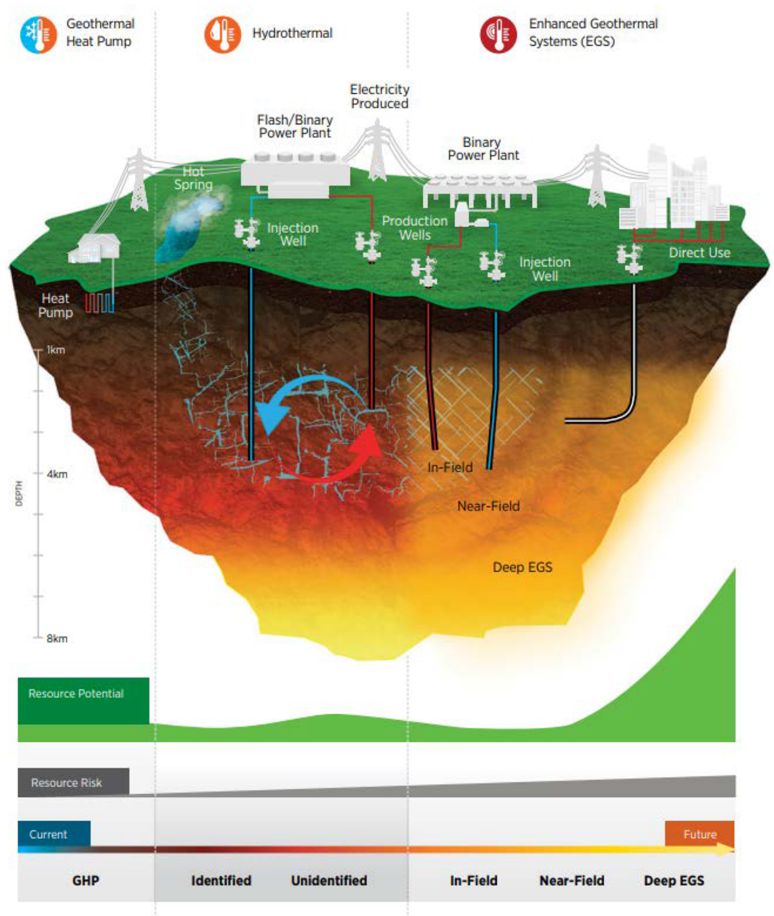

Figure 2: in-Field and Near-Field Candidates. GeoVision Study. 2019.

Funding for the Geothermal Technology Office has followed a good trend in recent years but still lags behind other energy R&D efforts. Funding in 2018 for the GTO was $80,906,000 from $38,094,000 in 2013. This compares to $241,600,000 and $290,719,000 for Solar Energy in the same years, respectively, or $726,817,000 and $536,969,000 for Fossil Energy Research and

Development in the same years, respectively[7][8]. Continued or increased growth of the Geothermal Technology Office Budget would enable more innovation opportunities.

To put these numbers into context, despite its great promise, geothermal typically receives <1% of renewable electricity federal subsidies and support (see Figure 3). Increasing funding could accelerate the progress of already ongoing promising R&D efforts and lead to a step-change in our likelihood of unlocking the potential $200 billion investment opportunity for geothermal in the United States. The right combination of early-stage R&D support and investment tax credits led to tremendous success in cost reduction and deployment for wind and solar and lessons from their success can drive similar progress for geothermal energy.

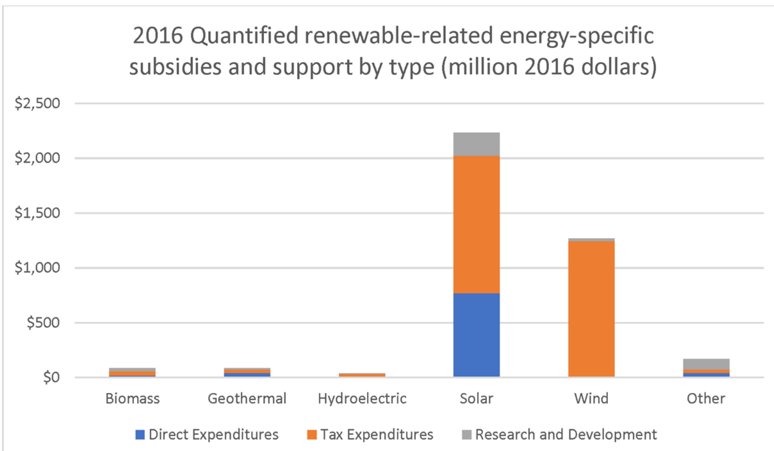

Figure 3: US Energy Information Agency Financial Interventions and Subsidies. Table 4. 2018.

Forces are aligning for geothermal energy and the time to act is now

Private sector, market, and technology forces are intersecting to create a unique opportunity in geothermal energy development. The GeoVision study outlines the $200 billion opportunity that would enable 16% of US electricity to come from clean, always-on geothermal electricity. Ambitious state level Renewable Portfolio Standards are driving renewed interest in geothermal energy. Private sector investors, like Breakthrough Energy Ventures, have identified geothermal

[7] Department of Energy FY2014 Budget Highlights. https://www.energy.gov/sites/prod/files/2013/04/f0/Highlights.pdf

[8] Department of Energy FY2019 Budget in Brief. https://www.energy.gov/sites/prod/files/2019/03/f60/doe-fy2020-budget-in-brief_0.pdf

as one of the most promising areas to help us achieve deep decarbonization to address climate change. Oil and gas technology has advanced at a rapid pace, and high interest in alternative sources of energy from the oil and gas operators make this a compelling time to focus on technology transfer. With the right policy and funding support, the geothermal industry can achieve the ambitious goals outlined in the GeoVision study and unlock a huge, valuable domestic clean energy resource.

The CHAIRMAN. Thank you, Mr. Latimer.

Okay, we have had four in a row say that this is a critical time for geothermal.

We will now hear from you, Mr. Thomsen, and I am reminded that you were actually before this Committee the last time we had a hearing on geothermal which was in 2006. So welcome back.

STATEMENT OF PAUL A. THOMSEN, VICE PRESIDENT, BUSINESS DEVELOPMENT–AMERICAS, ORMAT TECHNOLOGIES INC.

Mr. THOMSEN. Thank you, Chairman and Ranking Member.

I was also going to point out that I was at Chena Hot Springs for the first renewable energy summit with then-Governor Murkowski and Senator Stevens. So it's an honor and a privilege to be back here.

And it is a timely point. I would steal a line from Malcolm Gladwell and say, I think there's a tipping point and we're seeing that in the marketplace.

By way of introduction, Ormat Technologies is a geothermal energy developer, owner, operator and that sets us apart because we manufacture the equipment and we are responsible for over three gigawatts of geothermal generation around the world in over 30 countries.

We own and operate just under a gigawatt of geothermal development in the United States and six other countries with the vast majority of that geothermal generation right here in the United States and in the great states of Nevada and California, but we are branching out throughout the West.

Owning all of that generation has let us see that the electric power system is undergoing massive changes. We are seeing massive operational reliability and market changes due to shifting economics, the rapid penetration of intermittent resources and the prevailing climate goals in many states.

When I testified in front of this Committee 13 years ago, it was a very different situation. The fracking boom was nascent, solar was about $9.00 a watt, and the very first geothermal project in the country received the then new, production tax credit and that was Ormat's Richard Burdett power plant. Today I'm proud to say that we've developed hundreds of megawatts but, as you've heard from this panel, I think there are thousands more that we can do.

And we developed the hundred megawatts that we did and it's not just geothermal, it's recovered energy generation, it's low temperature generation, as the Chairman pointed out, it's co-production with oil and gas, and we did that using innovative technologies, by pioneering new power purchase agreements and responding to a market that demands a resource that can be flexible, absorb intermittency, all while reducing greenhouse gases. And geothermal can do that and not many technologies can say that today.

I also am happy that this Committee is going to talk about geothermal, not just from the typical hydrothermal standpoint but also, we've heard about enhanced geothermal systems and we've heard about district heating. And I'm also going to talk about recovered energy generation because all of these technologies and their ability to convert thermal heat to energy without the combustion of a new fossil fuel is what sets apart geothermal and lets it impact almost every member of this Committee moving forward.

To say a minute about district heating. The carbon footprint from heating can be two to three times greater than that of electricity production, so by using geothermal for district heating in places like Maine and Vermont, we can reduce the carbon footprint massively.

As Chairman of the Public Policy Committee for the Geothermal Resource Council, I often am asked to give an elevator pitch and I was really proud of Ms. Young because she hit most of them.

And I would be remiss if I didn't give it here today which is that geothermal is valuable. We see that in states that are trying to have high penetrations of renewables, the energy and capacity value of geothermal is exceeding that of intermittent resources. Number two, it's cost-effective. When I was here a decade ago, the cost of geothermal was probably about $0.09. Today we're seeing prices in the $0.06 to $0.07 range for the energy, capacity and all of the environmental attributes and ancillary benefits that geothermal provides.

As the Chairman pointed out, it works well with others. When the sun goes down, geothermal is still there. If you want to have high penetration of renewable resources moving forward, you have to have geothermal. It has no emissions and a small footprint. Geothermal can do it all.

In my written testimony before you today we highlight what needs to be done to rapidly expand geothermal development and you heard most of it from my colleagues here.

We need to, as the report says, increase our access to geothermal resources. Most of them are on public lands. We need to streamline permitting, and we need to evaluate transmission and interconnection delays and also look at wilderness study areas that are close to these geothermal resources at our ability to look underneath those areas to fully, to get the full potential of our geothermal development.

We need to reduce the costs and improve the economics of geothermal projects. You heard about the fact that geothermal was orphaned. It needs to receive the production tax credit. We need to reform the DOE loan guarantee program, and we need to support projects that highlight the district heating capability of geothermal moving forward.

So, with that, I look forward to your questions, and I'm honored to be here.

[The prepared statement of Mr. Thomsen follows:]

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Statement of Paul A. Thomsen
Vice President, Business Development - Americas
Submitted to the U.S. Senate Committee on Energy and Natural Resources
June 20, 2019

Chairman and members of the committee, it is my honor to testify today on behalf of not only ORMAT Technologies, but also on behalf of the Geothermal Resource Council.

By way of introduction, ORMAT Technologies is a New York Stock Exchange registered company (symbol "ORA"). Ormat Technologies, Inc. is a leading geothermal company and the only vertically integrated company engaged in geothermal and recovered energy generation ("REG"). The Company owns, operates, designs, manufactures, and sells geothermal and REG power plants primarily based on the Ormat Energy Converter—a power generation unit that converts low-, medium-, and high-temperature heat into electricity. With 77 U.S. patents, Ormat's power solutions have been refined and perfected under the most grueling environmental conditions. Ormat has 584 employees in the United States and 762 overseas. Ormat's flexible, modular solutions for geothermal power and REG are ideal for a vast range of resource characteristics. The Company has engineered, manufactured, and constructed power plants, which it currently owns or has installed, to utilities and developers worldwide, totaling over 2,900 MW of gross capacity. Ormat's current 910 MW generating portfolio is spread globally in the U.S., Kenya, Guatemala, Indonesia, Honduras, and Guadeloupe. Ormat expanded its operations to provide energy storage and energy management solutions by leveraging its core capabilities and global presence, as well as through its Viridity Energy Solutions Inc. subsidiary. I have the pleasure of serving as Vice President of Business Development for the Americas.

The Geothermal Resource Council (GRC) is a non-profit professional association for the geothermal industry and community in the USA and abroad. Founded in 1972 and headquartered in Davis, California, the GRC has over 1,300 members from around the world working to advance our industry by supporting the development of geothermal energy resources through the communication of robust research, knowledge, and guidance. The GRC Policy Committee is a separate part of the GRC, independently funded by interested organizations, to advocate on behalf of the geothermal community. I have the pleasure of serving as Chair of the Policy Committee.

We applaud the U.S. Department of Energy and the Geothermal Technologies Office for initiating the GeoVision analysis and presenting the comprehensive roadmap that calls for broad Stakeholder action across the geothermal community. We can—and we must—move toward realizing the GeoVision deployment levels of 60 GW by 2050 for our nation.

1. Today's Geothermal Market

In 2017, for the first time, the combined energy and capacity values of geothermal energy significantly exceeded the value of solar photovoltaic (PV) resources in California. When you account for geothermal's ancillary services and operational flexibility, combined values climb to more than $40/MWh higher than solar PV. These calculations demonstrate that geothermal can compete with solar PV on a net cost basis, even as PV costs continue to decline.[1]

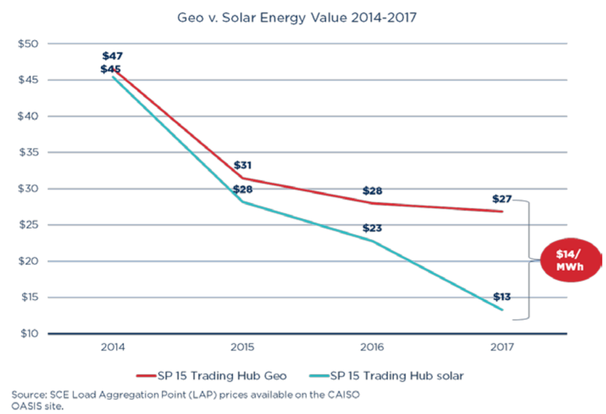
[1] Orenstein, R., Thomsen, P., The Increasing Comparative Value of Geothermal – New Market Findings and Research Needs, GRC Transactions, Vol. 41, 2017.
Thomsen, P., The Increasing Comparative Value of Geothermal in California-2018 Edition GRC Transactions, Vol. 42, 2018
Thomsen, P., Geothermal Selection in California Resource Planning: Preliminary results from CPUC's IRP Tools and Recommendations for future Development and Analysis, GRC Transactions Vol 42, 2018

Source: California ISO OASIS

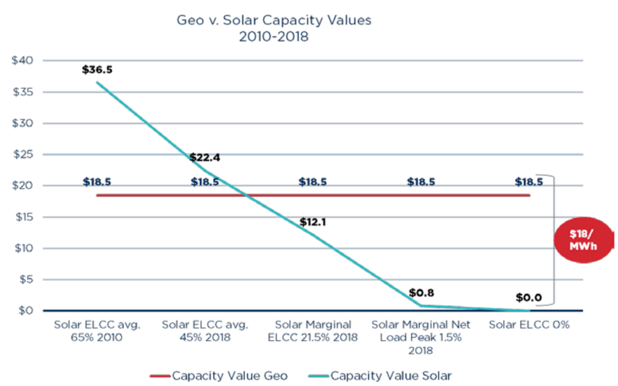
The California electric power system, like many in the nation, is undergoing many operational, reliability, and market changes due to the rapid penetration of solar PV. Solar penetration in California has increased from 500MW in 2010 to over 14GW today.[2] At low penetration levels (e.g., under 5 percent of annual energy), solar in California had high energy and capacity values because it generated during what were then the peak load hours.

As a result of increased solar penetration—and because now solar provides energy and capacity during times of low or even negative pricing—energy and capacity values for solar have plummeted. Geothermal can obtain higher energy and capacity values because it can produce outside the solar PV production hours during the new peak load hours, illustrated by the famous CAISO "duck curve."

[2] http://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf



Source: Orenstein, R., Thomsen, P., The Increasing Comparative Value of Geothermal – New Market Findings and Research Needs, GRC Transactions, Vol. 41, 2017.

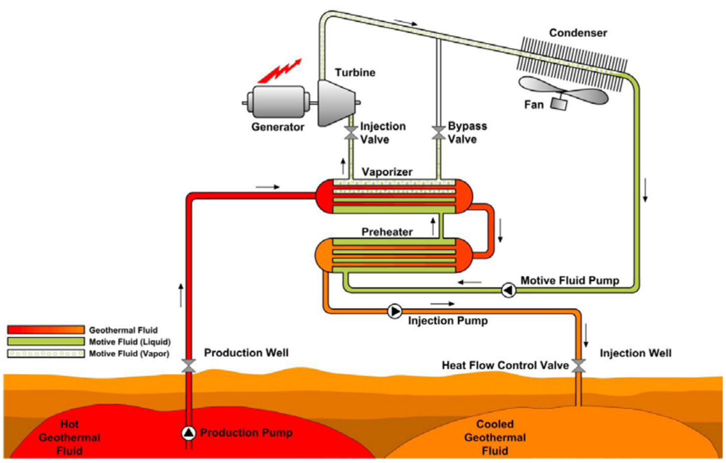


Source: Orenstein, R., Thomsen, P., The Increasing Comparative Value of Geothermal – New Market Findings and Research Needs, GRC Transactions, Vol. 41, 2017.

Geothermal's operational flexibility further enhances geothermal's value. For over 50 years, geothermal facilities have performed diligently to provide power 24 hours a day, seven days a week. So effective was the industry in marketing this attribute that many believe geothermal is solely a baseload resource. That is no longer the case. Since 2010, 96 percent of all installed geothermal facilities in the U.S. utilize a binary geothermal technology that can ramp up and down as fast, if not faster than, many "flexible" gas turbines such as the LM2500 or GELMS1003.

A binary geothermal facility cycles geothermal fluid through a set of heat exchangers, where the heat is transferred to a motive fluid that vaporizes and spins the turbo-generator, while the geothermal fluid is returned to the underground reservoir. Decoupling the geothermal reservoir and well field from the power generating equipment through the use of a working fluid allows binary geothermal facilities to operate in both a baseload or an operationally flexible mode that provides 100 percent dispatchability at unparalleled ramp rates—up to 30 percent of generator nameplate per minute—and can even be controlled by the system operator using Automatic Generation Control (AGC). Geothermal power plants offer additional benefits to grid stability like voltage support and inertia. Ormat's Puna geothermal facility in Hawaii has provided these services since 2011.[4]

Air-Cooled Binary Geothermal Power Plant



Source: Ormat Technologies

After years of solar dominating new renewable energy contracts in California, utilities, the CAISO and CCA's are starting to appropriately value renewable resources that provide energy and capacity value while also being operationally flexible. On June 1, 2017, the Los Angeles Department of Water and Power (LADWP) announced it had entered into a new, 26-year power sales agreement for approximately 150MW of power to be generated by a portfolio of new and existing binary geothermal power plants. LADWP explained in its press release: "In addition to producing fossil-free power, geothermal energy offers many desirable benefits. Because it can provide continuous energy generation, a geothermal plant is expected to produce power at 95 percent or more of its capacity year-round—a higher capacity

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[3] http://www.ge.com/mining/docs/2981884_1346772682_GE_Aeroderivative_
Product_and_Services_Solutions.pdf
[4] Nordquist, J., T. Buchanan, and M. Kaleikini, Automatic Generation Control and Ancillary Services, GRC Transactions, Vol. 37, 2013.

than the wind or solar renewable energy resources. With its baseload predictability, geothermal energy also saves on transmission and other integration costs, as compared to variable renewables like wind and solar power."[5]

Independent System Operators are now looking for flexible resources that can perform the following functions:[6]
• sustain upward or downward ramp;
• respond for a defined period of time;
• change ramp directions quickly;
• store energy or modify use;
• react quickly and meet expected operating levels;
• start with short notice from a zero or low-electricity operating level;
• start and stop multiple times per day; and
• accurately forecast operating capability.

Geothermal stands alone in providing all of those operating capabilities while assisting in absorbing more variable renewable energy resources and reducing greenhouse gas emissions. Higher renewable penetration and greenhouse gas reductions are absolutely possible when utilities, regulators, and system operators appropriately evaluate, procure, and develop cost-effective, flexible renewable resources such as geothermal to meet goals.

2. "Increasing Access to Geothermal Resources" *(GeoVision 2019)*

Ormat and the Geothermal Resources Council Policy Committee have identified the following regulatory reform initiatives that enable the geothermal industry to deploy more megawatts on public lands, creating new jobs and royalty revenues for our local states and counties. The following recommendations are the result of extensive consultation within the industry, whitepapers, and a review of geothermal permitting conducted in 2013 and 2014 conducted by the National Renewable Energy Laboratory (NREL). NREL's researchers noted:

"Reducing the overall project time directly attributable to NEPA, whether by reducing the time of individual NEPA processes or reducing the frequency of NEPA analysis for a particular project, can alleviate some of the major barriers to geothermal development. Reducing NEPA timelines directly decreases overall project timelines which indirectly decreases the perceived risk profile—lowering three of the four barriers to geothermal development identified by industry. Lowering these barriers is in line with one of NEPA's stated goals: to "enhance the quality of renewable resources."

Therefore, we outline four targeted concepts below that will significantly relieve the permitting burden for the geothermal industry without undermining environmental stewardship. They are:

I. Strengthen the administrative categorical exclusion for geothermal resource confirmation drilling
II. The Public Land Renewable Energy Development Act (PLREDA)
III. Eliminate Casual Use permits for select geothermal exploration activities
IV. Transmission and Interconnection

Executing these suggested changes, many of which can be found in the geothermal title in S. 2012 (114th Congress, 2015-16), would help unlock new projects and their associated economic impacts.

I. In order for the geothermal industry to grow rapidly, Ormat and the GRC Policy Committee have requested that DOI or Congress issue a new rulemaking or memorandum to expand, clarify, and strengthen the administrative categorical exclusion (CX) from NEPA, to reduce the permitting burden for geothermal resource confirmation and

[5] http://www.ladwpnews.com/new-geothermal-project-helps-create-clean-energy-future-for-los-angeles/
[6] https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

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observation. This action would immediately unlock new projects and their associated economic impacts, while allowing the hardworking BLM field staff to focus on appropriate permitting priorities.

Many geothermal resources that are commercially viable for energy production using today's technologies are located on public lands. BLM manages all subsurface geothermal resource on federal lands, regardless of the federal agency that manages the surface estate (such as the Forest Service). Therefore, almost all geothermal development must conduct a National Environmental Policy Act (EPA) review. While geothermal is inexpensive to operate and maintain once a project is complete, during the resource discovery, phase developers must drill resource confirmation holes to determine the true quality and quantity of the underground resource. This means the industry has a disproportionate permitting burden at the "front end" of a project, before a revenue payback is guaranteed. A heavy permitting burden means a slow development cycle, and a slow development cycle means developers pay a lot for financing.

Geothermal resource confirmation wells are distinct from geothermal production wells, which are permitted and constructed differently from resource confirmation wells. Resource confirmation wells are needed for geothermal developers to assess the underground resource for project viability. While developers do what they can to determine the quality of the underground resource through mapping and surface observations, it simply is not possible for developers to characterize the resource without making physical contact with the geothermal fluid deep in the earth. At this time, most geothermal resource confirmation wells must be permitted with BLM via a detailed Environmental Assessment (EA), even though resource confirmation wells are very limited in scope, are reclaimed quickly after confirmation, and result in tiny surface disturbance. These resource confirmation wells also cannot be "repurposed" as production wells under the same permit. This means developers can't access the heat resource they need to evaluate whether a commercial project would even be viable without undertaking significant, time-consuming environmental review. A Categorical Exclusion from NEPA for select types of geothermal resource confirmation wells and other low-impact activities would help the industry tremendously, without undermining environmental stewardship. When developers are able to utilize a CX, they can avoid conducting a full Environmental Assessment and instead perform a CX review, which is far quicker and less costly. A more useable geothermal CX that allows developers to evaluate their energy resource for viability before undertaking extended environmental review could drastically improve timelines and cost profiles for project development. This step would also provide greater parity between geothermal and oil and gas, which is afforded a broad CX for exploration activities, including resource confirmation wells, under Section 390 of the Energy Policy Act of 2005.

II. Ormat also supports passage of the Public Land Renewable Energy Development Act (H.R.825 and S.282)[7]. The Public Land Renewable Energy Development Act (PLREDA) makes a commitment to improving and expanding renewable energy projects on public lands. If passed, this legislation would promote the development of wind, solar, and geothermal resources on public lands by identifying priority areas and encouraging smart siting and efficient permitting of project in places with high energy potential and low impact on wildlife and habitat.

This bill provides economic benefits to states and counties in the West, supports community conservation efforts, and improves access to public lands. Specifically, this legislation would distribute the revenue collected from renewable energy development on public lands in the following way:

- 25 percent would go to the state where the project is built,
- 25 percent would go to the county where the project is built,
- 25 percent of the revenue would be deposited in a fund for wildlife and land conservation and securing recreational access to public lands,
- and 25 percent of the revenue collected would go to the Bureau of Land Management to facilitate permitting of renewable energy projects.

[7] Status this Congress- Senate – The Public Land Renewable Energy Development Act of 2017 was introduced in the Senate by Sen. Heller [R-NV] on February 2, 2017. House – The Public Land Renewable Energy Development Act of 2017 was introduced in the House by Rep. Gosar (R-AZ) and Rep. Polis (D-CO) on February 2, 2017. The bill was reported out of committee to the House of Repredssentatives by unanimous consent on July 26, 2017.

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PLERDA would also direct the Department of Interior to identify priority areas for wind, solar, and geothermal projects on public lands, using the 2012 Western Solar Plan as a model. Priority areas must meet certain criteria, including having access to transmission lines and being likely to avoid or minimize conflict with wildlife habitat.

III. Declare that Casual Use Permit notifications to DOI are not needed for specified noninvasive geothermal exploration activities.

Under NEPA, Casual Use (CU) is an action on Federal Lands that causes no disturbance, i.e. no drilling or digging or major construction. Geothermal developers need to notify BLM in advance of Casual Use activities, which are listed below. In general, a company will send a letter to BLM with their proposed activities as a Notice of Intent (NOI). BLM reviews the NOI, responds to the applicant in a letter verifying that the exploration activity are casual use, and may request that the applicant notify BLM when the activity commences and when it has been completed. This process takes about one month.

Under the current program, Geothermal CU Activities are:

- Aerial surveys—This includes both manned flights of small aircraft (helicopters and airplanes) down to Unmanned Aerial Vehicles (drones) less than 2 kg that are equipped with thermal infrared cameras. The manned aerial surveys, because of aircraft noise, are the most likely of the CU activities to incur any disturbance of federal lands.
- Sampling existing streams and water wells
- The use of all-terrain vehicles (ATVs) in off-road vehicle areas
- Two meter probe surveys—A 2-meter long, thin (<1/2 in) hollow steel tube with a tungsten-carbide alloy tip is driven into the ground. Then a high-precision resistive-temperature device is inserted into the tube. The probe is then left in place for at least one hour.
- Magneto-Telluric (MT) surveys—Typically 3-10 small observational instruments are placed 2-3 inches deep in the ground over a span of just a few yards to record observations of microseismicity, etc. The total instrument combined is about 20 lbs. The small holes dug for the electrodes are refilled when the equipment is removed.
- Gravity surveys—A relative gravimeter is transportable by one person with a backpack and weighs roughly 17 lbs. The instrument is carried to the measurement station, placed on the ground surface, and leveled. The gravity measurement takes a few minutes, and then the gravimeter is picked up and transported to the next station.
- Geochemical surveys—Very small samples of soils and surface fluids are collected at the site and removed. The review of these materials is conducted in a laboratory.
- Archaeological surveys—The field work component of geothermal archaeological surveys involves simple visual observations and photographs.

It is clear that most of the activities above cause zero or near-zero disturbance, so we believe that the CU process is unnecessary in many cases. All federal lands are open to most Casual Use by the public with no prior notification, permitting, or approval from the BLM or USFS. For example, if a tourist wants to sample a stream and test it, they don't need prior permission. Geothermal should be no different. We seek to exempt the use of public lands for several Casual Use-style geothermal exploration activities from any notice requirement and approval by the federal agency. We acknowledge some CU actions likely still merit a notice to BLM, namely manned aerial surveys, and do not seek to eliminate CU requirements for cases like these where they are warranted. While CU permits are not especially difficult to get, they take one month on average. If developers can limit their CU burden, that would represent a real savings in time and money.

IV. Due to the aging infrastructure of the electric grid, interconnection and transmission are now major hurdles to the development of renewable energy. This affects geothermal in a unique way when compared to other renewables because geothermal resources are stationary and can't be moved around depending on interconnection costs and transmission availability. System upgrades that are required to interconnect projects can take between five and

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seven years to complete and can cost developers millions of dollars, which puts project development at risk. Once interconnected, transmission service is costly, and system congestion and transmission line losses can also be significant factors in project development. Ormat would encourage this committee to evaluate what can be done to interconnect these vital projects more efficiently.

3. "Reduced costs and improved economics for geothermal projects" ***(GeoVision 2019)***

In order to reduce costs and improve the economics of geothermal projects, Ormat and the Geothermal Resources Council (GRC) urge Congress to pass the Tax Extender and Disaster Relief Act of 2019 introduced on February 28 by Senate Finance Committee Chairman Chuck Grassley and Ranking Member Ron Wyden.

Quick action on this issue is critical for the geothermal industry, which saw its tax credits lapse at the end of 2017, creating confusion for the numerous industry sectors that utilize these incentives to support deployment of clean energy solutions. The continued uncertainty also undermines the effectiveness of these incentives and stands as a needless barrier to additional job creation and economic growth. Our industry needs an extension of the expired tax credit — two years retroactive (2018-19) and at least two years forward (2020-21) to level the playing field with other technologies and provide predictable market signals for project development, which in turn leverages private investment and promotes job creation and local economic benefits across the country. Geothermal should be restored to an ITC schedule identical to what was provided to solar under the 2015 PATH Act.

May 17, 2019

Ms. Mary Neumayr
Director, Council on Environmental Quality
730 Jackson Place, NW
Washington, DC 20503

Dear Director Neumayr,

The Geothermal Resources Council (GRC) is a non-profit professional association for the geothermal industry and community in the USA and abroad. We were founded in 1972 and are headquartered in Davis, California. We have over 1,300 members from around the world and are working to advance our industry by supporting the development of geothermal energy resources through communication of robust research, knowledge and guidance. We congratulate you on your confirmation as CEQ Director and we look forward to working together.

The Policy Committee of the GRC writes to recommend a new Administrative Action to expand, clarify and strengthen the Bureau of Land Management's categorical exclusion from the National Environmental Policy Act (NEPA) for geothermal exploration activities – in particular, for test wells that provide resource confirmation. We are confident that if this recommendation is heeded, the geothermal industry will be able to deploy more megawatts on public lands, creating new jobs and royalty revenues for our local states and counties.

This recommendation is the result of extensive consultation within the industry members of the GRC and the whitepaper findings that result from a review of geothermal permitting conducted over most of the last decade by the National Renewable Energy Laboratory (NREL). While the proposal to establish a CX for certain exploration activities was originally developed for a legislative play in Congress,[1] we believe that Department of Interior is empowered to undertake these activities Administratively.

We thank you for your consideration. I am available to discuss further at your convenience. Please contact me at wpettitt@mygeoenergy.org with any questions.

[1] See most recently S. 1460 and H.R. 4568 from the 115th Congress.

Respectfully,

Dr. Will Pettitt
Executive Director
Geothermal Resources Council

Attachments:

A. Why does geothermal need permitting relief?
B. Supporting data from National Renewable Energy Laboratory
C. Existing policy for geothermal and categorical exclusions
D. Industry recommendation for reforms

A. Why does geothermal need permitting relief?

90% of the underground geothermal resources that are commercially viable for energy production using today's technologies are located on public lands. BLM manages all subsurface geothermal resource on federal lands, regardless of the federal agency that manages the surface estate (such as the Forest Service). Therefore, almost all geothermal development must conduct NEPA review, and BLM is the true industry gatekeeper for the pace of development.

While geothermal is extremely inexpensive to operate and maintain once a project is underway, our resource discovery is a longer-term effort than other types of energy technologies. Developers must drill exploration holes to determine the true quality and quantity of the underground resource. This means the industry has a disproportionate permitting burden as the "front end" of a project, before a revenue payback is guaranteed. A heavy permitting burden means a slow development cycle, and a slow development cycle means developers pay a lot for financing. At this time, the most expensive line item for a new geothermal power plant is the cost of money.

We kindly request that DOI issue a new rulemaking or memorandum to expand, clarify and strengthen the administrative categorical exclusion (CX) from NEPA, in order to reduce the permitting burden for geothermal exploration and observation (including exploration wells). This action would help unlock new projects and their associated economic impacts, while allowing the hardworking BLM field staff to focus on more pressing and appropriate permitting priorities.

P.O. Box 1350, Davis, California 95617-1350 • 630 Peña Drive, Suite 400, Davis, California 95618
Phone (530) 758-2360 • Fax (530) 758-2839 • grc@geothermal.org

About geothermal exploration

Geothermal exploration wells are distinct from geothermal production wells, which are permitted and constructed differently from exploration wells. Exploration wells are needed for geothermal developers to assess the underground resource for project viability. While developers do what they can to determine the quality of the underground resource through mapping and surface observations, it simply is not possible for developers to characterize the resource without making physical contact with the geothermal fluid deep in the earth.

At this time, most geothermal exploration wells must be permitted with BLM via a detailed Environmental Assessment (EA), even though exploration wells are very limited in scope, are reclaimed quickly after exploration, and result in tiny surface disturbance. These exploration wells also cannot be "repurposed" as production wells under the same permit.[2] This means developers can't access the heat resource they need to evaluate whether a commercial project would even be viable without undertaking significant, time-consuming environmental review.

A Categorical Exclusion from NEPA for select types of geothermal exploration wells and other low-impact activities would help the industry tremendously, without undermining environmental stewardship. When developers are able to utilize a CX, they can avoid conducting a full Environmental Assessment and instead performs a CX review, which is far quicker and less costly. A more useable geothermal CX that allows developers to evaluate their energy resource for viability before undertaking extended environmental review could drastically improve timelines and cost profiles for project development. This step would also provide greater parity between geothermal and oil and gas, which is afforded a broad CX for exploration activities, including exploration wells, under Section 390 of the Energy Policy Act of 2005.

[2] DOI considered this matter in its response to stakeholder questions published in the Final 2007 amendments to the BLM's Procedures for Managing the NEPA Process, Departmental Manual Part 516. It noted, "Geophysical exploration activities are data collection activities used to gather information that may be used to inform future decision-making regarding oil, gas or geothermal development proposals by providing information on the location of energy resources. It is not a forgone conclusion that the energy resources identified through this data collection will actually be developed."

B. Supporting data from the National Renewable Energy Laboratory

A comprehensive study of geothermal development and permitting conducted by NREL in 2013 and 2014 yielded quantitative impartial information that corroborates the industry perspective outline above.[3] NREL's researchers noted:

> "Reducing the overall project time directly attributable to NEPA, whether by reducing the time of individual NEPA processes or reducing the frequency of NEPA analysis for a particular project, can alleviate some of the major barriers to geothermal development. Reducing NEPA timelines directly decreases overall project timelines which indirectly decreases the perceived risk profile– lowering three of the four barriers to geothermal development identified by industry. Lowering these barriers is in line with one of NEPA's stated goals: to "enhance the quality of renewable resources."[4]

NREL also found that the average time frame for an Environmental Assessment is 337 days (10 months), while the average for a categorical exclusion is only 88 days (<3 months).[5]

Table 1: Types of Environmental Reviews

Federal Action Description	Resulting Environmental Review	Approximate Time frames	Comments
Action would not ordinarily result in significant disturbance[1] to federal lands, resources, or improvements.	Casual Use (CU)	<1 month	A CU does not require any NEPA analysis and usually results from the review of a NOI for geothermal exploration.
Action that has been adequately analyzed under an existing NEPA document(s) and is in conformance with the land use plan.	Determination of NEPA Adequacy (DNA)	1 month	Not all new proposed actions will require new environmental analysis. In some instances an existing EA or EIS may be relied upon in its entirety, and new NEPA analysis is unnecessary.
Action that the agency or Congress has determined does not have a significant effect[1] on the quality of the human environment[2] (individually or cumulatively) and for which neither an EA nor an EIS is required.	Categorical Exclusion (CX)	2 months	A CU does not require any NEPA analysis. A CX can be established administratively through agency rulemaking or legislatively through congressional action.
Action that may significantly impact the environment	Environmental Assessment (EA)	10 months	EAs are conducted to determine whether action would significantly affect the environment. The EA process results in either a Finding of No Significant Impact (FONSI) or the preparation of an Environmental Impact Statement (EIS).
Major federal action that significantly affects the environment.	Environmental Impact Statement (EIS)	25 months	The EIS process requires public participation for all federal agencies.

[1]Definition of "effects" is provided in CFR 1508.8
[2]Definition of "human environment" is provided in CFR 1508.14 6

[3] See supporting info from NREL here: http://www.nrel.gov/docs/fy14osti/62624.pdf.
[4] From Geothermal Permitting and NEPA Timelines. Katherine R. Young, Kermit Witherbee, Aaron Levine, Adam Keller, Jeremy Balu, Mitchell Bennett. National Renewable Energy Laboratory, 2013.
[5] http://pubs.geothermal-library.org/lib/grc/1033639.pdf
[6] Environmental review table from Young, Katherine, Kermit Witherbee, Aaron Levine, Adam Keller, Jeremy Balu, and Mitchell Bennett. GEOTHERMAL PERMITTING AND NEPA TIMELINES. National Renewable Energy Laboratory. June 2014.

C. Existing policy for geothermal and categorical exclusions

NEPA allows federal agencies to establish CXs for federal actions at their discretion if those action do not, "individually or cumulatively have a significant effect on the human environment".[7] BLM has rulemakings already on the books that allow CXs for some geothermal exploration activities, but they are limited and vague, and field offices have not been using the authority.

A CX is provided by BLM to geothermal activities in two ways:

1. First, Departmental Manual 516, Section 2, Appendix 1 contains a list of "DOI-wide" categorical exclusions[8]. Among these named activities is:

   "(e) Nondestructive data collection, inventory (including field, aerial, and satellite surveying and mapping), study, research, and monitoring activities."

2. Second, an update to the DOI Departmental Manual 516, which was published in the Federal Register on August 14, 2007, revised the BLM's procedures for Managing the NEPA Process. Section 11.9 lists Actions Eligible for a Categorical Exclusion:[9]

B. Oil, Gas, and Geothermal Energy.

(1) Issuance of future interest leases under the Mineral Leasing Act for Acquired Lands, where the subject lands are already in production.

(2) Approval of mineral lease adjustments and transfers, including assignments and subleases.

(3) Approval of unitization agreements, communitization agreements, drainage agreements, underground storage agreements, development contracts, or geothermal unit or participating area agreements.

(4) Approval of suspensions of operations, force majeure suspensions, and suspensions of operations and production.

(5) Approval of royalty determinations, such as royalty rate reductions.

(6) Approval of Notices of Intent to conduct geophysical exploration of oil, gas, or geothermal, pursuant to 43 CFR 3150 or 3250, when no temporary or new road construction is proposed.

[7] 40 CFR 1508.4
[8] Also found in 43 CFR 46.210.
[9] https://www.federalregister.gov/articles/2007/08/14/E7-15746/notice-of-final-action-to-adopt-revisions-to-the-bureau-of-land-managements-procedures-for-managing

P.O. Box 1350, Davis, California 95617-1350 • 630 Peña Drive, Suite 400, Davis, California 95618
Phone (530) 758-2360 • Fax (530) 758-2839 • grc@geothermal.org

Item 6 on the DOI DM 516 list, "geophysical exploration," was specified earlier that year in a Final Rule published May 2, 2007 - *Geothermal Resource Leasing and Geothermal Resources Unit Agreements; Final Rule*.[10] This rulemaking was the implementing regulation for the geothermal energy provisions in Sections 221-236 of the Energy Policy Act of 2005.

Further clarification on the applicability of the geothermal CX was issued under a DOI Instruction Memorandum, No. 2009-044, published in December 2008.[11]

Then a March 24, 2016 Instructional Memorandum, No. 2016-071,[12] clarified restrictions on the CX and was targeted specifically at how Thermal Gradient Wells may be treated under the CX. This IM allowed geothermal operators to drill deeper TGWs than the 500 feet of depth previously allowed. However, with this change, the IM put into place new requirements for blowout prevention equipment and a threshold for maximum temperature at which operators must either stop drilling or obtain a waiver. The IM also restates explicitly that operators are still not allowed to test or touch the geothermal resource itself and sustains the requirement of zero surface disturbance. This means that operators must be able to drive to the location without creating a road or pad and must use tanks to circulate drilling muds because reserve pits are not allowed.

To summarize, between the Departmental-wide CXs and the geothermal-specific ones, the following activities can be conducted with a CX:

- Varied leasing activities and changes in business agreements related to geothermal projects;
- Approval of royalty determinations;
- Nondestructive data collection, including passive surveys and monitoring activities;
- Suspension of geothermal operations; and,
- Drilling of temperature gradient wells deeper than 500 feet, as long as they don't access the heat resource directly and do not require a road, wellpad, or reserve pit.

The following activities are not currently eligible for a CX:

- Accessing/direct testing of the heat resource directly via an exploration well;
- Construction of temporary or permanent access roads to test drilling sites;
- Construction of temporary or permanent reserve pits at test drilling sites;
- Construction of temporary or permanent well pads;
- Drilling once bottom-hole temperatures exceed a certain level (rule of thumb is 212 degrees F, but BLM officials must decide on case-by-case basis); and,
- Full-scale development of geothermal resource.

[10] https://www.blm.gov/or/programs/minerals/files/geothermal_resources_agreements.pdf
[11] https://www.blm.gov/policy/im-2009-044
[12] https://www.blm.gov/policy/im-2016-71

D. <u>Industry Recommendations for Reforms</u>

We ask BLM to issue a new Instruction Memorandum and/or rulemaking that does two things:

(1) Clearly restates all the geothermal activities that are already eligible activities for Categorical Exclusions, in order to ensure consistent and predictable application across field offices; and

(2) Establishes a new classification of well - a Resource Confirmation well - and clarify its eligibility for Categorical Exclusions.

These recommendations are informed by NREL's 2018 finding that "a new well classification or expedited NEPA compliance could potentially reduce permitting and regulatory compliance timelines when compared to the current process."[13] Resource confirmation wells would be wells with the express and singular purpose of obtaining "sufficient subsurface information that proves with high probability that a resource of a certain magnitude can be developed."[14]

As noted above, the current CX prevents developers from accessing the heat resource directly without conducting an Environmental Assessment at a minimum. Without being able to access the resource itself in order to assess the temperature and its chemistry, the developer has limited certainty as to whether this particular site is worth developing. In turn, the upfront cost and risk profile of the project as perceived by outside funding agents and project partners is greater, putting geothermal at a disadvantage to competing energy technologies.

The suggested language below would allow for geothermal operators to create small test wells to take samples that will provide necessary information on the temperatures, fluid chemistry, fluid pressure and geophysical formation underfoot. It reflects Section 3012 of S. 2012, the *Energy Policy and Modernization Act* of the 114th Congress. This bipartisan legislation passed the Senate by voice vote in 2016. This language is also included in S. 1460, the Energy and Natural Resources Act of 2017.

Any new IM or rulemaking to amend the previous policy may need to amend or replace the following passage in IM 2016-071, published March 24, 2016.[15]

[13] Young, Kate et al. "Environmental Concerns and Mitigation Associated with Geothermal Resource Confirmation Drilling Activities." National Renewable Energy Laboratory. *GRC Transactions*, Vol. 42, 2018.
[14] Ibid Page 1
[15] https://www.blm.gov/policy/im-2016-071

Recommended language for DOI Internal Memorandum or Rulemaking to expand the geothermal categorical exclusion

Policy/Action: *For geothermal resources, the Categorical Exclusion includes the following activities which are carried out by the holder of an appropriate lease provided by the Department of Interior. These are in addition to activities previously declared eligible by the BLM.*

(A) Geophysical exploration: *All geophysical exploration activities that do not require drilling, including seismic surveys.*

(B) Geothermal resource confirmation on greenfields and previously undeveloped lands: *On lands that have not been previously developed for geothermal production and for which a site-specific analysis has not been prepared under NEPA, the drilling of a well to confirm the availability of thermal resources that satisfies the following conditions:*

a. The activity causes fewer than 5 acres of soil or vegetation disruption at the location of each geothermal exploration well;
b. The activity and not more than an additional 5 acres of soil or vegetation disruption during access or egress to the project site;
c. The activity is completed in fewer than 90 days, including the removal of any surface infrastructure from the project site; and,
d. The activity site is restored not later than 3 years after the date of completion of the exploration activity, unless the project site is subsequently permitted and developed for commercial power production.

Resource confirmation testing may include the direct testing of geothermal resources. They may not include the production or utilization of geothermal resources.

(C) Exploration where a site-specific analysis has already been conducted: *If the land leased has already been assessed under a site-specific analysis under the National Environmental Policy Act, the drilling of a well to test or explore for geothermal resources if that activity causes an individual surface disturbance of fewer than 5 acres, and the total surface disturbance on the leased land is not more than 150 acres.*

(D) Exploration where drilling has already occurred: *The drilling of a well to test or explore for geothermal resources when the drilling is planned for an existing location or well pad site at which the drilling has occurred within 5 years before the date of spudding the well.*

(E) Exploration within a developed field: *The drilling of a well to test or explore for geothermal resources in an existing developed field for which:*

a. an approved land use plan or any environmental document prepared under the National Environmental Policy Act of 1969 (42 U.S.C. 17 4321 et seq.) analyzed the drilling as a reasonably foreseeable activity; and,
b. the land use plan or environmental document was approved within 10 years before the date of spudding the well.

When the BLM considers using a CX to fulfill the agency's NEPA obligations with respect to any decision the BLM may make regarding any action or approval, the NEPA regulations at 40 CFR 1508.4 require the BLM to evaluate the effect of the proposed action relative to extraordinary circumstances. The extraordinary circumstances that must be considered are applicable throughout the Department of the Interior. If the proposed action may involve one *or more of the extraordinary circumstances, an EA or Environmental Impact Statement must be prepared.*

We thank you for your consideration. I am available to discuss further at your convenience. Please contact me at wpettitt@mygeoenergy.org with any questions.

Respectfully,

Dr. Will Pettitt
Executive Director
Geothermal Resources Council

June 12, 2019

The Honorable Chuck Grassley
135 Hart Senate Office Building
Washington, DC 20510

The Honorable Ron Wyden
221 Dirksen Senate Office Building
Washington, DC 20510

The Honorable Richard Neal
2309 Rayburn House Office Building
Washington, DC 20515

The Honorable Kevin Brady
1011 Longworth House Office Building
Washington, DC 20515

Dear Chairmen Grassley and Neal and Ranking Members Wyden and Brady,

The Geothermal Resources Council (GRC) kindly urges Congress to immediately pass legislation to extend the expired federal tax credits benefiting geothermal energy.

The tax credits have remained lapsed since the end of 2017, creating confusion for the numerous industry sectors that utilize these incentives to support deployment of clean energy solutions. The continued uncertainty also undermines the effectiveness of these incentives and stands as a needless barrier to additional job creation and economic growth.

As the professional association for the geothermal industry and community, the GRC can attest to the vital importance of the tax credits to the success of geothermal energy business. Our industry needs an extension of the expired tax credit — two years retroactive (2018-19) and ideally at least two years forward (2020-21). The tax credits provide a predictable market signal for project development, which in turn leverages private investment and promotes job creation and local economic benefits across the country.

We strongly support the Tax Extender and Disaster Relief Act of 2019 introduced on February 28 by Senate Finance Committee Chairman Chuck Grassley and Ranking Member Ron Wyden. We applaud them for including an extension within "Section 107. Credit For Electricity Produced From Certain Renewable Resources", specifically Section 107(a)(3), which benefits geothermal energy. We urge the Senate to take up this bill as soon as possible and for the House to follow suit expeditiously. Quick action on this issue is critical. Once the extenders package is passed, we look forward to a discussion on the long-term future of geothermal energy incentives.

Geothermal power is a critical source of renewable electricity for U.S. households and businesses as we transition to a clean energy future. It is affordable, reliable and plays a critical role in maintaining a functioning electric grid – due to its position as flexible, renewable, baseload resource that can complement other intermittent renewable resources. Extension of the expired tax credits will play an important role in continuing the development and support of our industry.

The GRC is a non-profit professional association for the geothermal industry and community in the USA and abroad. We were founded in 1972 and are headquartered in Davis, California. We have over 1,300 members from around the world and are working to advance our industry by supporting the development of geothermal energy resources through communication of robust research, knowledge and guidance.

We thank you for your consideration. We are available to answer questions and discuss further at your convenience.

Respectfully,

Paul Thomsen
GRC Policy Committee Chair
pthomsen@ormat.com

Will Pettitt, PhD
GRC Executive Director
wpettitt@mygeoenergy.org

The CHAIRMAN. Well, thank you.

Listening to all of you, I think okay, geothermal is like the little engine that could. It is just, kind of, really good and solid. We need to take advantage of this moment in time, this critical juncture, this tipping point, whatever it is that you want to call it. I have a whole bunch of questions here, so let's get going.

I want to start by asking about what may be happening in the research space at DOE and within our national labs with regards to low temperature geothermal.

We have talked about Chena Hot Springs. I cannot remember whether it is 165 degrees. This is not hot, hot. Everybody said you cannot do it with low temperature geothermal, and what Bernie Karl and the others at Chena are doing is demonstrating what you can do with low temperature geothermal.

As we think about the technologies that are in place to find that national heat exchanger, somebody used the terminology here, to find just that hottest of hot water, we are realizing that it does not have to be as hot as we may have in certain other areas.

Can either one of you share with me to what extent we are doing the research in our national labs or within the Department on low temperature energy systems?

Mr. SIMMONS. I'll start and then hand it off. How's that?

The CHAIRMAN. Okay.

Mr. SIMMONS. So low temperature is a very important area of research for us just because so much of the country has low temperature geothermal resources.

The CHAIRMAN. Right.

Mr. SIMMONS. All of the eastern United States is essentially low temperature geothermal resources.

The CHAIRMAN. So if he wants to put in his blue lagoon, he is probably going to have a lower temperature than you might have otherwise, like in Nevada?

Mr. SIMMONS. Correct, correct—than the West where you have much, much warmer geothermal resources.

So one of the most important things is improving the science of heat exchange and that is both in the earth itself, but also in once that water comes to the surface to make sure that is as efficient as possible just because the difference in temperature is not as great.

And also, one of the opportunities for low temperature heat is for use as a thermal storage, as in to add heat during periods of low electricity rates and then to be able to withdraw that heat to help geothermal have new opportunities in a world where we need more flexibility on the electric grid.

So those and, most importantly, we need to advance enhanced geothermal systems to do a better job of adding fractures and also to understand in the areas where we don't have enough fluid, how we do a better job with that.

The CHAIRMAN. And you are doing that R&D within the Department?

Mr. SIMMONS. Yes.

The CHAIRMAN. Ms. Young?

Ms. YOUNG. Yes, I think, when you talk about power conversion, certainly, the greater temperature differences have a bigger impact. And so, that's why it's working so well in Alaska.

And I think that even in other places in the U.S. you don't need a lot of temperature to be able to use it for direct heating. So for heating homes and schools and offices, for industrial purposes, for paper drying, for laundries, beer brewing, and so, it really is something that can be done anywhere.

A lot of what we're doing right now in this area is trying to incorporate geothermal into these techno economic models that model for municipalities, for communities, for campuses, what the potential is for reducing their carbon footprint, to make sure that geothermal is part of the conversation and part of the options that are being considered.

The CHAIRMAN. So for Senator King or Senator Manchin on the East Coast, where you do not think about geothermal potential as much, are you doing that kind of mapping that would help them in their states to try to advance something that might be viewed as more low temperature?

Ms. YOUNG. Yeah, DOE's portfolio actually looks at—Deep Direct-Use is what they're calling it. And they have a Deep Direct-Use portfolio that spans the entire U.S. where they're doing demonstration projects looking at techno economics for projects throughout the U.S. So that's certainly an area where they're trying to demonstrate the versatility and the geographic availability of this resource.

We're also, you know, as we mentioned, the cost of drilling is applicable, regardless of the temperature. And so, lowering the cost of drilling certainly would help benefit these low temperature resources as well.

The CHAIRMAN. Yes, we saw that with one of our projects in Alaska where after many years and lots of money, they were disappointed with the temperature.

Let me turn to my colleague from West Virginia.

Senator MANCHIN. Thank you. Thank you, Madam Chair.

I live on a boat that has geothermal. Basically my boat takes the water and extracts it through my keel with a glycol tubing and takes whatever is in the water. The water goes down to 40 or the water is up to 80. I use it differently that way. It is really unbelievable. So I have a little bit of an idea of how this is supposed to work when everything is working on the boat.

With that being said, we have done an awful lot of drilling in West Virginia for the fracking. We are in the Marcellus-Utica Shale. We will be going down into Rogersville Shale which is much deeper. That technology that we have been able to develop with horizontal drilling—can that be used, Mr. Simmons, and any of you all who have that knowledge? Can that be used and be helpful because so much has been done already in that arena as far as maybe extracting for geothermal?

Mr. SIMMONS. Sir, well——

Senator MANCHIN. Whoever.

Mr. SIMMONS. I'll start with one quick note about this, about the relationship between geothermal and the Fossil Energy Office on drilling.

The most commonly used drill bit for drilling for oil and gas today is the PDC, the polycrystalline diamond compact, drill bit which was developed from geothermal research because of the need to be able to drill for geothermal technologies. It is critical because it's that we improve those drilling technologies to really drive down the cost of geothermal, and it can definitely be used to, those technologies. And with that, I'll pass it off to the experts who actually are out there doing this.

Senator MANCHIN. That is what I was going to ask, Mr. Latimer. Where are you right now on the commercial development? Because we saw this firsthand, in Iceland. I mean, it is a mammoth operation. I forget the wattage on that, but I think they are taking the water out at 180 degrees.

The CHAIRMAN. It is hotter——

Senator MANCHIN. Was it hotter than that?

The CHAIRMAN. ——400.

Senator MANCHIN. Oh, okay. I am not sure. You would know.

How far are we behind or do you think we are progressing, and when can we get into commercial?

Mr. LATIMER. Yeah, that's a great question.

And I think one thing to talk about is that it's not—one thing I'd like to get across is that there's not two different, really, categories of geothermal energy. I think that's a convenient way to talk about it sometimes where there's this hydrothermal resource that we can produce today and then this far off in the future, enhanced geothermal system resource that's in the future.

What you really have is a spectrum, and there's a lot of in between. And I think that where we are, both Fervo Energy as a company and also the geothermal industry. I think we have the right technology, that we've developed the right things on the drilling side that we can start accessing that next, more challenging tier of resource.

In the GeoVision study they refer to this as the "In-Field" resource and the "Near-Field" resource where these are not quite the, you know, very large numbers of gigawatts that are outlined in the report, but these are opportunities that are hundreds of megawatts or a few gigawatts that could probably be commercially viable on a very short timeframe. And so, these are opportunities.

I don't think we're behind Iceland. I think we're definitely the leader in drilling, and we're at a great point to attack these resources.

Senator MANCHIN. Also, in Michigan and Germany, they proposed tapping abandoned underground mines as a source for geothermal. How far are they along with that? We have had some hot spots in the northern part of our State of West Virginia.

Mr. LATIMER. Yeah.

Senator MANCHIN. And of course, you know, we have a lot of mines everywhere. So how promising is that? Have you heard much about that?

Mr. LATIMER. About abandoned mines, specifically?

Senator MANCHIN. Yes.

Mr. LATIMER. I'm not too familiar. I visited a few geothermal plants in Germany where they, much like Chena Hot Springs, do a great job of using not just the electricity but power nearby industry in district heating. So there's several pilot plants in Germany and many being built right now. But I'm not too certain on the mining.

Senator MANCHIN. Mr. Thomsen?

Mr. THOMSEN. Sure, thank you, through the Chairman to the Ranking Member, if I can go back.

Senator MANCHIN. Sure, go wherever you want to go.

Mr. THOMSEN. A couple questions, and I'll try to hit all of them. So I want to get to the low temperature question, because the role that DOE has played in bringing on the innovation in geothermal is pivotal.

Senator MANCHIN. What do you consider low temperature?

Mr. THOMSEN. It can't be overlooked. 165 degrees is pretty low. When Ormat started looking at 350 degrees Fahrenheit, that was considered really low. The Geysers in California are about 500 to 600 degrees Fahrenheit, and the wells in Alaska at 500 bars of pressure and, you know, upwards of 650 degrees Fahrenheit are very, very hot.

Ormat's story behind this is that they used a DOE loan to build the very first project in Ormesa in California, and they chased a binary technology which is the most prevalent geothermal technology today. What we do is we bring up hot water to heat a secondary working fluid which vaporizes, builds pressure and spins a turbine. At the time, it was thought to be too complex and the DOE sponsored that project. It was successful, and Ormat was able to pay back that loan in a year.

Moving on to Chena Hot Springs, they received a federal grant from DOE to look at pioneering the 165 degrees F. And so the story there is we can chase these low temperatures. Sometimes we need assistance, and that's where I would——

Senator MANCHIN. Has that been successful at Chena?

Mr. THOMSEN. Absolutely, yes, it was very successful.

Senator MANCHIN. How come they got a grant and not a loan?

Mr. THOMSEN. That's a good question for Mr. Bernie Karl, who is not here today.

Senator MANCHIN. If it is that good at paying back, they should have paid it back.

Mr. THOMSEN. And this leads me to, you know, I think when we look at, kind of, refining the loan guarantee program, this money is needed because there are large, upfront capital expenditures.

Senator MANCHIN. Sure.

Mr. THOMSEN. But once a project is successful, we should be able to pay it back very quickly.

Ormat is the recipient of a large era loan, and we are realizing it is really hard to pay it back because it's not only are we paying back the base rate, but the marginal rate. And so, we've locked up about $300 million in financing from the Federal Government through the ARRA loan program that we want to pay back early, and we're unable to do that.

And so, I think one of the areas that we should look at is how do we make it easier for companies to prepay that loan, pay back the base rate so the government is held harmless and that that money can be used by other innovative developers like Fervo or Chena Hot Springs and get that money moving quicker because if in our current state, you know, we would have to pay about $35 million to be kept whole and, or we keep that loan for the next 30 or 40 years. So those are great success stories, and the DOE has been pivotal in both of those.

To enhance geothermal systems, that you talked about. Ormat participated in a co-production well. So at the Rocky Mountain Oilfield Testing Center in Wyoming, they were producing oil and had a water break. And the water break was—and I'm not an oil and gas guy, so please correct me if I speak incorrectly on it—was about 250 degrees of water that they were producing from this oil well. And instead of just wasting that water, they ran it through a geothermal heat exchanger, were able to produce electricity and use that electricity to help power the well field operations making it incredibly more efficient and reducing their cost from having to purchase that power from the nearby utility.

And so that's a source of innovation that can be applied to West Virginia and what you're doing in mining and so forth. Anywhere that we have heat and water, we can run that through a heat exchanger and start producing power.

That was also, that cost share drilling program was a DOE-funded project. I had the pleasure of working on it. And I'll tell you, nothing has been harder than getting DOE renewable and DOE fossil to work together and share the cost of that project, but they did and it really created some innovative technology there.

Finally, to your question on enhanced geothermal systems, again using DOE money, Ormat brought online the first commercial EGS project, I would argue, in the United States.

We looked at a well that had heat and water but poor permeability. We built up the pressure of water in that well. We created greater permeability and we were able to then use the geothermal fluid from that well through an existing power plant and prove the viability of that. Ormat has done this project in Germany and in the United States, and so we are at the cutting edge of this technology. And I think what it's going to take to move it forward is an investment in the DOE programs and the continued focus and hearings like this where we can explain the incredible things that this industry has done with the help of DOE moving forward.

Thank you.

The CHAIRMAN. And just for the record, I want to let you know that Bernie Karl, through Chena Hot Springs, received a $1 million grant from DOE. They put in $400,000.

With that $1.4 million they have not only turned themselves into 100 percent renewable at their little resort area but they are this center of innovation and he calls it, imagineering, that goes on.

I would invite any of my colleagues and all the folks from DOE to come out to Chena to see what is possible when you have a vision, a lot of imagination, a few bucks and a really sassy attitude. It has been extraordinary what they have been able to do out there.

Mr. Thomsen, if you have not been out since you visited with Senator Stevens and my father, you are in for a good trip too.

Let's go to Senator Heinrich.

Senator HEINRICH. I want to say a word or two about the DOE loan program because, as one of you mentioned, back in 2006 solar was at $9.00 and now it is at well below $1.00, right?

There is a tendency in this town to focus on something that grabs headlines, like a Solyndra, but if you don't take risks, you don't drive innovation. And what we have done well, historically as a country, is taken the risks to drive that innovation.

We need things like the DOE loan program, even if there are a handful of Solyndras along the way. The truth is, we won that battle. We drove those costs down, and we have changed the entire energy industry globally as a result.

Mr. Thomsen, when you say reform the DOE loan program, what are some of the things that we can be doing to make that program work better?

Mr. THOMSEN. Thank you very much, through the Chairman to Senator Heinrich.

So, I think, when that loan program was created, we were in a recession and money, you know, was incredibly tight for these projects. And I want to caveat my comments as kind of a double-edged sword.

So Ormat received a $300 million loan which helped us move forward three projects in the State of Nevada. And you know, at a low interest rate of about four percent, it really moved the needle for us on those projects. What has happened, I guess, the commercial lending appetite has gotten better.

Senator HEINRICH. Sure.

Mr. THOMSEN. And we are now able to get commercial lending at better rates.

Senator HEINRICH. At better rates under that.

Mr. THOMSEN. Better terms that are more flexible.

And so, I just have a couple of examples. So that project that was funded almost ten years ago has been successful. We have three great operating facilities. Anytime we try to expand one of those facilities, we get to talk to DOE and DOE's lawyer and their lender's lawyer at John Hancock. We pay two sets of lawyers on the same side of the discussion, you know, $1,000 an hour. These aren't the good local lawyers in Nevada rates.

And so one recommendation would be that DOE and the lenders should be represented by the same counsel as a first, quick 50 percent cut on the costs of maintaining those loans.

Number two, the terms need to be the same as, you know, commercial lenders or I would even argue, the Overseas Private Investment Corporation, or OPIC. One example for that is we are building the McGinness Hills 3 power plant in Nevada. It's in the same reservoir as the McGinness Hills 1 plant built a decade ago, and the lenders want us to put up that facility and any future facility as collateral in case that reservoir has an issue. And it seems somewhat absurd to be leveraging now another 150 megawatts of power plants off that first DOE loan project. And we go round and round and have this discussion.

The third issue that I'll just point out, that I brought up earlier is we would prepay that loan to get out from underneath it. I think it's about $240 million today. But because of the margin basis, we would be upside down by about $35 million on that loan and that, you know, is untenable for a publicly-traded company. If we could just pay the base rate of that loan, keep the government whole, as I said, and free up that money so that it can be used for other projects, we would love to do that. I'm not really familiar with the first, or Mesa-DOE project I discussed in the 1980s, but we were able to repay that loan in a year. And so, working on those terms to help us repay that money and get it moving and useful again would be incredibly helpful.

Senator HEINRICH. Ms. Young, I want to ask you if we should be thinking about this from the spectrum of projects that are electrical generation projects. At a time when, you know, air source heat pumps now, I mean, we have gotten so much better at heat transfer that if we can make air source heat pumps work as widely as they do today, when they were a joke 20 years ago, what about the commercial applications for, literally, just heat transfer as opposed to electric generation? And what are some of the examples of how we should be moving those toward commercial application today?

Ms. YOUNG. So I think a lot of it comes from economies of scale and just public awareness of some of the resources. And so, you know, when you're driving down the road and you see people have solar panels on their roof, it starts driving conversation and it drives deployment really.

Senator HEINRICH. No question, there have been many studies that have shown that if you have solar panels in your neighborhood, you are dramatically more likely to get solar panels.

Ms. YOUNG. And I think a lot of people today just aren't as aware that geothermal heat pumps are an option. You know, when I talk to people about installing them, they say, well I don't want some new technology. But it's not. And when they realize, when they start to see that their neighbors have it, their local school has it, the state capital has it. When all these, when it becomes more visible it changes the conversation.

And so, I think certainly making it more visible, talking to developers who are building new subdivisions and making them more aware of it. You know, when people pick out their, build their homes, they're picking out their tiles, they're picking the colors of their cabinets, but they're not picking out their heating unit. It's really the developers that are doing that. So working on the conversation with them.

And then additionally, working with the appraisers and the real estate industry to make sure that there's value added to the real estate properties when they're being sold, when they're pulling comps on a property that you can get extra value from having renewables such as geothermal heat pumps.

Senator HEINRICH. Thanks.

The CHAIRMAN. Senator Cortez Masto.

Senator CORTEZ MASTO. Thank you. Thank you, Madam Chair and to our Ranking Member, first of all, for holding this hearing. This is an incredible opportunity for us to take advantage of geothermal as well as utilize new technologies that are out there. I say that because after California, Nevada is the second most heavily geothermal-installed state in the nation and has the greatest untapped geothermal potential of any state. In fact, a 2008 U.S. Geological Survey report suggested that Nevada alone, by the most conservative estimate, had nearly 996 megawatts of undiscovered geothermal resources, roughly enough to cover the electricity demands of 747,000 homes. So we are excited to have this hearing today.

For that reason, because it is an untapped resource and what we are hearing today with the opportunities to enhance this resource, Senator Wyden and I just recently introduced the Geothermal Energy Opportunities Act. Many of you are already familiar with it, but it sets the national geothermal energy generation goals over a ten-year period and directs the Department of the Interior to identify high priority areas on our public lands most apt for future development. It reduces the barriers to obtaining leases, allowing co-production on areas already developed for other energy development, it promotes geothermal heat pump research and development for large-scale applications, and it sets up public-private partnerships to improve geothermal data collection in order to reduce risk and help advance potential projects.

Paul and everyone on the panel, thank you so much. Paul, it is great to see you. We have had the opportunity to talk in Nevada on several occasions. I also want to congratulate Ormat, who just began construction this Monday on a new geothermal facility in Reno, which is going to provide electricity for 22,000 homes, right, while offsetting four million tons of CO_2. So congratulations on that. This is a great conversation, I appreciate that.

One of the things that I want to talk about in the bill—and you mentioned the efforts taken by the Federal Government to expand opportunities to site renewable energy projects. The bill that Senator Wyden and I have introduced requires that data from all exploratory wells carried out on federal lands be made public for the purpose of mapping national geothermal resources. And we have talked a little bit about that.

Paul, can you talk a little bit about how Ormat has utilized public data and how it can be best put to use by the geothermal industry?

Mr. THOMSEN. Absolutely, through the Chair to Senator Cortez Masto, first and foremost, thank you for introducing this bill. That is fantastic news. And thank you for coming out and visiting a geothermal power plant.

As you mentioned, the Steam Boat complex in Reno, we just heard, can be seen by everybody driving from the Reno Airport to the capital in Carson City, and it produces enough electricity to supply the entire residential load of the City of Reno.

If I go back to those original projects that Ormat took DOE funding on, I believe all of the data that we collected was shared with the Department of Energy and I think that's critical for future developers because we're not always going to be successful in developing a project as we heard about the innovation on temperature.

And so, a lot of resources that maybe were looked at 20 years ago weren't feasible based on the technology of that day because they weren't hot enough. And so, being able to go back to DOE or going back to NREL or to our University of Nevada, Reno, Great Basin Geothermal Center and getting some of that data has allowed us to reevaluate it decades later and say, actually that resource might be developable today with our new innovative technology.

And so, Ormat absolutely looks at all the institutions where this data is collected and mined and I think it's a brilliant idea to, you know, especially if you're getting federal funds, to share that information and use it to expand the industry as quickly as possible.

Senator CORTEZ MASTO. Great.

Can you talk a little bit about the investment tax credits (ITC)? I've heard this conversation as well, that to continue to promote this investment, ITC is helpful with the upfront costs. What else can we be doing?

Mr. THOMSEN. Sure. So geothermal is a little unique in the fact that it's eligible for both the kind of a base rate ITC and used to be eligible for the production tax credit. And that really put geothermal on a level playing field with the other renewable technologies that got this. In the last extension of the production tax credit, geothermal was not included in that and so it fell back to, kind of reverted back to, a ten percent investment tax credit. And that has put geothermal at a disadvantage from a developer's standpoint of competing with those other technologies that get the 30 percent investment tax credit.

I think I misspoke earlier, in production, they get a 30 percent investment tax credit, we get a 10 percent.

By including geothermal and putting it on that level playing field we will expedite its deployment, especially in states that are trying to mitigate climate and find resources that can, you know, be flexible and firm and meet their climate goals moving forward.

And so, as, you know, I think the industry and on behalf of the Geothermal Resources Council, we are ready to, kind of, have that discussion should a tax bill come forward. It's pivotal moving forward.

Senator CORTEZ MASTO. Thank you.

I notice my time is up. Thank you all for being here.

The CHAIRMAN. Thank you.

Let's go to Senator Cantwell.

Senator CANTWELL. Thank you, Madam Chair.

Continuing on that thought, I know we are not the Finance Committee, but you are in front of us as industry experts and we want to explore what we think that potential really looks like.

One, do you think the cost of geothermal-generated electricity, once it is scaled up, can be competitive, and where do you think that falls? And what do you think we get out of another six to eight years of an ITC?

Mr. THOMSEN. Through the Chairman to Senator Cantwell, the answer is yes.

What I mean by that is, we are already seeing in California, for example, utilities procuring geothermal at about seven and a half cents. They've recognized that when they take the energy value of geothermal and its capacity benefits, meaning that it's there at night or when the intermittent resources aren't there, that it's of value to them. With geothermal prices, you know, going below seven and a half cents, it's absolutely commercially viable today in states that are looking for high renewable penetration rates.

Turning back to the tax credit question.

Senator CANTWELL. Well, what do you think about it when it is scaled up? Where do you think that falls? Do you think that would drop further?

Mr. THOMSEN. Absolutely.

Senator CANTWELL. Okay.

Mr. THOMSEN. I mean, I think if you look at, like I said earlier, ten years ago we were probably at nine, nine and a half cents per kilowatt for geothermal developed. And today, publicly available information, the last publicly available Ormat contract is at seven and a half cents. And I'll tell you we're having negotiations and discussions of prices lower than that and that is, you know, without a lot of the innovation and continued development here.

So I think you will see those prices come down. And you know, when you look, I use California as an example, when you look at a resource that can ramp up or down to meet the loads, it can provide grid support, far support, droop response and things and doesn't have emissions, you run out of technologies to turn to.

You look at hydro or geothermal. And that's why, frankly, we're seeing a resurgence in the Western markets for geothermal. People are procuring it again.

And the simple evolution of that is California built ten gigawatts of intermittent resources in the last decade. They had built, you know, it's been an absolute success story for solar and wind projects. What they are realizing now is that they need that backbone to their renewable development, and that's geothermal moving forward.

Senator CANTWELL. Right.

And so, having been involved in those tax credit bills as it relates to renewables writ large, it is very unfortunate that geothermal dropped out in 2017. But what do you think that structure should look like in six years, eight years?

Again, I know we are not the Finance Committee, but nonetheless, you are the industry experts sitting before us on one of the best opportunities in the renewable area. So I'm just trying to think about what you think the industry structure needs for certainty. Six years? Eight years? What?

Mr. THOMSEN. If I put on my hat from the Geothermal Resources Council Policy Committee, our simple ask there is to be treated the same as the wind and solar tax credit as it steps down.

I do think, you know, if we want to be aggressive and look at creating parity and helping the grid moving forward, you know, and I want to be somewhat technology neutral when I say this, but technologies that can provide ancillary benefits to the grid to make our transmission and infrastructure better, maybe should get an incentive moving forward.

I served as the Energy Advisor to the Governor of Nevada and we had a tax, a state tax credit system. And it was amazing to me that we had about a ten to one return on our investment for projects that we gave a state tax incentive to that came to the State of Nevada and then built these projects, put people to work and they are long-term investments, you know, for 20 or 30 years under our power purchase agreements.

Senator CANTWELL. Well, if we were neutral you would have been in the tax bill. You would have stayed in the tax bill.

All we are doing today is trying to breathe more life into the understanding of geothermal so that our colleagues will understand, at least people on this Committee will be supportive of it as the opportunity presents itself this year.

Mr. THOMSEN. Absolutely.

Senator CANTWELL. Thank you, Madam Chair.

The CHAIRMAN. Thank you.

Senator King.

Senator KING. Thank you, Madam Chair. This is a great hearing on a really important topic, I think.

I asked a geologist friend once when I looked at the map, I said why is all the hot water out West? And he said, well, it's obvious, those states are closer to hell.

[Laughter.]

You can tell I am not running for President, Madam.

[Laughter.]

But I do want to focus on geothermal resources in the non-Western states where the temperature may only be 45 degrees, but we have a well-developing geothermal heat pump market in New England. But the issue is installation costs: $40,000 for a 2,000 square foot home. How do we drive those costs down?

And you talked about drilling technologies because you have to drill deep wells. Are there other ways and what are the answers that will improve the ability of these kind of more localized projects in areas of the country that do not have 180-degree water under the surface?

Ms. YOUNG. Yeah, and I think a lot of that comes from scale. Certainly, if you're doing a one-off project and you have to mobilize your rig and you have to mobilize the heat pump unit and you're deploying all of this.

Senator KING. So that gets to the district heating solution you were talking about. Is that part of a solution, particularly if you are in an urban area?

Ms. YOUNG. Yes, district heating is very popular, in fact, in Europe for this reason. And it's because they have a much higher population density than a lot of the places here in the U.S.

But when you do have densely populated areas, a lot of the cost of these district heating systems is in the surface piping. So the district heating become viable in larger cities and in densely populated areas.

Senator KING. The economics in Maine are quite good. It works out to about $0.85 a gallon of oil, a comparable heating value, and that oil is now about $2.75. The economics are good, but still the upfront cost is a significant barrier. And there are tax benefits and incentives, but I think that is something we really need to think about.

I am very interested in what you were talking about, about permitting. It has always struck me that environmentally strong projects like solar, wind, or geothermal, have to pass the same exact permitting requirements as if they were strip malls. In other words, there is no, sort of, net environmental benefit analysis done.

What about permit by rule, which we have been very successful with in Maine, where if you have great experience with this technology, you know what the impacts are and the agency says, if you do it this way and meet these standards, you have your permits. We don't have to do 100 environmental studies of each individual site. Is that a possibility in this area?

Ms. YOUNG. So I don't know a lot about Maine's permit by rule, but it does, the way you've described it sounds a lot like what a categorical exclusion is.

Senator KING. Same idea.

Ms. YOUNG. Yeah, that you have this category of activities that you've reviewed the environmental impacts.

Senator KING. Now, my question is, is it federal permitting? Is that the issue? Or is it local and state permitting?

Several of you mentioned permitting as a barrier. What is the barrier? Is it the State of Nevada or the State of California or is it NEPA? Where do we need to focus here?

Ms. YOUNG. Well, for the first part of the development project where they're drilling for the wells and don't, haven't yet accessed the resource, that's where the risk is the highest and that's where we focused on these federal categorical exclusions. So the ability to drill and access the resource as quickly as possible and inexpensively as possible in order to get financing for the rest of the project.

It depends, obviously, on the location of the project, if it's on federal lands and also in which state you're in and how well the different states work together in aligning their processes.

Senator KING. And I want to be clear, I am not talking about waiving environmental requirements or ignoring environmental impacts.

Ms. YOUNG. We agree.

Senator KING. But if you have done the same project 100 times and you know exactly what the impacts are and what they will be and what to look for and how to mitigate, it seems to me there is an opportunity there for dealing with this.

And as you point out, these are upfront costs. These are high test dollars. There is no tax subsidy. If the project does not go, you have lost that money.

Ms. YOUNG. That's correct.

Senator KING. Other comments?

Yes, sir.

Mr. THOMSEN. If I can, through the Chair to Senator King, I like the analogy of the strip mall except a strip mall doesn't have to get the permit three times and that's the case for geothermal projects on federal lands.

You know, unlike a wind or solar project where you can put up an anemometer or look at the solar radiation without disturbing the land. To find the geothermal resource below the surface, we have to go out and do some preliminary exploration or resource confirmation. And what's different in the United States than in the rest of the world is to go out and drill those slim holes and start to do exploration which sounds like the rule by law.

Senator KING. It is a—tower—down instead of up.

Mr. THOMSEN. Exactly.

But in order to drill those wells, we have to go through NEPA and get an environmental assessment on each one of those exploration wells. And that is what has just incredibly slowed down the industry because you are now getting a delay and a cost before you even know if there's a resource there or you want to pursue it.

And so, what is in most of our written testimony here is the concept of, like you said, every exploration well looks very similar, the surface disturbance is minimal and they can be reclaimed, you know, very, very quickly. It's to treat all of those the same and give a categorical exclusion in NEPA.

Senator KING. With certain requirements, if you follow these requirements.

Mr. THOMSEN. With certain requirements.

And then, once we, you know, qualify a resource and say, this is something we want to build, then we go through NEPA again for an environmental assessment on a production well which is treated in code much differently than an exploration well. And then we get to do one for the actual siting of the power plant as well.

And so, that is, you know, those three things are what we are trying to streamline to say, give us the categorical exclusion through exploration or resource confirmation. We're not skirting any environmental concerns. And once we decide to drill a full-size production well, start moving, you know, thousands of gallons of geothermal fluid through a power plant, we will go through the full EA and EIS project.

We operate about 400——

Senator KING. Bearing in mind that we are building a project that is a net positive for the environment in terms of carbon, which is the goal, our universal goal here.

Mr. THOMSEN. 100 percent.

And a project with a smaller surface footprint for the amount of megawatt-hours it reduces than any technology outside of nuclear.

Senator KING. Thank you.

Thank you, Madam Chair.

The CHAIRMAN. Senator Hirono.

Senator HIRONO. Thank you, Madam Chair.

Mr. Thomsen, Ormat owns the Puna Geothermal Venture Plant on the Big Island of Hawaii. That plant provided about 30 percent of the power for that island until the lava from Kilauea Volcano caused the plant to have to be closed in May 2018.

As you proceed to reopen the plant, I would like your commitment that your company will engage with the local community and other interested people on the Big Island to hear their views and concerns.

Mr. THOMSEN. Through the Chairman to Senator Hirono, you absolutely have my commitment to do that.

Ormat has been proud to operate that facility for some time. And you know, it's a compelling story because we often talk about energy security.

Senator HIRONO. Yes.

Mr. THOMSEN. And it's going to be an incredible success story to say that a geothermal facility surrounded by lava was able to, you know, weather the storm, come back online and whether those geothermal projects are located in the Caribbean and hit by hurricanes, tropical storms or sit through this, geothermal power plants are incredibly resilient.

And so, you have my full commitment as we go through the re-permitting process, as we build the new transmission lines, this is really going to be a story of rebirth and I'm thrilled. I want to take a moment and thank our Power Plant Manager, Jordon Herrera, and our Senior Hawaiian Affairs, Michael Kaleikini, for working with the community to bring the roads back, bring the power back up and bring new life to the, kind of, Eastern Pāhoa area. Additionally, what's amazing about that story is that when that power plant went down, Hawaii had to replace 30 percent of its load and it did that through the use of bunker fuel. And so, the emissions went up and, as the Chairman pointed out earlier, the price of oil at that point was quite high. And so, I was shocked to hear the other day, HELCO say, the price on ratepayers went up by $2 or $3. Well, that can be a stunning amount if you consume a lot of power.

Senator HIRONO. Of course.

Mr. THOMSEN. And so, we are doing everything in our power to get that facility back up and operating and, frankly, hope that the geological activity that occurred will make those wells hotter, more productive and maybe we'll see a greater product out of the Puna Geothermal Venture moving forward.

Thank you.

Senator HIRONO. Yes.

I would like to thank your company for your sensitivity to the views of the community as well as your commitment to the community.

And I would also like to join with Chair Murkowski in asking the Department of Energy to include all 50 states in its research, like the recent GeoVision report, especially as both Hawaii and Alaska have very significant geothermal sources. Can you nod your head?

Mr. SIMMONS. Sure, yes.

And the challenge there in GeoVision is that we were looking at three electric sector scenarios and the model that we use for that is, unfortunately a model of the continental 48 states. It is a modeling impediment, let's say.

Senator HIRONO. Well, can you fix that then going forward?

Mr. SIMMONS. Yeah, we can look into fixing that because——

Senator HIRONO. Yes, please do because our two states have significant volcanic activity and, as you well know, the entire Hawaiian chain is as a result of volcanic activity. Even as we speak there is a new island being formed off the Big Island, not during our lifetime, that is going to pop up.

So I have another question for you, Mr. Simmons. You testified to the DOE's expanding support for enhanced geothermal systems that require engineering to allow for the movement of heat and water that happened naturally in more traditional hydrothermal resources found in Hawaii. What are the costs of development of a traditional hydrothermal resource compared to an enhanced or engineered geothermal system, and what share of DOE's geothermal budget is spent on hydrothermal versus enhanced geothermal research and development?

Mr. SIMMONS. So, there are, as Paul mentioned earlier, there is maybe, there is hardly any enhanced geothermal systems in the world today. Arguably, they have one of the first and only, so it's difficult to really be able to compare costs because the costs are much greater for the enhanced geothermal systems. And that's the reason that we are working on with FORGE to really, hopefully, drive down those costs of enhanced geothermal systems and make them cost competitive with electricity generally.

The breakdown is——

Senator HIRONO. So yes, give me the breakdown.

Mr. SIMMONS. Do we have a breakdown? What is it? Okay, so slightly over half is for enhanced geothermal systems versus the rest of our portfolio.

It is a critical area for the future because enhanced geothermal systems expand the opportunity away from only the places with really excellent geothermal resources currently to expand to many other areas.

Senator HIRONO. So do you think that kind of distribution of funding, considering that enhanced geothermal systems cost so much more, do you think that is appropriate rather than continuing to make sure that we are doing whatever we can to do enough research on the hydrothermal side to make hydrothermal cheaper?

Mr. SIMMONS. Well, currently I think that this is a good division of resources. If the Senate thinks otherwise, I'd very much like to hear that. If the industry thinks otherwise, I'd very much like to hear that.

One of the important parts of my job is to make sure to talk to stakeholders and to hear their perspectives on how we are spending our research dollars. The money spent on enhanced geothermal systems is really a play for the longer-term future.

Senator HIRONO. I understand.

Mr. SIMMONS. That's a key area, but also it is critical that we are working on driving down the costs of what is available today to, you know, to continue to make incremental improvements there as well.

Senator HIRONO. Madam Chair, may I ask, as long as we have the panel here, if any of our panelists would like to weigh in on the 50/50 distribution?

Yes, please?

Mr. LATIMER. Thank you, Senator.

I would just like to make a couple points.

One is that there's a significant amount of overlap in the type of research done for the hydrothermal and what the EGS does. So it's not like that money that is spent on EGS does not have crossover benefits to hydrothermal and vice versa.

So I think in that sense, when you're dealing with anything in the subsurface, whatever we learn about these specific geologic systems that are good for geothermal energy is going to be able to be applicable across both.

The other is to get at the specific cost question. And I think it's important to understand that there's the Ormat project and a couple other examples around the world of commercial EGS, but we just don't have that many data points right now. And it's a very early technology, but it has a lot of potential, both in terms of its scale and in its cost reductions.

And so, if we look at the project like FORGE, that the Department of Energy is leading, there's technologies that we just have not tried yet for enhanced geothermal systems. And so, it's a little unknown what the true potential could be. And there's a possibility that the cost could be far lower than what we think if these research programs are successful.

Senator HIRONO. I take it you agree, Mr. Thomsen, you are nodding your head.

Mr. THOMSEN. Through the Chair to Senator Hirono, I do.

I think, you know, for years we have asked the Department of Energy to look at the subsurface research and that's, and what I mean by that is the drilling of the wells, you know, can we do it more cost-effectively? Can we do it quicker? Are there new innovative technologies?

I often tell people, I'm proud to work for the largest geothermal developer in the United States. We have a market cap of $3 billion. That is smaller than the R&D budget of any major oil company out there.

And so, we can't do a ton of that subsurface R&D which actually brings me back to a project in Alaska at Mount Spurr. We spent $10 million drilling and looking for that project before we had to say we can't spend any more in the exploration phase.

So for DOE to spend a considerable amount of their funds to look at how to, and the FORGE site, the Frontier Observatory for Geothermal Energy, is going to be their playground to look at how do we drill wells differently? How do we deploy new technologies? Anything that the industry can take from that and reduce our costs will be hugely helpful.

To give you just a basic breakdown. We typically say one megawatt of geothermal energy costs us $5 million, and half of that is subsurface drilling. If we can reduce that cost, that would be huge to the industry.

Senator HIRONO. I understand. Thank you for the clarification.

Thank you, Madam Chair.

I would just like to note that for Hawaii, while we do have large geothermal sources, that there are cultural concerns relating to the use of geothermal in Hawaii and I want to note that because I certainly do not want to make light of those concerns in Hawaii.

Thank you, Madam Chair.

The CHAIRMAN. Thank you, Senator Hirono. I appreciate you bringing up the absence of Alaska and Hawaii from the GeoVision report. It is my understanding that this is an old survey, USGS survey, from 2008. The resource assessment indicates that Alaska has a mean conventional hydrothermal resource potential of about 6.3 percent of the total identified U.S. hydrothermal, and that Hawaii has about 14 percent of the total identified U.S. hydrothermal resource potential.

There is no doubt that the potential is there. The fact that we are not included as part of the model of the continental United States is a reality, unfortunately, that oftentimes we are excluded from a level of analysis. Then, because we have been excluded from the modeling, when it comes time to access opportunities, we are not included or we are omitted or it is viewed as well, we just don't know enough about it. So we are happy to have our own modeling and I think we certainly demonstrate that we have good, strong potential out there and know that Hawaii does as well. So we want to work with the folks at DOE on that.

I want to ask a couple questions in, just exactly, this vein with regards to the potential.

I recognize, Mr. Thomsen, the effort that Ormat made some years ago at Mount Spurr. I know that you have had folks within your company that continue to look at Alaska.

I am curious to know from you, Mr. Latimer, with your very impressive story about how you got into geothermal in the first place, what it would take for a company like yours to consider the opportunities for Alaska.

And Mr. Spisak, we have not brought you into the conversation a lot today, but in my state it is my understanding that with the potential that we have in the state, BLM has areas that, they too, could prove to be highly potential with regards to the resource. What is BLM doing to accelerate the opportunity for potential geothermal opportunities within the State of Alaska? I throw it out to all of you for a little bit of discussion about what would it take to come back and look at the production possibilities in terms of bringing more geothermal into the market. You all can jump in, because you have all got your question here.

Mr. THOMSEN. Chairman, if I can maybe just set the stage?

From our experience a couple of ideas, one, you know, in places that geothermal is very difficult to develop, you know, the prices go up very quickly. And so, our experience with Mount Spurr was quite unique in the fact that it was across the Cook Inlet. There weren't very good roads. We had to build ice roads to get drill rigs there. We had a very consolidated drilling season. That project, you know, from the big scheme of things was quite complicated. We invested about $10 million to procure the land and do the initial drilling of that project with zero federal help. We did receive some money from the State of Alaska to do that and then had to make the tough decision.

So, going back to, you know, what really put Ormat on the map in the '80s was a DOE cost share program. When they look at states with great geothermal potential but that are very difficult to develop projects in, maybe due to a short drilling season or due to having to construct roads and things that can be very costly that, you know, geothermal developers from Nevada are, kind of, triaging the first time, that would be hugely helpful.

The other one I think is transmission. And I mentioned it earlier that transmission and interconnection is a huge issue and not just in Alaska or Hawaii but in the U.S. with the, kind of, antiquated transmission system. When we build these power plants, the geothermal resource is where it is and we have to get that transmission, you know, that power to the transmission system. We can build the distribution lines, but interconnecting to transmission is becoming an issue. We're getting five- to seven-year delays and when we look at places like Hawaii, we would absolutely love to move power from the Big Island of Hawaii to the other islands and, you know, maybe looking forward and if I come back to this Committee in another decade, what we should be looking at now is how do we move that power and our undersea cables and so forth, a reality. What are the costs of those today and if those can move power, it unleashes the geothermal potential?

We looked at other resources in Alaska along the Aleutian Island chain and they're phenomenal resources. They just don't have a market nearby. They have a fishing market that's maybe there for a couple months but for a private sector company to, you know, look at a payback of 60 years is untenable.

So how do we connect those resources to the rail belt and transmission and infrastructure is going to be a huge part of that as we look to the next, as we look forward.

I think many companies would go back and look at Alaska if they could share those costs and burdens or get some innovative help from the Department of Energy and, you know, that's my quick and dirty pitch for giving them more funding to do that.

The CHAIRMAN. Well, I hope your pitch does not discourage Mr. Latimer.

What would it take?

Mr. LATIMER. Yes, thank you for the question, Senator.

I think Alaska is a fantastic market for geothermal, and we've talked at length about the Chena Hot Springs and that's just a great example. It's highly efficient because the ambient temperatures are cooler. It's the same reason it works so well in Iceland. And there's all kinds of additional benefits from the heat resource.

The biggest constraint I see in Alaska is the lack of data. We spoke earlier about the public datasets of bottom well temperatures and how that informs. It's a low-cost way to really narrow down your resources.

And when you think about where it's difficult to do private capital on projects, it's the gap between that low-cost data and when you have a confirmed project because doing surface studies and your confirmation drilling is extremely costly and challenging to do if you don't have confidence of some publicly available data to lower the cost of the early studies.

Examples of places that have done a great job of spurring an industry in light of low data, I think one of the best success cases you could say from a policy and market innovation standpoint would be Kenya over the last decade. Kenya is at a point now where 50 percent of their electricity comes from geothermal energy, and it's increased by a factor of ten since they passed the new Reform Act of 2007.

And they did many things there, but one of the most interesting ones was they worked with KfW, the Development Bank of Germany, to install a facility they called the East African Risk Mitigation Facility where private partners can apply and get competitively accepted for matching funds for that pre-exploration, exploration and confirmation drilling work which really cuts down on the risk of the point where private capital is the hardest to do.

So imagining looking at the success of how that instrument kickstarted the industry in Kenya, I think there's many geographies in the United States that could benefit from a similar type structure to attack the highest risk part of the project.

Thank you.

The CHAIRMAN. Mr. Spisak, what is BLM doing to help facilitate, whether it is on the mapping side or just, you know, we have heard the issues with the permitting and how that adds to the cost. The fact that it is six to ten years on public lands to advance a project and that does nothing to enhance the interest from the investor's perspective.

Mr. SPISAK. I appreciate the question, Senator.

Basically, we react to interest by industry and where they put in expressions of interest and then we process those through sale. And Alaska, as has been mentioned, there hasn't, we have not gotten any expressions of interest to the point where we would go through the NEPA analysis and identify and put parcels up for sale like we've done in California and Nevada.

The CHAIRMAN. Do you think, though, that fact that you have to go through, what did you say, six different NEPA steps there? Do you think that that discourages just from the get-go anybody looking to a prospect that might be on public lands?

Mr. SPISAK. Certainly, the discussion here would convey that and I don't doubt that at all.

We're looking at and with this report we reviewed it, the Geo report that's been discussed about streamlining NEPA, Secretarial Order 3355 which came out here this last year regarding NEPA analysis.

So we're implementing and that's improving the NEPA process for energy projects, including geothermal.

The CHAIRMAN. I think we have heard a clear message here that there can be much that can be taken or learned from what has happened within the oil and gas industry and how we can use some of those lessons learned to either help facilitate a better process or the technologies themselves.

Mr. SPISAK. Absolutely.

The CHAIRMAN. Ms. Young, you had called for a dedicated geothermal team at BLM and, you know, I think maybe it is ideas like that that can help us focus on this as an opportunity. What do you think about that as a suggestion? Is there anything else that BLM might be able to do to improve the processing time for the geothermal leasing?

Mr. SPISAK. Yes, certainly.

As you've mentioned, we experienced different teams on the oil and gas side and have lessons learned in that. As geothermal ramps up we would very likely look at pulling people together to focus on that, tiger team or strike team, what have you, as expressions of interest come to us for processing.

The CHAIRMAN. And then my last question, and Senator Hirono has additional so we will turn to her.

But we have heard from you all that there is a hurdle there when it comes to the permitting, and the time that is required, the development timelines here in the United States on our public lands.

Ormat operates a lot of facilities around the world. How does the timeline, say for instance, a year, you have a project in the Philippines. How does that compare to what we see here and what can we be learning from how they are operating in other nations?

You also mentioned Kenya. Share with me a little bit of the international perspective versus where we are in the United States.

Mr. THOMSEN. Thank you, Chairman.

To boil it down, you know, in other countries we do not have to go through the rigorous permitting for exploration. We typically get a tender for an area that's been designated to look at for geothermal development. We can then go do, you know, this resource confirmation incredibly quickly, refine and define where the resource is and then proceed with the permitting once we are ready to, you know, build a facility and move forward.

And so, that is the, you know, the single biggest difference in the United States than in the rest of the world is that exploration delay, requiring NEPA. Simply put.

The CHAIRMAN. Easy as that.

Senator Hirono.

Senator HIRONO. I have just one question for Mr. Simmons.

The DOE's Geothermal Technologies Office Play Fairway Analysis program was successful in identifying a variety of prospective resources in Hawaii and elsewhere, and Hawaii has one of the deepest geothermal resources and highest mobilization costs in the country—Alaska and other Western states also have higher than average exploration costs.

Do you think the Department's Geothermal awards should reflect that higher levels of funding will be needed to conduct exploration activities in places with higher exploration costs due to different geologies?

Ms. SIMMONS. Yes, and along those lines, one of the things that we're looking at next year is to look at a sub to do, to focus on, have a focus, a focus on, subsurface R&D that includes volcanic terrains which obviously includes both Alaska and Hawaii, but also those are higher costs but then again, with those higher costs you also have incredible resource potential because of the high temperatures.

Senator HIRONO. Thank you.

Thank you, Madam Chair.

The CHAIRMAN. Thank you, Senator Hirono.

Thank you all. We really appreciate the conversation.

I cannot believe that with my enthusiasm for geothermal we really have not had a hearing since 2006. I am so glad we remedied that today. Mr. Thomsen, it is not going to be another decade before that happens around here.

I think one of the things that we heard today is there is a lot, there is a lot out there. Several of you have used the term "advanced geothermal." I think when we recognize where we are as a country, where we are globally with energy portfolios out there, instead of talking about nuclear nowadays, we talk about advanced nuclear. Instead of just plain old yesterday's geothermal, there is a heck of a lot more out there.

And so how we work to develop some of the technologies, how we allow for our processes to keep up with the potential and the new technologies the way that we are accessing them, the way that we can be doing more.

I think it is an exciting time. I think that our failure to harness the potential is on us. We have to figure out where we are, where we have barriers in place and why we have barriers in place and how we can move around them, set those aside and really start harnessing this potential.

We have heard from each and every one of you that there is just such a bonus when it comes to geothermal whether your focus is on reduced emissions or how we avoid intermittency, the potential is really, really something that we should all get very energized about and that is, no pun intended, it is really sincere.

I look forward to talking with you all more about some of these developments and what we can be doing from a policy perspective here on this Committee and in the Congress to help advance some of what we have heard discussed today.

Thank you for your leadership, and we will be working on these things.

The Committee is adjourned.

[Whereupon, at 11:38 a.m. the hearing was adjourned.]

APPENDIX MATERIAL SUBMITTED

U.S. Senate Committee on Energy and Natural Resources
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Questions for the Record Submitted to the Honorable Daniel R. Simmons
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QUESTIONS FROM CHAIRMAN LISA MURKOWSKI

Q1. The development of the Frontier Observatory for Research in Geothermal Energy (FORGE) site in Utah is an important step, as it represents the first foray into enhanced geothermal in the U.S. in decades.

Q1a. How will the site involve other university and private sector partners outside of the University of Utah? Will the data resulting from the FORGE site be available for private sector developers?

A1a. The DOE has developed the Frontier Observatory for Research in Geothermal Energy (FORGE) as a dedicated site where scientists and engineers will be able to develop, test, and accelerate breakthroughs in enhanced geothermal system (EGS) technologies and techniques.

FORGE's five-year Phase 3 is slated to start late this summer, after the final go/no-go of Phase 2C. Half of the annual funding in Phase 3 will be used for competitive R&D open to the entire geothermal stakeholder community, including university and private sector partners. A FORGE S&T roadmap has been developed and published, sharing likely research topics for solicitations; this roadmap can be found at https://www.ida.org/-/media/feature/publications/f/fo/forge/d-10474.ashx.

All data resulting from FORGE is and will be available publicly at https://gdr.openei.org/.

Q1b. At the conclusion of the planned five years of operation, what will happen to the site? Will it be available for other companies to test?

A1b. As currently planned, the site will revert back to the site owners at the end of the five-year Phase 3, currently slated for FY 2024. The University of Utah will demonstrate completion of FORGE decommissioning, disposition, or ownership transfer, eliminating all DOE future liability.

The FY 2020 budget request includes $5 million to be used in FY 2024 to support final site decommissioning in FY 2024. Closeout activities will include demobilizing any equipment and facilities, shutting in wells, remedial activities, and transferring land and subsurface ownership.

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Q2. The Department of Energy's (DOE) Fiscal Year 2020 budget request included a new initiative called the Harsh Environmental Materials Initiative (HEMI), which is a collaboration between the offices of fossil energy, nuclear energy and advanced manufacturing for materials and sensors in high temperature and pressure power plants. As many of the greatest challenges for developing enhanced geothermal technologies are due to the high temperature and hard rock of deep geothermal resources, is there an opportunity for geothermal energy to benefit from HEMI if it is funded?

A2. The harsh subsurface environments lead to challenges for geothermal development. Hardened materials are required for everything from drilling and completions to geothermal gathering and processing facilities on the surface; advances in this area will reduce both costs and risks in geothermal development. The Geothermal Technologies Office (GTO) is addressing these issues through their Efficient Drilling in Geothermal Energy (EDGE) and Zonal Isolation projects as well as staying actively engaged with EERE's Advanced Manufacturing Office (AMO) in this crossover space. GTO and AMO are considering opportunities in the space of advanced manufacturing for geothermal energy development with a focus on hardening materials to withstand harsh geothermal conditions. In addition, it is likely that the geothermal industry will be able to pick up crossover technologies from the Harsh Environmental Materials Initiative.

Q3. A growing area of interest in the U.S. is around low-emissions sources of high quality heat for industrial applications. What research is DOE conducting around the direct use of geothermal heat, and how is DOE engaging with private-sector industrial partners to tailor that R&D?

A3. Direct use of lower-temperature geothermal resources (<150°C) can provide many benefits, including electricity, storage, heating and cooling solutions, and additive value in mineral recovery and desalination. Industrial processes that requires only heat and not steam, such as food processing, dehydration, and greenhousing, can potentially utilize low-temperature geothermal resources.

Research and development in low-temperature geothermal technologies could improve heat-exchange mechanisms and system design for geothermal heat pumps as well as add more capacity to direct-use technologies. The *GeoVision* report analyzed one such application specifically, district heating, and projected that through drilling and subsurface stimulation technology improvements (TI scenario), the nation could realize enormous economic potential, equivalent to as many as 17,500 installations nationwide. These same technologies could unlock similar direct use potential for industrial and commercial process heat applications mentioned above. Reservoir thermal energy storage, which is low-temperature heat stored in geothermal reservoirs for later use, in addition to the ancillary grid services that geothermal power generation technologies can provide, tie directly into grid modernization and energy storage, areas of research prioritized in the Budget.

Currently, GTO spends $8-10 million annually on projects across the low-temperature spectrum. In the area of industrial use, GTO has been funding a Deep Direct Use project in Texas with Eastman Chemical as a primary partner. This project is investigating the feasibility of using direct-use heat to make Eastman's industrial processes more efficient. Having Eastman Chemical as a partner ensures that the research being funded meets the needs of industry.

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QUESTIONS FROM RANKING MEMBER JOE MANCHIN III

Q1. The natural gas boom has not only revolutionized our energy sector, it has exponentially increased our understanding of the subsurface in some areas of the country. These cross cuts have been invaluable, but there are some things we can't learn from the natural gas industry. In all cases, it's important that DOE's R&D programs are well positioned to take advantage of the experience of industry but also to fill gaps where they exist.

Q1a. How much of this new subsurface understanding can we apply to advancing geothermal technology and accelerating deployment? What lessons are NOT transferrable from the natural gas industry? How well aligned is DOE's research program to capture lessons and fill in identified gaps?

A1a. To realize the potential of EGS, advances in drilling and stimulation technologies, such as those employed in oil and gas (O&G), will likely be adapted for geothermal. However, geothermal wells are generally much hotter than those encountered in O&G, and the holes drilled are larger and in generally harder rock. R&D can enable this adaptation. Most of the technologies developed for O&G are transferable, but given the lower "barrel for barrel" value of geothermal fluids and resources compared to hydrocarbon production, not all technologies will make sense to adapt to geothermal. It is also likely that new technological advances will be required. GTO is still in the early stages of understanding what combination of technologies may be most successful for EGS, but the DOE geothermal R&D portfolio is specifically targeted to capture lessons and fill in the identified gaps. For example, the $15-million Play Fairway Analysis program supported over the last several years by the GTO, which looks to combine various data sets to better predict where a geothermal resource may be found, was adapted from the oil and gas industry, and in FY 2018 GTO awarded projects in Zonal Isolation, several of which focused on adapting oil and gas technologies to geothermal conditions. As with many things, progress is scalable and in this case compoundable. R&D investments in these technology areas can generate improvements that are not purely additive, but they could leverage momentum to achieve geometric rate of improvement.

Many of the drilling and reservoir technology advancements developed by the O&G industry have already been readily adopted with success by the geothermal industry. As the *GeoVision* analysis report explains, technology transfer has been bi-directional; for instance, one notable example of

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geothermal technology transfer to the O&G industry is the research, development, and commercialization of PDC bits, led and supported by DOE for the geothermal industry. This innovation ultimately catalyzed the growth of a $1.9 billion industry and resulted in cost savings for the O&G industry.

Q2. As the industry continues to grow, geothermal energy is a potential source of new career opportunities requiring diverse skillsets. Specifically, geothermal electrical development requires exploration, well drilling, reservoir engineering, and plant operation. The skills required for exploration, well drilling, and reservoir engineers are similar to those employed in the mining, petroleum, and hydrology industries. And, like other industries, the geothermal industry will be affected by an aging workforce as well as recruitment and retention issues.

Q2a. How can the Department of Energy help strengthen the alignment across industries, and create common educational and training pathways and easy workforce mobility between industries?

A2a. Both the *GeoVision* report (Section 4.4.1 – Jobs and Economic Development) and the *GeoVision* Analysis Supporting Task Force Report: Impacts (https://www.nrel.gov/docs/fy19osti/71933.pdf) make many of the same points about the needs and opportunities for a geothermal workforce. As you correctly indicate, many of the same labor categories you might find for exploration, drilling, construction, and manufacturing in the oil and gas or mining industries are directly transferrable to the geothermal industry. Growth of a robust geothermal industry could help support workforce resiliency, especially for extractive industries with a lot of exposure to commodity price volatility.

Although many skills are transferable from other industries, training is going to be required to meet demand if deployment increases to the levels forecast in the more aggressive *GeoVision* analysis scenarios. The *GeoVision* Roadmap specifically addresses the need for increased awareness of employment and training opportunities across all geothermal energy technologies. The Roadmap also explains how the geothermal industry can benefit from approaches similar to other renewable technology industries, which have established training and licensing programs to develop robust and sustainable workforces.

The Geothermal Technologies Office is supporting the National Geothermal Academy, which has a goal to develop and conduct a multidisciplinary, higher-education geothermal program in geothermal science and technology to educate and train the next generation of the U.S. geothermal energy workforce. Course curricula and materials are developed in consultation with leading geothermal experts and industry professionals in the geothermal sector, and classes are taught by a range of instructors. This Academy will be particularly important as GTO looks to cross-train workers from closely related industries such as the mining, petroleum, and hydrology industries.

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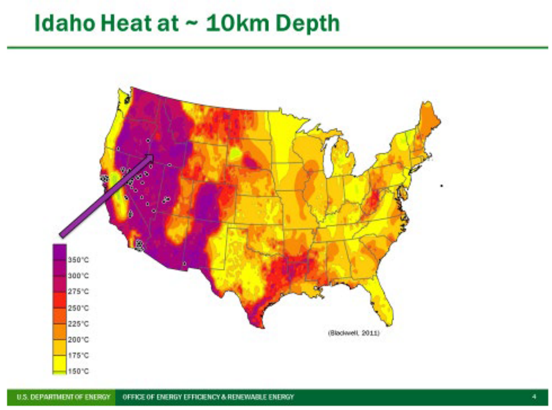
QUESTIONS FROM SENATOR JAMES E. RISCH

Q1. Idaho has been a world leader when it comes to developing geothermal resources and demonstrating new technologies. In the Geovision report, you note that technology improvements could go a long way in deploying additional geothermal resources. Can you please explain what technologies you think would be the most beneficial in developing additional geothermal resources in Idaho?

A1. Idaho has significantly elevated heat at depth, with particularly high heat in the Snake River Plain, as shown in the figure below.



Lowering the costs of geothermal development through technology improvements can make geothermal developments more cost effective and catalyze additional deployment of those resources. As indicated in the *GeoVision* analysis, technology improvements in the areas of exploration, drilling, and well stimulation are essential to finding resources faster and more cheaply, as well as targeting wells with improved precision and success.

These same subsurface technology improvements in exploration, drilling, and well stimulation can help unlock the enormous potential for similar direct-use applications of lower-temperature geothermal resources. Furthermore, the Idaho National Laboratory (INL) led the investigation of the *GeoVision* analysis of hydbridized geothermal technologies. Hybridizing and linking geothermal energy with other generation technologies can drive operational synergies. Historically, Idaho has led the way in the area of direct-use geothermal utilization, with the nation's oldest and longest-operating district heating installation in the city of Boise.

These technology advances, many of which the Geothermal Technologies Office (GTO) is addressing in current research and has proposed for FY 2020, will be beneficial to further geothermal development in Idaho.

Q2. You highlighted various research initiatives that are currently taking place at the Department. For example, the FORGE initiative. What role do the National Labs – including the Idaho National Lab – play in these efforts?

A2. The DOE National Laboratories maintain core competencies that span across the geothermal spectrum and are critical to the success of GTO's R&D programs. Historically, GTO has executed appropriated funding at a roughly 50-50 split between National Laboratory research and development (R&D) and R&D conducted by academia and the private sector.

The National Laboratories are engaged in all of GTO's program areas, with INL participating in FORGE, EGS Collab, the proposed Advanced Energy Storage Initiative, and Play Fairway Analysis. INL also leads the Geothermal Student Competition, an annual competition designed to encourage students to get engaged with geothermal data and communications.

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Questions from Chairman Lisa Murkowski

<u>Question 1</u>: Geothermal energy must go through the NEPA process multiple times for any development on public lands, which can result in a total development time of up to 10 years. Many of the low environmental impact exceptions to NEPA that encourage oil and gas exploration do not apply to geothermal. Is the Bureau of Land Management (BLM) examining opportunities to develop administrative categorical exclusions for geothermal energy? How can we further reduce the regulatory barriers?

Currently, each geothermal project on public lands requires a separate environmental review under the NEPA at both the drilling stage, such as exploration wells to test the resources, and when the resource is to be utilized. According to the Department of Energy, improving the efficiency of the regulatory process for the drilling of resource confirmation wells could reduce the administrative costs of geothermal development on public lands and spur new development. The current policy for oil and gas employs categorical exclusions for various drilling and field expansion situations that were authorized by federal legislation. The BLM is exploring opportunities to streamline the NEPA and other geothermal permitting processes to alleviate the delays caused by multiple environmental reviews.

<u>Question 2</u>: While enhanced geothermal technologies may allow development anywhere, 90 percent of current geothermal resources are on public lands, making near-term geothermal development largely dependent on federal policy.

- **How is the BLM working to make geothermal development easier?**

Secretary's Order 3355 directs the BLM to streamline the NEPA review for all energy development on public lands. This Secretary's Order directs the BLM to keep Environmental Impact Statements (EISs) under 150 pages and, within one year of the issued Notice of Intent, to publish the EIS. In addition, in recent years, the BLM has offered geothermal leases via online auctions thus providing the opportunity for greater bidder participation.

- **What are lessons that can be transferred from oil and gas development on public lands to geothermal development?**

For oil and gas, the BLM has marshaled teams of subject matter experts to review applications expeditiously. Should the volume of geothermal applications increase, such a strategy could also be used to more efficiently and timely process geothermal applications. The categorical exclusions established by the Energy Policy Act of 2005 for oil and gas exploration have helped to expedite oil and gas exploration, and may offer similar efficiency for geothermal.

<u>Question 3</u>: The final Programmatic Environmental Impact Statement (EIS) for Leasing of Geothermal Resources in Eleven Western United States and Alaska, Including Proposed Amendments to Selected Land Use Plans, published in 2008, included a reasonable foreseeable development (RFD) scenario that was developed to predict future geothermal development trends.

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The RFD scenario estimated a potential for 5,540 megawatts (MW) of new electric generation capacity from 111 new geothermal power plants in the 11 Western States and Alaska by 2015. It also estimated an additional 6,600 MW from another 133 plants by 2025. In fact, in 2008 BLM had the largest geothermal lease sale in its history bringing in a record $28.2 million for a total of 105,211 acres. As of today, only nine new plants are operational since 2008 with a total combined MW capacity of 345 – none are in Alaska.

- **Please explain how the programmatic EIS intended to facilitate easier leasing.**

The establishment of a programmatic EIS sets standardized frameworks for the processing of environmental reviews across BLM States and districts. This consistency makes it easier for private operators to develop plans that do not have to be tailored to each region or State.

- **Do you think that it achieved its intended effect?**

The 2008 programmatic EIS continues to be implemented consistently and there have been no major legal challenges to it since it was finalized. Without a programmatic EIS, a more extensive and time-consuming NEPA process would be required for each lease sale, so the programmatic EIS has met its goal in facilitating the expeditious processing of geothermal leases.

- **Do you think any changes are necessary, and if so what?**

The BLM is exploring opportunities to streamline the NEPA reviews and other permitting processes. The BLM will continue to look for innovative solutions to reduce regulatory burdens on the development of domestic energy and its delivery to the America people.

<u>Question 4</u>: **On the BLM Geothermal Energy website five projects are listed as pending, all within the State of Nevada. Two projects require baseline studies, one a project redesign, another is pending environmental assessment, and the final is a competitive lease sale. All anticipate approvals by 2021. It appears that the last approved project that is currently operational was Tungsten Mountain, NV in 2016. Why it is taking so long to get these plants operational?**

The BLM website will continue to be updated to include the latest information regarding pending and approved projects. As of July 5, 2019, there are 6 pending projects.

Approval from the BLM is not the only factor in putting a new geothermal power plant on line. State regulations, market demand, infrastructure development, and litigation from outside groups all cause delays. For example, the environmental assessment for one geothermal project, the Dixie Meadows Utilization Plan, went out for public comment in May of 2017. However, because an emergency listing petition from the Center for Biological Diversity regarding the Dixie Valley toad species remains unresolved by the U.S. Fish & Wildlife Service, the permitting and construction of that facility has been delayed by two years thus far.

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Question 5: BLM recently released a geothermal online lease sale notice for 21 parcels in White Pine County, NV that is scheduled for this September.

- **Is BLM making any changes to streamline the permitting process for this lease sale?**

BLM Nevada has a streamlined geothermal leasing process in place, which follows the Information Memorandum *Updated Oil and Gas Leasing Reform – Land Use Planning and Lease Parcel Reviews* (IM 2018-034) to the extent possible under the Geothermal Steam Act, including annual lease sales in 2016, 2017, and 2018. The September 17, 2019 lease sale hosted by the NV State Office, which will be conducted via online auction, contains 142 parcels totaling approximately 400,000 acres in multiple counties across the State; that is, far more than just the 21 parcels in White Pine County, NV. Three Environmental Assessments and two Determinations of NEPA Adequacy (DNAs) have been prepared for this lease sale, and the Notice of Competitive Lease Sale was posted on the BLM website on August 2, 2019.

- **Are the potential leases currently able to conduct casual use exploration in this area?**

According to the 43 CFR 3250 regulations, anyone may request BLM approval to explore any BLM-managed public lands open to geothermal leasing, even if the lands are unleased or leased to another entity. To do so, it is necessary to submit a Notice of Intent (NOI) to Conduct Geothermal Resource Exploration Operations, Form 3200-9. If the proposed activities are determined to be limited to casual use, then the BLM will deny the NOI as unnecessary, and casual use exploration could proceed without further review or approval by the BLM. If the impacts of the proposed exploration operations are deemed to exceed casual use, and include surface disturbing geophysical activities, such as vibroseis surveys or temperature gradient hole drilling, the proposal would be reviewed according to the 43 CFR subpart 3251 regulations. NEPA analysis would be conducted and the NOI permit would be approved, denied, or approved subject to conditions of approval. A lease is not required to conduct exploratory geophysical operations through the NOI process under the 43 CFR 3250 regulations, but a lease is required to drill for or to utilize geothermal resources, which includes "resource confirmation" drilling intended to make direct contact with or directly test geothermal resources.

- **When determining lease areas, are you ensuring that these locations have access to a power grid?**

Although the BLM can self-nominate lands for a lease sale, this is rarely done because the geothermal industry knows better which areas have the best potential for the development of geothermal energy. Thus, prospective geothermal producers provide expressions of interest for lands that they are interested in leasing for geothermal development. Factors such as the accessibility of infrastructure and other considerations related to getting the energy to market are the responsibility of the private developer of any potential geothermal project on public lands. The BLM ensures that any lands nominated or projects proposed meet all appropriate regulatory requirements and conforms to applicable BLM policy and legal requirements.

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Questions from Chairman Lisa Murkowski

Question 1: *Oil and gas development has moved at a rapid pace since the shale boom. Many of the new technologies pioneered for shale development could be used for geothermal as well. What are the best ways the Department of Energy and the Department of the Interior could further foster cooperation between the oil and gas and geothermal energy sectors?*

The shale boom example, and others, demonstrate the agility of the oil and gas industry to do what was previously thought impossible. It is an industry that is highly knowledgeable in accessing resources underground—from exploration through well drilling and increasing recovery. Therefore, the strongest synergies between oil and gas and geothermal are in the subsurface: accessing the heat. The right combination of robust, sustained early-stage R&D support and incentives led to tremendous success in technology cost reduction and market deployment for wind and solar. Lessons from their success can drive similar progress for geothermal energy.

From the R&D perspective, oil and gas players have suggested that **robust, sustained R&D support** will help to transition drilling technologies to harder rocks and hotter temperatures, and transition reservoir creation technologies to enhanced geothermal system (EGS) applications. R&D organizations in the petroleum industry have suggested that R&D budgets needed for development of new downhole tools grow exponentially with temperature. Identification of larger markets with multipurpose needs for new technologies will be critical. For example, the market for high-temperature power electronics in general has benefits in vehicle, aviation, and military applications. Recent research in these industries has allowed high-temperature electronics capabilities to soar and prices to decline; application to oil and gas technologies is the next step in advancing tool capabilities for geothermal use. Materials for harsh environments are needed not only in geothermal, but in chemical manufacturing and vehicles. These larger market demands can help to spread R&D costs across multiple industries and drive down component commercialization costs for all.

Oil and gas service companies (e.g., Halliburton, Baker Hughes) have suggested that it is challenging to justify commercialization of new technologies for geothermal because of the small market; however, this becomes a chicken or the egg challenge because these new tools will drive down costs and create a larger market. **Commercialization support and detailed analyses that identify larger markets for commercialization** of these tools can help to make the case in the near term. For example, the market for hard-rock drilling goes beyond geothermal, but also has applications in mining and in hard-rock oil and gas plays located in deepwater offshore Brazil, Kazakhstan, West Africa, China, and Vietnam. There are also scattered plays across the continental United States, such as the Powder River Basin (Montana, Wyoming). Similarly, low-cost, high-temperature downhole tools would have applicability not only in geothermal, but also in many high-temperature oil and gas plays located in the Gulf of Mexico (especially deepwater), the North Sea, Southeast Asia, Africa, and the Middle East. This type of support can also mitigate against oil and gas market volatility by providing alternative markets for these services.

A second way to drive commercialization of technologies is by **creating a stronger market for geothermal deployment**. Oil and gas operators are increasingly interested in investing in renewables. Government policies and incentives created a market for wind and solar technologies that drove new businesses into the market, watching deployment soar in years with incentives, significantly drop off when incentives ended, and pick back up again when incentives were reinstated.[1] This demonstrates the need for incentives early on while new technologies are being developed and adopted, eventually driving down costs to the point where they are today—wind and solar are now competitive, multibillion-dollar economies for the United States, even without incentives.

The *GeoVision* study showed the potential for cost reduction for geothermal, and the market growth possible with these lower costs. Model runs published in a supporting task force report[1] suggest that incentives could have a

[1] Young, K., A. Levine, J. Cook, K. Hernandez, J. Ho, and D. Heimiller, 2019. "Crossing the Barriers: An Analysis of Market Barriers to Geothermal Development and Potential Improvement Scenarios." *GRC Transactions*, Vol. 41, 2017. http://pubs.geothermal-library.org/lib/grc/1033868.pdf

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similar impact for geothermal as they had for wind and solar, driving deployment—and in doing so, driving new players like oil and gas into the market and spurring innovation and cost reduction for geothermal to become independently cost competitive.

Question 2: *America's growing reliance on foreign lithium for use in battery technology is an area of concern, but there is the potential to coproduce lithium from certain geothermal energy resources.*

- *How does this work, and what is the total potential relative to U.S. lithium consumption?*
- *Could the co-production of resources potentially lower the cost of geothermal energy, or of lithium?*

Technologies

There are several potential technologies being developed to mine lithium from geothermal brines, including **evaporation, sorption, precipitation, and electrical and membrane separation**. Each has its pros and cons, and new, more efficient, lower-cost technologies are being explored. Some of these extraction technologies (e.g., for silica and lithium) have been successfully tested with pilot-scale facilities in the United States.

Research

The current issue in deploying technologies to recovery lithium from geothermal brines is in figuring out how to move one or more of the technologies over the so-called R&D "valley of death" from early-stage research to commercialization. Developing standards for reservoir and process modeling and lab-scale testing to compare techniques (while protecting businesses' intellectual property) can help to overcome challenges and increase bankability. These analyses would evaluate things such as material and infrastructure costs, by-products, environmental impacts, energy costs, efficiency, scalability, adaptability, and quality of end products. Also needed are field demonstrations validating technology scalability (for investors) and quality of end products (for offtakers).

Available Resources

Global lithium production currently comes from South America (Argentina, Chile), China, and Australia. Per the U.S. Geological Survey Mineral Commodity Summary 2019[2]:

U.S. lithium **imports** (2018)	4,000 tons
U.S. lithium **exports** (2018)	1,600 tons
U.S. lithium **production** (2018)	withheld
Identified lithium **resources** in the United States *from continental brines, geothermal brines, hectorite, oilfield brines, and pegmatites*	6,800,000 tons *Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence*
Lithium **reserves** in the United States	35,000 tons *That part of the reserve base that could be economically extracted or produced at the time of determination*

National Renewable Energy Laboratory (NREL) analyses (such as the "2015 Research Highlights"[3] from CEMAC) suggest that the market for automotive lithium-ion batteries are growing at a rapid rate, doubling between 2015 and 2020. Though estimates vary, most studies suggest that the amount of lithium in geothermal brines in the Salton Sea area in California alone could meet the current U.S. demand. Lithium exists in geothermal brines throughout the west, however, and could meet the growing demand for lithium with domestic resources.

[2] https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/mcs2019_all.pdf
[3] https://www.nrel.gov/docs/fy16osti/65312.pdf

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Economics
The Ohaaki geothermal plant in New Zealand[4] isolates and markets the silica in its brine, and is an example of mineral recovery improving plant economics. Developers in the Salton Sea, where lithium concentrations are highest, estimate that the value of the lithium in their brines is in the billions of dollars annually and could be worth **5x their annual profits from selling electricity alone.** Projected costs of lithium extraction from brines in the Salton Sea are expected to be about average—slightly higher than South American lithium, but lower than lithium from Australia and China, particularly if commercialized within the next 5 years.

Question 3: *Geothermal energy must go through the NEPA process multiple times for any development on public lands, which can result in a total development time of up to 10 years. Many of the low environmental impact exceptions to NEPA that encourage oil and gas exploration do not apply to geothermal. How is a "resource confirmation" categorical exclusion different from typical drilling exploration categorical exclusions and why is it needed?*

Resource Confirmation vs. Exploration Categorical Exclusion
It really comes down to regulatory terminology, but we are talking about the same thing: a categorical exclusion that allows developers to drill into the reservoir and confirm the presence of a resource for the purposes of reducing risk and obtaining project financing. Geothermal resource confirmation generally requires drilling at least two (preferably three) successful wells (6–8 inches in bottom-hole diameter) into the resource to conduct the necessary tests, including an interference test.[5] Developers often call this exploration drilling.

But federal regulations define:

- Geothermal "Exploration Operations" (§ 3200.1) to expressly exclude the direct contact and testing of geothermal resources, though it does allow for drilling thermal gradient holes as long as they do not touch the reservoir.
- "Drilling Operations," however, describe wells into the reservoir and require a Geothermal Drilling Permit.

Discussions with the Department of Interior solicitor revealed that industry requests for a categorical exclusion for "exploration wells" to confirm the reservoir conflict with the regulatory definition of "exploration." In the discussions, we identified that should a categorical exclusion be developed, it would be clearer to define a new class of wells—something between "exploration" and these "Geothermal Drilling Permits" that allows for "resource confirmation." This would involve drilling two or more wells into the reservoir for the express purpose of testing and confirming the resource.

Referring to this activity as resource confirmation rather than exploration avoids the confusion caused by the difference in the way the industry and the federal regulations define exploration.

Why is a categorical exclusion needed?
Geothermal has protracted regulatory timelines. The extensive timeframe needed for geothermal development is because of the series, rather than parallel nature of geothermal permitting and project development as well as the disparity between geothermal permitting requirements versus those for similar activities for other industries. Because of the current regulatory scheme and the phased development approach used by most geothermal project proponents, projects may require compliance with the National Environmental Policy Act of 1969 (NEPA) numerous

[4] http://www.thinkgeoenergy.com/silica-extraction-firm-geo40-receives-funding-for-expansion-plans/
[5] For more information about technical needs for resource confirmation, see Beckers, K. and K. Young. 2018. "Technical Requirements for Geothermal Resource Confirmation." *GRC Transactions*, Vol. 42, 2018. (attached)

times over the course of project development (e.g., during land use planning, leasing, exploration, wellfield development, power plant and transmission siting, and project enhancement/expansion).[6] Historically, depending on the level of NEPA analysis required (Determination of NEPA Adequacy, Categorical Exclusion, Environmental Assessment, Environmental Impact Statement), the review may take between 1 month and 3 or more years. As a result, under the current approach, a geothermal project may take 8 years to develop.[7]

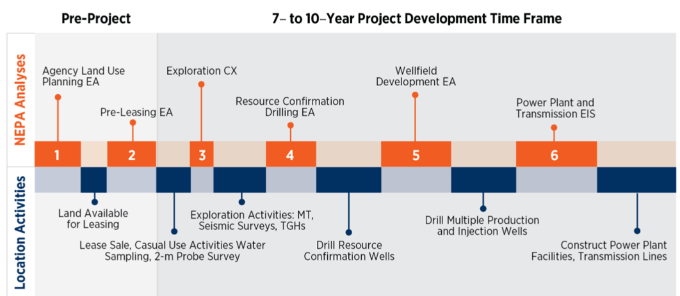

Figure 1. Example timeline of a geothermal project on federal lands, illustrating that a single location could trigger NEPA analyses six separate times. (Source: Young el al. 2014[8]). EA = Environmental Assessment, EIS = Environmental Impact Statement, CX = Categorical Exclusions, MT = magnetotelluric, TGH = temperature gradient hole

Why target resource confirmation?

Similar to oil and gas, geothermal development has high upfront risk because (1) the resource quality is unknown prior to resource confirmation, and (2) resource confirmation (drilling) is expensive. Figure 2 illustrates both the upfront risk and the sharp drop in risk after drilling the resource confirmation wells. Protracted permitting timeframes during resource confirmation further compound this risk. Permitting resource confirmation via categorical exclusion (~1–2 months) rather than an environmental assessment (~10 months–2 years) could help to significantly reduce upfront cost and risk.

[6] Young, K., K. Witherbee, A. Levine, A. Keller, J. Balu, and M. Bennett. 2014. "Geothermal Permitting and NEPA Timelines." *GRC Transactions*, Vol. 38, 2014. http://pubs.geothermal-library.org/lib/grc/1033639.pdf
[7] Young, K., A. Levine, J. Cook, D. Heimiller, and J. Ho. 2019. *GeoVision Analysis Supporting Task Force Report: Barriers. An Analysis of Non-Technical Barriers to Geothermal Deployment and Potential Improvement Scenarios*. NREL/TP-6A20-7164. https://www.nrel.gov/docs/fy19osti/71641.pdf
[8] Young, K., K. Witherbee, A. Levine, A. Keller, J. Balu, and M. Bennett. 2014. "Geothermal Permitting and NEPA Timelines." *GRC Transactions*, Vol. 38, 2014. http://pubs.geothermal-library.org/lib/grc/1033639.pdf

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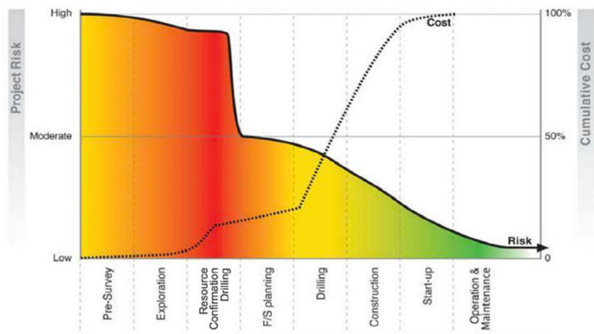

Figure 2. Geothermal project development risk profile (Source: World Bank) showing high risk associated with resource confirmation drilling and the sharp drop in risk after drilling the resource confirmation wells

Is there precedent?

Under EPAct 2005 Section 390, oil and gas operations using similar drill rigs and drilling to similar depths received a statutory categorical exclusion from Congress for activities similar to resource confirmation. The Bureau of Land Management (BLM)-funded NREL analysis[9] of NEPA documents and related discussions with geothermal stakeholders resulted in a finding that geothermal resource confirmation drilling does not have a significant impact on the environment and could therefore be considered for development of a categorical exclusion. One noted benefit of statutorily established categorical exclusions (akin to those for oil and gas) is the ability to apply these across multiple federal departments (e.g., Department of the Interior, Department of Agriculture), whereas administrative categorical exclusions established at the departmental level may lack consistency across departments/agencies.

In addition, the Energy and Natural Resources Act of 2017 (115 S. 1460) included a categorical exclusion from NEPA for "Geothermal Test Projects" (Sec. 3012). This proposed legislation is generally consistent with NREL's technical and environmental analysis concerning the requirements for (and related impact of) geothermal resource confirmation drilling, though the bill's proposed 90-day provision to conduct all exploration testing may not be adequate.[10]

What impact could it have?

Reducing these timeframes alone could double geothermal deployment by 2050 without any new technology. NREL's *GeoVision Analysis Supporting Task Force Report: Barriers* analyzed non-technical barriers to geothermal deployment and potential improvement scenarios. In part, this report highlighted that reducing project development timelines from 8 years to 4 years can increase resource discovery and (primarily because of improved financing costs) more than double geothermal deployment over the Business-as-Usual scenario by 2050, resulting

[9] Levine, A., N. Taverna, and K. Young. 2018. "Environmental Concerns and Mitigation Associated with Geothermal Resource Confirmation Drilling Activities." *GRC Transactions*, Vol. 42, 2018. https://www.geothermal-library.org/index.php?mode=pubs&action=view&record=1033934

[10] For more information about technical needs for resource confirmation, see Beckers, K. and K. Young. 2018. "Technical Requirements for Geothermal Resource Confirmation." *GRC Transactions*, Vol. 42, 2018. (attached). For more information on the environmental impacts associated with resource confirmation, see Levine et all 2018. "Environmental Concerns and Mitigation Associated with Geothermal Resource Confirmation Drilling Activities."

in an additional 6.7 gigawatts of geothermal deployment[11], as shown in Figure 3. Categorical exclusions are one way to reduce regulatory timeframes and significantly reduce project cost and risk.

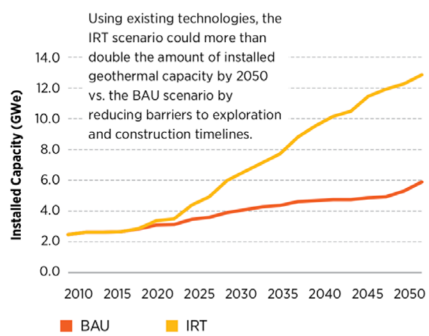

Figure 3. GeoVision's *Improved Regulatory Timeline (IRT) scenario results and comparison to the Business-as-Usual (BAU) scenario for conventional hydrothermal resources. The IRT scenario modeled the impact of 4-year regulatory timelines against the current average BAU regulatory timeline of 8 years and shows total deployment would reach nearly 13 gigawatts-electric by 2050.*

Question 4: *Please elaborate on the concept of a dedicated geothermal team at the Bureau of Land Management, and do you have any examples of similar dedicated teams that could be used as a model for geothermal energy?*

NEPA is a process—no one thing causes delays in all projects. The question is, how do we improve process efficiencies? A geothermal subject matter expert team is one concept that could improve efficiencies.[12]

A Geothermal Team Would:	Description:	Impact:
Allow BLM to keep a staff trained up on geothermal and not be as diluted	Currently at field offices, one person handles many topics: sand and gravel, oil and gas, mining, geothermal, and so on). A dedicated expert team would allow specialization helpful for permitting geothermal projects.	Develop efficiencies by repetition and development of expertise
Allow for efficient use of BLM resources by reducing duplication of staff capabilities	Instead of training each person in several areas, train a few on geothermal only for expert team. Field office staff would remain experts on local resources related to permitting.	Save money in annual training and allow more on-the-job experiential training through increased exposure
Allow for less competition for staff time	Because of the team structure, redundancy in capabilities allows for backup during staff absence because of training, leave, and other project obligations.	Create consistency in timelines and permitting practices

[11] Young, K., A. Levine, J. Cook, D. Heimiller, and J. Ho. 2019. *GeoVision Analysis Supporting Task Force Report: Barriers. An Analysis of Non-Technical Barriers to Geothermal Deployment and Potential Improvement Scenarios*. NREL/TP-6A20-7164. https://www.nrel.gov/docs/fy19osti/71641.pdf
[12] Levine, A., K. Young, and K. Witherbee, 2013. *Coordinating Permit Offices and the Development of Utility-Scale Geothermal Energy*. GRC *Transactions*, Vol. 37, 2013. http://pubs.geothermal-library.org/lib/grc/1030662.pdf

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Allow for development of instruction memorandums, best practices, pre-leasing Environmental Assessments and programmatic Environmental Impact Statements, accountability in permitting, and even support tools.	Example: Well-designed and implemented workflow management software tools: Studies of workflow management software tools have shown: ○ Reduce costs for processors (i.e., agencies) by 30%–40% ○ Increase compliance by 40%–50% ○ Reduce errors and process timeframes.	Foster continual dedication to process improvement and efficiency.

FEDERAL EXAMPLES:

- **Pilot Project to Improve Federal Permit Coordination [for oil and gas permitting] (EPAct 2005 § 365)** Included DOI agencies, U.S. Forest Service, EPA, and Army Corps. Consultation timeframes went from 7–9 months down to weeks/days.
- **Establishment of the National Renewable Energy Coordination Office. Updated.** (**IM 2011-072)**

STATE EXAMPLE:

Though this is a state example, the concept applies and is a fantastic example of how coordination across multiple agencies helps with efficiency.

- **Alaska's Office of Project Management and Permitting**
  - Established in the early 1990s
  - Alaska Department of Natural Resources used for coordinating the permit process for large-scale natural resource development projects
  - Does not remove authority from any entity, but instead works to reduce duplication in effort on the part of the agencies, reduce information supplied on the part of the developer, coordinate timelines, and improve overall project efficiency
  - Originally developed in response to the mining industry; it was so successful that it was expanded to include oil and gas, railroads, hydropower, and roadway projects.

Questions from Senator James E. Risch

Question 1: *Idaho has been a world leader when it comes to developing geothermal resources and demonstrating new technologies. In the GeoVision report, you note that technology improvements could go a long way in deploying additional geothermal resources. Can you please explain what technologies you think would be the most beneficial in developing additional geothermal resources in Idaho?*

Idaho certainly is a world leader in geothermal; Boise's district heating system is the oldest geothermal district heating system in the world, opening in 1860 and still in operation today more than 150 years later. From heating buildings to sidewalk snowmelt and warming recreational pools, Boise's geothermal heating utility is innovative, renewable, and sustainable. Idaho has more than 70 direct-use geothermal installations in the state, including aquaculture, greenhouses, resorts, and district heating.[13] The state also has a 15-megawatt (MW) power plant at Raft River, with an additional 50 MW in development.[14]

[13] Snyder, D., K. Beckers, and K. Young, 2017. "Update on Geothermal Direct-Use Installations in the United States." PROCEEDINGS, 42nd Workshop on Geothermal Reservoir Engineering, SGP-TR-212. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2017/Snyder.pdf
[14] Matek, B., 2016. "2016 Annual U.S. & Global Geothermal Power Production Report." Geothermal Energy Association. http://geo-energy.org/reports/2016/2016%20Annual%20US%20Global%20Geothermal%20Power%20Production.pdf

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According to a recent Idaho Office of Energy Resources report,[15] the state produces approximately 27% of the total energy it consumes, so increasing use of local geothermal resources means more domestically produced energy and fewer imports. The U.S. Geological Survey identified more than 300 MW of identified hydrothermal, 1.8 gigawatts (GW) of undiscovered, and 68 GW of EGS potential.[16] A recent Geothermal Energy Association publication[17] identified that this was enough to provide as much as 44% of the electricity demand and 100% of the heating demand.

In Idaho, and throughout the United States, **reducing drilling costs** can have significant impact in improving project economics for both electricity and direct-use geothermal projects. The cost of geothermal development is about 50% on the surface (e.g., heat or power plant, piping) and 50% below ground (e.g., drilling and well construction costs). Many of the below-ground costs are borne at the front end of the project development, which can make project financing challenging. Target areas for research and industry adoption include:

1. Drilling efficiency, including development of low-cost, high-temperature power electronics
2. Technologies that reduce drilling rates, such as energy drilling technologies, and
3. Low-cost materials for well construction.

The second research area is focused on **accessing geothermal anywhere**. Today, geothermal projects are developed at locations where a natural heat exchanger exists, including both fractures and fluid to transport the heat to the surface. There are two challenges to this model, however. First, these systems exist in a limited number of places. Second, finding these sites requires sophisticated exploration techniques, which are still sometimes unsuccessful.

The *GeoVision* suggests that shifting this paradigm is the key to unlocking vast geothermal potential. If instead of looking for natural heat exchangers, new technologies instead allow us to create our own, we remove not only the limited nature of the resource, but also many of the challenges associated with exploration. EGS research, such as that being conducted by the Department of Energy at their FORGE site, focuses on stimulating the subsurface to open the natural fractures in the rock. Other technologies use horizontal drilling techniques to drill boreholes between wells to circulate fluids. Advancing these technologies to commercial feasibility, understanding their scalability, and reducing deployment costs are critical to advancing the "geothermal anywhere" goal, allowing geothermal to be developed anywhere in the state of Idaho—and throughout the United States.

Question 2: *You highlighted various research initiatives that are currently taking place at the Department. For example, the FORGE initiative. What role do the National Labs – including the Idaho National Lab – play in these efforts?*

The Department of Energy's national laboratories are a core engine of the U.S. national innovation system. The labs conduct credible, objective analyses (such as the task force reports that supported the *GeoVision* study) that inform technology innovation options and program, policy, and investment decisions, leading to more resilient, reliable, and efficient energy systems. The labs aim to increase understanding of geothermal energy technologies, policies, markets, resources, and infrastructure to address U.S. economic, security, and environmental priorities.

Robust and sustained commitment to federally funded geothermal research by national labs is focused on

[15] Idaho Governor's Office of Energy Resources, 2018. *Idaho Energy Landscape*. https://oemr.idaho.gov/wp-content/uploads/3.6.18-Energy-Landscape-2018.pdf
[16] Williams, C., M.J. Reed, R.H. Mariner, J. DeAngelo, S.P. Galanis, Jr., 2008. *Assessment of Moderate- and High-Temperature Geothermal Resources of the United States.* USGS Fact Sheet 2008-3082. https://pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf
[17] Geothermal Energy Association. "Geothermal Energy Potential—State of Idaho." http://geo-energy.org/pdf/Guides_2015/Idaho.pdf

foundational science, integration of applied science, and transition to commercialization to reduce drilling costs and allow for geothermal anywhere, which can lead to a step change in unlocking the potential $200 billion investment opportunity for geothermal in the United States.

Foundational science and early-stage research occur throughout these research efforts. The insights we gain from science inform our understanding of the essential materials—such as those for high-temperature downhole electronics, materials, and tools—all the way through to the R&D that deploys the first demonstration. There is no line where science ends, and each stage is critical to commercialization and adoption of these technologies.

A collaboration of eight national labs (including NREL and Idaho National Laboratory) have been working on demonstrating and modeling EGS technologies at the Sanford Underground Research Facility (SURF) at Homestake Mine in South Dakota. This initiative facilitates direct collaboration between reservoir modelers, experimentalists, and geophysicists in developing and implementing wellfield characterization and development, monitoring, and stimulation methods. Four of the national labs (including NREL and Idaho National Laboratory) are key members of the FORGE operational team, and other labs are likely to play a significant role in the R&D conducted at the field laboratory over the next 5 years.

Ideally, national labs first answer the fundamental questions of science, then forge these new insights into workable concepts for breakthrough technologies. And, finally, we work in partnership with industry to reduce the technical risk of implementing the new technologies in the field—up to the point where private industry fully takes over and makes the investments needed for commercialization and deployment. Partnerships with industry are a key step in understanding R&D needs and moving new technologies toward adoption. This is why partnerships are an essential part of how NREL operates.

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APPENDIX B

Technical Requirements for Geothermal Resource Confirmation

Koenraad F. Beckers and Katherine R. Young

National Renewable Energy Laboratory
***corresponding author: koenraad.beckers@nrel.gov**

Keywords

Geothermal resource confirmation, geothermal wells, well pads, surface disturbance, well tests

ABSTRACT

In 2017–2018, the Bureau of Land Management's Renewable Energy Coordination Office, through its Geothermal Program, funded the National Renewable Energy Laboratory (NREL) to analyze technical and environmental considerations related to geothermal resource confirmation drilling. NREL solicited input from a group of technical and environmental experts in the geothermal industry, along with analyzing National Environmental Policy Act of 1969 (NEPA) documentation for previously approved projects. The collected data and analysis will be used by the Bureau of Land Management to examine the possibility of developing a new classification of wells and/or expediting the NEPA compliance process, which could potentially reduce permitting and regulatory compliance timelines when compared to the current process for obtaining a geothermal drilling permit for resource confirmation drilling activities.

This paper provides a summary of the technical requirements for confirming a geothermal resource. The analysis showed that confirming a geothermal resource requires confirming reservoir temperature, chemistry, permeability, and flow rate. Obtaining these data requires drilling at least two—preferably three—successful wells into the resource to conduct the necessary tests, including an interference test. Bottom-hole well diameters of at least 6" to 8" (0.15 to 0.2 m) are needed to limit the wellbore frictional pressure drop to effectively perform well flow and interference tests. Drilling these wells requires a drill rig with a mud pump and derrick capable of holding three drill pipes. This type of rig requires a minimum well-pad size of 2.5 acres (10^4 m^2) including surface area for a 1 million-gallon (3.8 million-liter) pit. Up to 15 acres (5×10^4 m^2) of total surface disturbance are needed for developing access roads and well pads to drill a total of three to five wells.

1. Introduction

The Bureau of Land Management's Renewable Energy Coordination Office, through its Geothermal Program, has funded the National Renewable Energy Laboratory (NREL) to analyze technical and environmental topics related to geothermal resource confirmation. Geothermal drilling has high up-front costs and high potential risk of unsuccessful exploration efforts, making it difficult to secure financing for these projects before the resource has been confirmed. This analysis looks at the possibility of developing a new classification of wells and/or expediting National Environmental Policy Act of 1969 (NEPA) compliance that could potentially be permitted more quickly than the current process for obtaining a geothermal drilling permit (GDP) for resource confirmation drilling activities.

Confirming a geothermal resource is defined as obtaining sufficient subsurface information that proves with high probability that a resource of certain magnitude can be developed. When a resource has been confirmed, banks are willing to provide financing for further project development. The resource confirmation phase follows the resource exploration phase. Geothermal exploration uses various techniques—such as interpreting geologic maps, analyzing surface manifestations, conducting seismic and resistivity surveys, and drilling core holes—to find promising geothermal resources (Stober and Bucher, 2013; Glassley, 2014). Once a promising region has been identified, larger-size wells are drilled, and additional tests are conducted (as discussed in Section 4) to confirm the resource.

This paper summarizes the technical interviews, monthly calls, and in-person workshop dedicated to technical requirements. Section 2 provides the methodology for this project. Section 3 provides an overview of the different types of geothermal wells and discusses which ones are used during the resource confirmation phase. Section 4 lists the resource confirmation tests conducted; well, well pad, and surface disturbance technical requirements; and project time needed for the confirmation phase. A conclusion of the results is included in Section 5. A parallel paper focusing on environmental concerns and mitigation strategies related to geothermal resource confirmation is presented at this conference by Levine et al. (2018).

2. Methodology

NREL conducted a series of technical and environmental interviews with geothermal stakeholders (i.e., Geothermal Expert Team) to understand the minimum technical requirements for confirming a geothermal resource, the associated potential environmental concerns, and measures to mitigate these concerns. As a follow-up to the one-on-one interviews with geothermal stakeholders, NREL organized a series of monthly calls with the Geothermal Expert Team to gain consensus on the feedback documented as part of the one-on-one interviews. In addition, NREL held an in-person workshop open to the public in February 2018, inviting a broader industry audience, during the Stanford Geothermal Workshop in Palo Alto, CA. The "technical experts" on the Geothermal Expert Team had backgrounds in geothermal exploration, geothermal drilling, well design, reservoir engineering, and project development (see Section Acknowledgments).

3. Types of Geothermal Wells

Various types of geothermal wells exist, which are drilled for different purposes in a geothermal project, and they include different designs, dimensions, drilling times, drilling costs, and more. In collaboration with the Geothermal Expert Team, five main categories of geothermal wells were identified, based on the (original) objective of the well (see Table 1). Other classifications and labels exist—for example, an "observation well," which could fall under any of the well types 2 to 5 in our classification—but are not discussed further here. At a specific geothermal site, typically at least one of each of these well types are drilled: temperature-gradient holes and core holes during initial exploration, slim holes for obtaining additional subsurface data, standard-completion confirmation wells for well and interference tests to further characterize and confirm the resource, and eventually, standard-completion production and injection wells used for regular geothermal plant operation. As discussed in Section 4, the geothermal wells needed for geothermal resource confirmation need to have sufficiently large bottom-hole diameter—at least 6” to 8” (0.15 m to 0.20 m)—to allow reliable flow and interference tests. These wells are of type 4 or 5.

Table 1. Comparison of different geothermal well types. (T = temperature, P = pressure, and OD = outer diameter)

Well Type	1	2	3	4	5
Well Name	Temperature-Gradient Hole (TGH)	Core Hole *(into reservoir)*	Slim Hole *(into reservoir)*	Standard-Completion Confirmation Well	Standard-Completion Production/ Injection Well
Main Objective	Measure shallow temperature-by-depth profile	Obtain subsurface core samples	Penetrate reservoir to assess T/P, chemistry and geology	Conduct flow and interference test	Regular production/ injection
Data Obtained	T gradient, geology	T/P, chemistry, limited flow test, geology	T/P, chemistry, limited flow test, geology	T/P, chemistry, flow test, interference test, geology	T/P profiles, flow test, interference test, chemistry, geology
Range of Typical Measured Depth	150 to 500 ft (46 to 152 m) (up to 1,500 ft [457 m] in some areas)	1,500 to 5,000 ft (457 to 1,524 m)	1,500 to 5,000 ft (457 to 1,524 m)	up to 12,000 ft (up to 3,658 m)	up to 12,000 ft (up to 3,658 m)
Conductor Size	Typically N/A	Hole Diameter: 15–20″ (0.38–0.51 m) Casing OD: 9–14″ (0.23–0.36 m)	Hole Diameter: 15–20″ (0.38–0.51 m) Casing OD: 9–14″ (0.23–0.36 m)	Hole Diameter: 22–24″ (0.56–0.61 m) Casing OD: 16–20″ (0.41–0.51 m)	Hole Diameter: 30–40″ (0.76–1.0 m) Casing OD: 20–30″ (0.51–0.76 m)
Surface String Size	Typically N/A	Hole Diameter: 10–15″ (0.25–0.38 m) Casing OD: 6–10″ (0.15–0.25 m)	Hole Diameter: 10–15″ (0.25–0.4 m) Casing OD: 6–10″ (0.15–0.25 m)	Hole Diameter: 16–18″ (0.41–0.46 m) Casing OD: 13–16″ (0.33–0.41 m)	Hole Diameter: 20–30″ (0.51–0.76 m) Casing OD: 18–22″ (0.46–0.56 m)
Size of Final Cemented String	None (2″ [0.05 m]) blind tubing)	4–6″ (0.10–0.15 m)	4–6″ (0.10–0.15 m)	6–10″ (0.15–0.25 m)	8–18″ (0.20–0.46 m); most common: 9-5/8″ (0.24 m) and 13-5/8″ (0.35 m)
Final Hole Size	3–6″ (0.08–0.15 m)	<6″ (<0.15 m)	<6″ (<0.15 m)	6–10″ (0.15–0.25 m)	8–12″ (0.20–0.30 m)
Drilling Time	1–5 days	15–45 days	15–45 days	30–60 days	30–70 days
Cost Range ($US)	$20–150K	$0.5–2M	$0.5–2M	$2–6M	$3–10M
MW_e Potential	0	<2 MW_e	<2 MW_e	< 5MW_e	< 20 MW_e
Lead Time (Designing and Permitting)	1–3 months	4–8 months	4–8 months	5–10 months	9–12 months

4. Results

The Geothermal Expert Team stated that to confirm a geothermal resource, various tests are required (Section 4.1) to confirm temperature, pressure, flow rates, and more. To effectively execute the well flow and interference tests, a minimum number of wells of sufficiently large bottom-hole diameter is required (Section 4.2). Drilling these types of wells requires surface disturbance for access roads and well pads (Section 4.3) as well as a large enough drill rig and surface fluid storage (Section 4.4). The resource confirmation timeframe (Section 4.5) should be long enough to conduct all on-site activities (e.g., drilling, testing) and account for delays (e.g., securing financing, snow fall, species breeding season).

4.1 Tests

Confirming a geothermal resource requires conducting tests to confirm temperature, pressure, chemistry, flow rate, and near-wellbore and overall reservoir permeability. These tests include:

- **Pressure/Temperature (P/T) or Pressure/Temperature/Spinner (P/T/S) survey:** Gives pressure and temperature (the S – or "spinner" – can be used to identify reservoir feed zones).
- **Chemical analysis test:** Conducted on fluid samples to estimate corrosion, theoretical reservoir temperature, and presence of non-condensable gases.
- **Well flow test:** Provides flow rate (after steady-state condition is obtained) and, when combined with pressure, provides productivity index/injectivity index. This test typically takes two to seven days. In case of two-phase flow for flash plants, the individual gas and liquid volume rates are measured to estimate the vapor fraction. Data obtained from a well flow test give developers an initial indication of reservoir transmissivity and allow for assessing the drilling-mud damage to the formation (also called skin factor). Banks generally require developers to demonstrate that a certain percentage (in the United States, typically 50%) of the target production flow rate is obtained during the confirmation phase. Depending on the size of the plant considered, fulfilling this criterion requires drilling a certain number of wells (see Section 4.2.1).
- **Interference tests:** Provides average reservoir permeability and can take four to eight weeks. Fluid is produced from one well and reinjected into another well to measure connectivity between the two wells. Preferably, a third well is instrumented to obtain additional transient pressure data.

4.2 Wells

4.2.1 Number of Wells

One well penetrating the reservoir would be sufficient to obtain data on reservoir temperature, pressure, and chemistry. However, multiple wells are needed to conduct well flow and interference tests:

- **To conduct interference test:** An interference test is conducted to estimate overall reservoir permeability. For this test, a minimum of two—preferably three—flowing wells are needed. One well can only provide information on near-wellbore permeability.
- **To conduct well tests:** A percentage (typically 50% in the United States) of the total target production flow rate should be demonstrated during the resource confirmation

phase. For example, considering a 20 MW_e plant, and sizing wells for a 5 MW_e power output per well, two flowing production wells would be required. The percentage required can be 70% to 80% for other countries such as Chile, Peru, and Uganda.

Several project-dependent factors impact the final number of wells that are required for well and interference tests to confirm a geothermal resource:

- **Field history:** An established geothermal region (e.g., Iceland) or a brownfield with prior development may need fewer wells to confirm a resource than new regions (e.g., Cascades) and greenfields.
- **Project size:** For the same geothermal resource, a 50 MW_e plant would need more wells than a 10 MW_e plant.
- **Resource quality:** For the same plant size, a high-enthalpy resource (e.g., high-temperature two-phase liquid/vapor) would need fewer wells than a low-enthalpy resource (e.g., low-temperature single-phase liquid).
- **Company history:** Smaller, less established companies may need more wells to convince a bank that a resource has been confirmed than larger, more established companies.

4.2.2 Diameter of Wells

Sufficiently large wellbore diameters are required to limit the wellbore frictional pressure drops to effectively run well flow and interference tests. These tests depend on several parameters including well depth, resource temperature and pressure, and target plant size; but, in general, a bottom-hole diameter of 6" (0.15 m) or larger is desired.

A slim-hole well with 4.5" (0.11 m) bottom-hole diameter allows for collecting fluid samples for chemical analysis, measurements of resource temperature and pressure, and for conducting initial transient pressure tests. However, this diameter is normally too small to effectively flow fluid during well flow and interference tests. Some developers may use a slim-hole well as a monitoring well in combination with two other wells with larger-diameter holes for interference tests.

If large flow rates are targeted, a 6" (0.15 m) bottom-hole diameter may be too small for the criterion of a 50% target flow rate. However, this well can still be used to obtain data on near-wellbore reservoir permeability with a well flow test and overall reservoir permeability with an interference test. In the latter test, this well is likely used as an injection well with a larger bottom-hole diameter (e.g., 8.5") serving as a production well.

If developers have enough confidence in the resource, they may choose to drill full-size production and injection wells with bottom-hole diameters of 8" (0.2 m) or larger during the resource confirmation phase. These wells will eventually be used for fluid production and injection during regular plant operation. In some regions, 20 MW_e wells have been drilled with bottom-hole diameters larger than 10" (0.25 m), but this is not likely for most U.S. resources. If the well must be pumped, the well should be sized appropriately to fit the pump in the well. For example, installing a 12" (0.30 m) pump requires at least 13-3/8" (0.34 m) casing.

4.2.3 Fate of Standard-Completion Confirmation Wells

Standard-completion confirmation wells with sufficiently large bottom-hole diameter (generally 8" [0.20 m] or larger) can be used as regular production or injection wells during plant operation. If the bottom-hole diameter is only 6" (0.15 m), in some circumstances—e.g., the well is right next to a power plant and intersects a fracture—the well can be used as an injection or even a production well. However, in most cases, these wells serve as observation wells and the developer may drill a new larger-diameter production or injection well from the same well pad.

4.3 Surface Disturbance

Developers need about 15 acres (5×10^4 m^2) of surface disturbance to confirm a geothermal resource. Developers use this acreage for three to five well pads and access roads.

4.3.1 Size of Well Pad

The minimum well-pad size for drilling standard-completion confirmation or production/injection wells is 2.5 acres (10^4 m^2). This acreage is distributed as follows:

- **Drill rig and equipment:** 1.3 acres (5.3×10^3 m^2).
- **Sump:** 0.6 acres (2.4×10^3 m^2). This assumes a 1 million-gallon (3.8 million-liter) sump at 5 ft (1.5 m) depth. However, depth will depend on location (e.g., in Nevada, typically a shallow sump depth is required because of a shallow water table). Experts stated that sumps up to 10 ft (3.0 m) deep are not uncommon. This includes 1 to 2 ft (0.3 to 0.6 m) of freeboard required to prevent spills.
- **Equipment moving:** 0.5 acres (2.0×10^3 m^2).

4.3.2 Number of Well Pads

Wells need to be spaced a significant distance apart to effectively run an interference test. A minimum distance of 1,000 ft (305 m) has been put forward by the expert team, measured from where the wells touch the reservoir. Depending on how much deviation from drilling vertically, the surface spacing may be slightly different. Directional drilling is not common for early-phase exploration wells. Hence, for drilling three wells, three well pads are needed (for a total acreage of about 7.5 acres). Developers may only know after drilling each well where they want to locate the next well pad.

4.3.3 Access Roads

The ability to construct access roads is desirable to have freedom in selecting the drill sites. Access road dimensional requirements are as follows:

- **Minimum width:** 18 ft (5.5 m)
- **Average length:** 0.25 miles (0.4 km). One access road of 0.25 mile (0.4 km) length and 18 ft (5.5 m) width has an area of about 0.5 acres (2.0×10^3 m^2).
- **Strength:** Sufficient road strength to allow a semi tractor-trailer load that is overweight highway permittable.
- **Turnouts:** Periodic (every 0.25 mile [0.4 km]) turnouts to allow 2-way traffic are desirable. In theory, an 18-ft-wide road would not require turnouts, but they are still

preferred by developers to facilitate two large semi-trucks coming from opposite direction to pass each other.

Rubber mats can be used on access roads in muddy/swampy environments as a base for the first layer to keep that layer from sinking. However, the expense can go up quickly when placing mats on access roads, so they are rarely used.

4.4. Well Pad Components

4.4.1 Drill Rig

To drill a standard-completion confirmation or production/injection well—with bottom-hole well diameter of 6" to 8" (0.15 m to 0.2 m) or larger, and typical depth of 5,000 ft (1,524 m) or deeper—a drill rig is required that uses a mud pump and has a derrick capable of holding three drill pipes. This type of drill rig is not mobile and cannot be mounted on a truck. Instead, this drill rig is usually deconstructed into 20 to 40 truckloads (overweight highway permittable) and requires a sufficiently large well pad (see Section 4.3.1) and sufficiently wide and strong access roads (see Section 4.3.3). A helicopter drill rig can be used for drilling core-hole and slim-hole wells, but not for confirmation and production/injection wells.

4.4.2 Fluid Storage

Surface fluid storage is needed during drilling and for well flow and interference tests. A 1 million-gallon (3.8 million-liter) open pit is preferred. Pits are typically clay-lined. Surface fluid storage can also be obtained with temporary tanks (e.g., Baker tanks). However, tanks are more expensive, typically have less total volume, lines can freeze in winter, and they can be difficult to clean out. Tanks are generally only used in an emergency or when no pit excavation is possible or allowed.

During a long-term interference test, the pit acts as a storage buffer. All fluid produced from one well gets reinjected into the other well. Fluid is not being stored from several weeks of production, but rather, only from a few hours or days maximum. A 1 million-gallon (3.8 million-liter) pit can store 12 hours of produced fluid flowing at 1,360 gpm (86 L/s).

4.5 Timeline

The resource confirmation timeframe can take up to 5 years. The clock starts ticking when "a rock gets kicked," i.e., when the first access road or well pad starts getting built.

This timeframe encompasses:

- On-site activities: Up to 1.5 years
  - 60 to 100 days for preparing roads
  - 30 to 75 days per well for well drilling and well tests. The decision to drill each consecutive well is made after evaluating data from previous wells (i.e., wells are not drilled concurrently).
  - 1 to 2 months for interference test.

- Account for delays due to securing additional financing, negotiating power purchase agreement, avoiding species breeding season, snowfall, and more: Up to 3.5 years[1]

5. Conclusions

The results presented in Section 4 provide typical technical requirements for confirming a geothermal resource with focus on average-sized hydrothermal systems in the United States developed by established companies. Requirements may vary in other countries, for different companies, for different-type geothermal resources, and for different-size geothermal systems. The technical requirements are heavily governed by the need for performing effective well flow and interference tests. These tests require two to three wells penetrating the reservoir with large enough bottom-hole diameter. Drilling these wells requires large enough drill rigs and fluid storage, which translates into requiring access roads, large enough well pads, and a long enough timeframe.

For this study, geothermal resource confirmation was defined as obtaining sufficient subsurface data to state with high probability—e.g., with 90% confidence level (Sanyal and Morrow, 2010)—that a resource of certain magnitude (in MW_e) can be developed. At this point, banks are willing to provide financing for further project development. An exploration phase (using data obtained, for example, from geologic maps, seismic surveys, and core-hole drilling) precedes the confirmation phase. The data collected during both phases become input in geothermal reservoir and geothermal resource assessment models to quantify the developable resource size (Glassley, 2011; Grant, 2011). Other terminology has been used in the literature to describe the geothermal resource confirmation activities, e.g., production testing (Grant and Bixley, 2011), resource confirmation testing (Glasspey et al., 2008), test drilling (Gehringer and Loksha, 2012), and confirmation drilling (Sanyal and Morrow, 2010).

The conclusions of the analysis on technical requirements for geothermal resource confirmation are as follows (typical requirements with focus on the United States):

- **Tests:** Tests are conducted to confirm temperature, pressure, chemistry, permeability (near wellbore and overall reservoir), and flow rates.
- **Wells:** Up to three successful wells are required that penetrate the reservoir with bottom-hole diameter of at least 6"–8" (0.15–0.20 m). A large enough wellbore diameter is needed to effectively run well flow and interference tests.
- **Well pad components:** A drill rig with mud pump and derrick capable of holding three drill pipes is required. A sump with typical size of 1 million gallons (3.8 million liters) is required to store fluid during drilling and tests.
- **Surface disturbance:** Up to 15 acres (5×10^4 m^2) of surface disturbance are required for developing access roads and well pads. The type of rig needed requires a well-pad size of 2.5 acres (10^4 m^2).

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[1] Note: This includes additional time for smaller companies that may be slower in developing wells than more established companies.

- **Timeframe:** A resource confirmation timeframe of up to five years may be required to conduct all on-site activities (e.g., drilling, testing) and account for delays (e.g., securing financing, snow fall, species breeding season).

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Environmental Concerns and Mitigation Associated with Geothermal Resource Confirmation Drilling Activities

Aaron Levine, Nicole Taverna, and Katherine R. Young

National Renewable Energy Laboratory

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ABSTRACT

In 2017–2018, the Bureau of Land Management's National Renewable Energy Coordination Office, through its Geothermal Program, funded the National Renewable Energy Laboratory (NREL) to analyze technical and environmental considerations related to geothermal resource confirmation drilling. NREL solicited input from a group of technical and environmental experts in the geothermal industry, along with analyzing National Environmental Policy Act of 1969 (NEPA) documentation for previously approved projects. The collected data and analysis will be used by the Bureau of Land Management to examine the possibility of developing a new classification of wells and/or expediting the NEPA compliance process, which could potentially reduce permitting and regulatory compliance timelines when compared to the current process for obtaining a geothermal drilling permit for resource confirmation drilling activities.

1. Introduction

Geothermal drilling has high up-front costs and high potential risk of unsuccessful exploration efforts, making it difficult to secure financing for these projects before the resource has been confirmed. As a result, the Bureau of Land Management's (BLM) National Renewable Energy Coordination Office, through its Geothermal Program, funded the National Renewable Energy Laboratory (NREL) to analyze technical and environmental considerations related to geothermal resource confirmation drilling. For the purposes of this paper, geothermal resource confirmation drilling can be defined as "obtaining sufficient subsurface information that proves with high probability that a resource of a certain magnitude can be developed." When a developer has confirmed a resource, financial institutions are more willing to provide financing for further phases of project development, including the wellfield and power plant. The resource confirmation phase is distinct from and follows the resource exploration phase. Geothermal exploration uses various techniques—such as interpreting geologic maps, analyzing surface manifestations, conducting seismic and resistivity surveys, and drilling core holes and temperature-gradient wells—to find geothermal resources (43 CFR § 3250 et seq., Stober and

Bucher, 2013; Glassley, 2014). Once a promising region has been identified, larger-size wells are drilled, and additional tests are conducted (as discussed in Section 3) to confirm the resource.

This analysis reviews technical requirements and environmental concerns for geothermal resource confirmation that will be used by the BLM to examine the possibility of developing a new classification of wells and/or expediting National Environmental Policy Act of 1969 (NEPA) compliance. The new well classification or expedited NEPA compliance could potentially reduce permitting and regulatory compliance timelines when compared to the current process for obtaining a geothermal drilling permit (GDP) for resource confirmation drilling activities.

As part of this analysis, NREL conducted a series of technical and environmental interviews with geothermal stakeholders (i.e., Geothermal Expert Team) to understand the minimum technical requirements for confirming a geothermal resource, the associated potential environmental concerns, and measures to mitigate these concerns. As a follow-up to the one-on-one interviews with geothermal stakeholders, NREL organized a series of monthly teleconferences with the Geothermal Expert Team to gain consensus on the feedback documented as part of the one-on-one interviews. In addition, NREL held an in-person workshop in February 2018, inviting a broader industry audience, during the Stanford Geothermal Workshop in Palo Alto, CA. Following completion of the interviews, monthly teleconferences, and in-person workshop, NREL staff reviewed 21 NEPA documents (see Appendix A) related to geothermal exploration and resource confirmation drilling to capture additional insight on the environmental concerns and mitigation measures from previous projects.

The following sections provide a summary of: 1) our methodology, 2) background information on NEPA and BLM geothermal permitting requirements, 3) basic technical requirements to confirm a geothermal resource, and 4) environmental concerns and associated mitigation measures from expert interviews and previous NEPA documents.

2. Methodology

In 2017, NREL staff identified technical and environmental experts in the geothermal industry to provide insight on the technical requirements and associated environmental concerns for geothermal resource confirmation drilling. For additional information on the technical interview criteria and technical members of the Geothermal Expert Team, see Beckers and Young 2018.

Environmental experts interviewed included representatives from the U.S. Department of Energy, BLM, environmental consulting firms, and geothermal project developers. Interviews with environmental members of the Geothermal Expert Team posed a series of questions concerning environmental concerns and associated mitigation measures related to geothermal resource confirmation drilling for the following categories:

- Site Access (e.g., road construction, transportation of equipment and personnel to the drill site)
- Drill Site (e.g., well pads, sumps/pits, material storage)
- Water Quality, Discharge, and Use
- Safety
- Timing for Plugging and Abandoning a Well

- Noise, Light, and Proximity to Population.

Upon completion of the environmental interviews, NREL staff held a teleconference with the environmental members of the Geothermal Expert Team to review feedback provided during the one-on-one interviews and obtain consensus on environmental concerns and mitigation measures. The results of the interviews and teleconference were then presented to a broader audience during a workshop held in Palo Alto, CA, during the 2018 Stanford Geothermal Workshop. The workshop provided a venue to verify the previously collect data and seek additional input from an international audience of geothermal professionals. Following the Palo Alto workshop, NREL staff circulated a draft memo to attendees and Geothermal Expert Team members to confirm the provided input was captured accurately.

Upon completion of the geothermal stakeholder engagement, NREL reviewed and analyzed NEPA documents—Environmental Assessments (EAs) and Findings of No Significant Impact (FONSIs)—for geothermal exploration drilling/resource confirmation drilling projects. Previous geothermal projects were selected based a review of the Regulatory and Permitting Information Desktop (RAPID) Toolkit's Geothermal NEPA Database and input from the Geothermal Expert Team.

3. The National Environmental Policy Act of 1969

Signed into law on January 1, 1970, NEPA requires federal agencies or departments to consider the environmental impacts of all major federal actions significantly affecting the quality of the human environment (NEPA, Sec. 102). NEPA is predominately a procedural tool through which a federal agency or department considers the environmental impacts of a proposed action and analyzes alternatives to a proposed action before making a final decision.

Generally, federal agencies use three types of reviews for compliance with NEPA, depending on the specific major federal action:

1. Categorical Exclusion (CX)
2. Environmental Assessment (EA)
3. Environmental Impact Statement (EIS).

3.1 Categorical Exclusion

The Council on Environmental Quality (CEQ) NEPA regulations define a *categorical exclusion* as "a category of actions which do not individually or cumulatively have a significant effect on the human environment and which have been found to have no such effect in procedures adopted by a Federal agency in implementation of these regulations and for which, therefore neither an environmental assessment nor an environmental impact statement is required" (40 CFR § 1508.4)

The BLM currently has one CX specific to geothermal exploration, which allows the BLM to use a CX for the approval of a Notice of Intent (NOI) to conduct geophysical exploration pursuant to 43 CFR § 3250, when no temporary or new road construction is proposed (516 DM 11 (6)). NOIs under 43 CFR § 3250 permit exploration operations, which include geophysical operations, drilling temperature-gradient wells, drilling holes used for explosive charges for seismic exploration, core drilling, and other drilling methods as long as the operations do not directly test, produce, or utilize the geothermal resource (43 CFR § 3200.1). In addition, the NOI permits the construction of new roads; however, the applicable CX does not allow new road construction (43 CFR 3200.1). As such, resource confirmation drilling projects reviewed for this analysis are not eligible for a CX under current BLM regulations.

Although BLM staff is authorized to use the CX when approving an NOI meeting the above-mentioned requirements, the BLM is not required to use the CX, and under certain circumstances may choose to complete an EA. The presence of extraordinary circumstances may prevent the BLM from using the CX and require the completion on an EA if the activity would have a significant impact on the human environment. Extraordinary circumstances are a list of activities that the BLM (or other federal agencies) must consider that may cause significant environmental effects (see Levine and Young 2014). The BLM list of *extraordinary circumstances* includes factors such as having a significant impact on public health and safety, environmentally sensitive areas such as wild and scenic rivers or national monuments, endangered species or their critical habitat, or historic properties and sacred Indian sites. The mere presence of an extraordinary circumstance within the project site does not prevent the use of a CX, but project impacts on the extraordinary circumstance generally requires at least the completion of an EA.

Previous analysis of BLM geothermal CX processing timeframes has shown that the process for completing a CX review takes about two months (Young et al. 2014).

3.1.1 Guidance on Developing New or Revised Categorical Exclusions

NEPA established the CEQ to oversee and assist in implementing the NEPA process and other requirements as enumerated in the Act (NEPA § 201). The CEQ has provided guidance on how to establish new or revised categorical exclusions under NEPA (Sutley 2010). The CEQ guidance provides mechanisms for substantiating new or revised categorical exclusions, including:

1. A review of previously implemented actions, including monitoring and evaluating "the effects of previously implemented actions that were analyzed in EAs and consistently supported Findings of No Significant Impact"
2. Impact demonstration projects
3. Information from professional staff, outside expert opinions, and scientific analyses
4. Benchmarking other agencies' experience with a comparable CX (Sutley 2010).

3.2 Environmental Assessment

The CEQ NEPA regulations define an environmental assessment as "a concise public document for which a Federal agency is responsible that serves to:

1. Briefly provide sufficient evidence and analysis for determining whether to prepare an EIS or FONSI.
2. Aid an agency's compliance with [NEPA] when no EIS is necessary.
3. Facilitate preparation of an [environmental impact] statement when one is necessary" (40 CFR §1508.9).

Where the BLM completes an EA but does not find the potential for a significant impact on the quality of the human environment, the BLM issues a FONSI and may proceed with permit approval. A FONSI is "a document by a Federal agency briefly presenting the reasons why an action, not otherwise excluded, will not have a significant effect on the human environment and for which an environmental impact statement therefore will not be prepared" (40 CFR § 1508.13). For purposes of this analysis, all of the projects reviewed completed an EA and resulted in a FONSI.

Previous analysis of BLM geothermal EA processing timeframes has shown that the process for completing an EA review takes about 10 months (Young et al. 2014).

3.3 Environmental Impact Statement

NEPA defines an *environmental impact statement* as "A detailed [written] statement…on —

(i) the environmental impact of the proposed action,
(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,
(iii) alternatives to the proposed action,
(iv) the relationship between short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

NEPA § 102(2)(C)

Projects reviewed for this analysis did not rise to the level of requiring an EIS (in general, resource confirmation drilling activities do not require completing an EIS). However, other geothermal activities—e.g., wellfield, power plant, and/or transmission line development—may require completing an EIS.

Previous analysis of BLM geothermal EIS processing timeframes has shown that the process for completing an EIS review takes about 25 months (Young et al. 2014).

4. Environmental Concern and Mitigation Findings from Interviews, Teleconferences, and Workshop

Environmental interview feedback was predominately based on the technical requirement assumptions for geothermal resource confirmation drilling provided by technical members of the Geothermal Expert Team. As further discussed in Beckers and Young 2018, the analysis showed that confirming a geothermal resource requires confirming reservoir temperature, chemistry, permeability, and flow rate. Obtaining these data requires drilling at least two—and preferably three—successful wells into the resource to conduct the necessary tests including an interference test. Bottom-hole well diameters of at least 6" to 8" (0.15 to 0.2 m) are needed to achieve the necessary flow rates. Drilling these wells requires a drill rig with mud pump and derrick capable of holding three drill pipes. This type of drill rig requires a minimum well pad size of 2.5 acres (10^4 m^2) including surface area for a 1 million-gallon (3.8 million-liter) pit. Up to 15 acres (5×10^4 m^2) of total surface disturbance are needed for developing access roads and well pads to drill a total of three to five wells.

The remainder of this section reviews the environmental concern and mitigation feedback provided by environmental members of the Geothermal Expert Team for each of the categories discussed in Section 2. The information collected was designed, in part, to address CEQ guidance on CXs discussed above and was gathered from professional staff, outside experts, and through scientific analyses.

Note that the commonly applied mitigation measures are **not intended to serve as requirements** for future geothermal resource confirmation drilling activities. Instead, these mitigation measures are illustrative and serve to show that potential environmental concerns associated with geothermal resource confirmation drilling typically are known and that addressing these concerns is fairly standardized.

4.1 Site Access: Environmental Concerns and Mitigation Measures

The following is a list of potential ***environmental concerns*** associated with accessing a geothermal resource confirmation drilling site:

- The presence of cultural, tribal, or paleontological resources; sensitive species and/or critical habitat (including migration corridors), and environmentally sensitive areas (e.g., wetlands, wild and scenic rivers) along the access route.
- The presence of creek crossings, which may impact endangered species and waters of the United States and/or give rise to state water resource issues.
- The spread of noxious weeds and/or invasive species.
- Access routes that include unstable road slopes, which will require extensive cut and fill to stabilize the road.
- The length of road in place and level (quality) of the road, which may require new road construction or upgrades to existing roads.
- Suitable drainage for roads to prevent flash flooding and storm-water runoff.
- Ruts caused by equipment on the roads during rain events, particularly in arid climates, which could last years after the road dries up.
- Fugitive dust emissions from transporting personnel and equipment along the access route.
- Construction of permanent roads, which the public will use for recreational purposes, leading to increased traffic in the area.
- Greenhouse gas emissions from vehicles accessing the site.

The following is a list of potential ***mitigation measures*** that project developers commonly utilize or the BLM may incorporate as mitigation measures in a NEPA document, best practices, or conditions of approval (for a drilling permit) to reduce environmental concerns associated with accessing a geothermal resource confirmation drilling site:

- Complete a “desk review” to avoid any known cultural resources, sensitive species and/or critical habitat, and environmentally sensitive areas.

- Complete an on-site review (if necessary) based on findings from a "desk review," including findings related to the granularity and certainty of existing surveys.
- Lay down temporary mats/pads to protect sagebrush routes or similar environmental concerns along the access route.
- Power-wash all construction equipment prior to arrival at the drill site to prevent transportation of noxious weeds into the project area.
- Inspect and treat employee clothing and shoes to prevent the spread of noxious weeds into the project area.
- Employ standard dust-suppression strategies to prevent fugitive dust emissions, including the use of water and/or magnesium chloride along the access road.
- Reclaim roads constructed to access the drill site.
- Comply with local air-quality requirements for vehicle emissions.

4.2 Drill Site: Environmental Concerns and Mitigation Measures

The following is a list of potential ***environmental concerns*** associated with a geothermal resource confirmation drilling site:

- The presence of cultural, tribal, or paleontological resources; sensitive species and/or critical habitat (including migration corridors), and environmentally sensitive areas (e.g., wetlands, wild and scenic rivers) at the drill site and along access routes between individual well pads located at the drill site.
- Terrestrial and avian species getting into a well or sump.
- Avian species (including eagles and other raptors) nesting/perching on drill rig towers, which may create a competitive advantage and threaten existing prey.
- The spread of noxious weeds and/or invasive species.
- The corrosiveness of and/or hazardous constituents in geothermal fluid and the potential for sump overflow to contaminate the surrounding area.
- The length of time the sump will be utilized and how long fluid will remain in the sump.
- Grading of land, which may destroy vegetation and displace species.
- Digging a cellar (e.g., hole) for the blowout preventer.
- Erosion occurring at the drill site.
- New material being brought into the drill site (e.g., road mix gravel).
- Cumulative and connected impacts generally, including ancillary construction activities and pipelines.

The following is a list of potential ***mitigation measures*** that project developers commonly utilize or the BLM may incorporate as mitigation measures in a NEPA document, best practices, or conditions of approval (for a drilling permit) to reduce environmental impacts associated with accessing a geothermal resource confirmation drilling site:

- Complete a "desk review" to avoid any known cultural resources, sensitive species and/or critical habitat, and environmentally sensitive areas.
- Complete an on-site review (if necessary) based on findings from a "desk review," including findings related to the granularity and certainty of existing surveys.
- Establish seasonal restraints for breeding and migration.
- Place fencing around sump and grate over wellbore to protect humans/species.
- Place netting over or rubber balls in sump to prevent avian species from entering.
- Place escape ladders in sump for humans/species to exit and/or make the sump shallower in one end to allow for easier exit for species (i.e., "beach approach").
- Place mats for vegetation at the drill site, particularly in wet climates to help avoid need for a Clean Water Act Section 404 permit.
- Power-wash all construction equipment prior to arrival at project site to prevent transportation of noxious weeds into drill site/project area.
- Inspect and treat employee clothing and shoes to prevent the spread of noxious weeds into the drill site/project area.
- Limit/prevent new material being brought into the drill site without specific environmental analysis.

4.3 Water Quality, Discharge, and Use: Environmental Concerns and Mitigation Measures

The following is a list of potential ***environmental concerns*** associated with water quality, water discharge, and water use during geothermal resource confirmation drilling:

- Effects to plant and animal species from briny, salty, corrosive, or scalding (hot) geothermal fluids.
- Source of water use (e.g., Where does the water come from? Is the withdrawal sustainable? Does the water require pipelines to the well pad? Is the water hauled to the site in tanker trucks?).
- Sump overflow and potential contaminants in the sump fluids.
- Leaching of sump fluid into the soil, potentially impacting the shallow drinking water table (if one exists).
- Creation of unstable slopes.
- Safe water discharge to natural drainages while avoiding erosion.
- Leaking or spilling tanks (if tank storage is utilized), particularly due to disconnecting hoses from storage tank.
- Spills associated with the drill rig that are not noticed until taking the drill rig off of the drill pad.
- Use of toxic drilling muds.

The following is a list of potential ***mitigation measures*** that project developers commonly utilize or the BLM may incorporate as mitigation measures in a NEPA document, best practices, or conditions of approval (for a drilling permit) to reduce environmental impacts associated with water quality, discharge, and use during geothermal resource confirmation drilling:

- Use of liners for sumps/pits (clay or ethylene propylene diene monomer rubber [EPDM]) if shallow groundwater is present.
- Use of separate pits for geothermal brine (large pit) and drill cuttings (small pit).
- Maintain 2 feet of freeboard to prevent sump overflow (freeboard height potentially changes based on sump dimensions, particularly depth).
- Case well to beneath the potable-water-quality aquifer (if one exists).
- Place impermeable (removable) protection under the rig to facilitate clean-up.
- Use water-based and non-toxic geothermal drilling fluids.
- Revegetate slopes to stabilize slopes.
- Reinject geothermal fluids or use storage tanks (as opposed to long-term storing on surface in sumps).[1]

4.4 Safety: Environmental Concerns and Mitigation Measures

The following is a list of potential ***environmental concerns*** associated with safety during geothermal resource confirmation drilling:[2]

- Improper storage of fuels or hazardous materials.
- Release of H_2S (where applicable).
- Fires.
- Well blowout.
- Dangers (e.g., human contact) resulting from very high-temperature geothermal fluids.

The following is a list of potential ***mitigation measures*** that project developers commonly utilize or the BLM may incorporate as mitigation measures in a NEPA document, best practices, or conditions of approval (for a drilling permit) to reduce environmental impacts associated with safety concerns during geothermal resource confirmation drilling:

- Add containment around stored fuels and hazardous materials.
- Use H_2S monitoring devices at drill site and potentially on drilling personnel.

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[1] A small sump for drilling mud, drill cuttings, etc., may always be necessary, but this can avoid the need for a larger sump.

[2] Note that the principal concern is based on the engineering of the well; the NEPA process does not matter if the well is not designed properly. Therefore, permit review for the GDP is more important to the safety aspect.

- Place danger signs to warn about fluid temperature and H_2S.
- Ensure adequate well design to control well and prevent blowout.
- Store fire safety equipment at the drill site.
- Plan an emergency escape/evacuation route.
- Use a blowout preventer.
- Wear protective clothing.

4.5 Noise, Light, and Proximity to Population: Environmental Concerns and Mitigation Measures

The following is a list of potential ***environmental concerns*** associated with noise, light, and proximity to population during geothermal resource confirmation drilling:

- Generally, limited concerns due to the temporary activity that is associated with the drill rig, which is only at the drill site for a couple of weeks.
- Noise and light impacts for specific species.
- Noise related to transporting equipment and personnel to the site, 24-hour drilling, and well testing may impact species or nearby populations.
- Small levels of induced seismicity that may impact nearby populations.

The following is a list of potential ***mitigation measures*** that project developers commonly utilize or the BLM may incorporate as mitigation measures in a NEPA document, best practices, or conditions of approval (for a drilling permit) to reduce environmental impacts associated with noise, light, and proximity to population during geothermal resource confirmation drilling:

- Use sound barriers or blankets.
- Shield light downward.
- Place time and seasonal restrictions on drilling to protect species and nearby populations.

4.6 Plugging and Abandoning Wells: Environmental Concerns and Mitigation Measures

The following is a list of potential ***environmental concerns*** associated with the timing for plugging and abandoning wells used for geothermal resource confirmation:[3]

- The site stays un-reclaimed for an extended period of time.
- Liner degradation may cause water quality impacts.
- Impacts to groundwater quality.

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[3] Some members of the Geothermal Expert Team suggested that plugging and abandoning a well in a specific amount of time may not be an environmental concern as long as the company is diligently pursuing development on the lease.

- Could cause more environmental impacts by plugging and abandoning a well than leaving it in place on an active project site, particularly if the developer plans to revisit and continue work.

The following is a list of potential ***mitigation measures*** that project developers commonly utilize or the BLM may incorporate as mitigation measures in a NEPA document, best practices, or conditions of approval (for a drilling permit) to reduce environmental impacts associated with plugging and abandoning a well during geothermal resource confirmation drilling:

- Provide sufficient bonding amount to cover the cost of reclamation.
- Ensure conditions of approval aimed at limiting the time period and well safety during that time period.

5. NEPA Geothermal Resource Confirmation Drilling Review and Analysis

As part of the environmental concern and mitigation analysis, NREL staff reviewed NEPA documents (EA/FONSI) related to 21 previously approved geothermal exploration and resource confirmation drilling projects (see Appendix A for a list of NEPA documents for reviewed projects). The review was used to: 1) capture additional insight on and validate the Geothermal Expert Team's feedback on the environmental concerns and mitigation measures for geothermal resource confirmation drilling, as well as 2) align with CEQ CX guidance on reviewing previously implemented actions, including monitoring and evaluating "the effects of previously implemented actions that were analyzed in EAs and consistently supported Findings of No Significant Impact."

NREL staff catalogued basic project information related to the project's location, required BLM permits, the planned exploration drilling and geothermal resource confirmation activities, the size and number of wells and well pads, and the total estimated surface disturbance. In addition, NREL staff catalogued environmental concerns and mitigation measures for species (e.g., endangered and threatened species, migratory birds, wild horses and burros, invasive/nonnative species), vegetation and soils, environmentally sensitive areas (e.g., wetlands, wilderness areas, wilderness study areas), cultural resources, water quality and use, air quality, safety, noise and visual impacts.

NEPA documents (EA/FONSI) used in this analysis were published between 2005 and 2014 and were chosen with the intent of gathering a broad scope of resource confirmation drilling scenarios. Projects occurred in California, Nevada, Oregon, and Utah on public lands (in some cases extending into private land) and the surface was managed by either the BLM or the U.S. Forest Service. The area of direct impact caused by the proposed actions (i.e., projects) ranged in size from 3.7 acres up to 620 acres of total surface disturbance, with a mean of 92 acres and median of 69.8 acres. As a sub-set, surface disturbance from new or upgraded access roads fell between 0 and 146 acres, with a mean and median of 20.7 and 12.7 acres respectively.[4] The analyzed projects proposed between 1 to 27 well pads, with a mean of 12.2 well pads and a

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[4] Total surface disturbance included well pads, access roads, pipelines and buffer zones.

median of 12.5 well pads, while the total number of wells ranged from 3 to 60, with a mean and median of 28.9 and 33 wells respectively.[5]

The remainder of this section provides illustrative examples of some of the most significant environmental concerns observed for each of these categories and the mitigation measures used to reduce the overall impact on the environment and resources.

5.1 Species

The projects reviewed for this analysis did not include any federally listed threatened or endangered species known to be present and potentially impacted in the project area (although some state-listed species were present). However, many of the projects reviewed did include potential impacts to migratory birds. The most common impact observed was a loss of habitat (either temporarily or permanently) resulting from project activities, including vegetation removal that impacted nesting and breeding, or contributed to direct mortality.

5.1.1 Tungsten Mountain Geothermal Exploration Project – Migratory Bird Impacts

The Tungsten Mountain Geothermal Exploration Project in Churchill County, Nevada, proposed to drill and test up to 27 wells on 27 separate well pads requiring BLM approval of GDPs and completion of an EA (BLM 2012). The EA identified about 131 acres of total surface disturbance, including 113.4 acres for well pads, 12.7 acres for access roads, and 5 acres for additional pit construction (BLM 2012). The EA identified about 131 acres of direct habitat loss for migratory birds in the area. Nevertheless, the EA noted that the amount of acreage lost was small relative to the hundreds of thousands of acres of available habitat in the project vicinity, and the population viability for any individual migratory bird species was not expected to be in jeopardy due to project construction or operation.

5.1.2 Tungsten Mountain Geothermal Exploration Project – Migratory Bird Mitigation Measures

To effectively mitigate the potential impact on migratory bird mortality and breeding, mitigation measures included suggesting (but not requiring) project activities occur outside of the migratory bird season (May 15 to July 15). If project activities were to occur during migratory bird season, a qualified biologist would need to conduct bird surveys for nesting species prior to construction. Further, if an active nest was identified during the study, a "no-activity" buffer of 200 feet would be established until the nest becomes inactive (BLM 2012).

5.2 Vegetation and Soils

Generally, impacts to soil and vegetation were a direct result of ground-disturbing activities (e.g., construction of access roads and well pads) that would remove vegetation and soil, resulting in the potential erosion of soils due to increased exposure to wind and water. In addition, control of non-native species and noxious weeds were a concern for the disturbed areas in which vegetation was removed.

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[5] Analyzed wells included temperature gradient wells (TGW), exploration wells (slim and full size), resource confirmation wells, observation wells, and production and injection wells.

5.2.1 Dixie Meadows Geothermal Exploration Project – Vegetation and Soils Impacts

The Dixie Meadows Geothermal Exploration Project in Churchill County, Nevada, proposed to drill and test up to 60 wells on 20 well pads requiring BLM approval of NOIs and GDPs and the completion of an EA (BLM 2011). The EA identified a maximum of about 137 acres of surface disturbance, of which 57 acres would occur in areas where vegetation cover was generally absent. As a result, the EA identified about 80 acres where the project would impact existing vegetation cover, representing about 14% of the vegetation cover in the project area. In addition to the direct impacts of vegetation removal, the EA also noted the potential for cleared areas to become susceptible to the spread of invasive vegetation (BLM 2011a).

5.2.2 Dixie Meadows Geothermal Exploration Project – Vegetation and Soils Mitigation Measures

To effectively mitigate the potential impact on vegetation and soils, mitigation measures included salvaging topsoil, which would reduce the effects of soil compaction during reclamation, as well as the use of certified weed-free seed mixes during reclamation. The EA noted that implementing reclamation of the project area would occur within two years of project completion (BLM 2011a).

5.3 Environmentally Sensitive Areas

The projects reviewed for this analysis did not take place in a wilderness area or wilderness study area. However, a few of the projects reviewed did have wetlands within the project area. Wetlands may be impacted by resource exploration through erosion and sedimentation, groundwater withdrawal, and leaks and spills of project-related hazardous materials (e.g., drilling mud and additives, petroleum products and emissions, and geothermal fluid).

5.3.1 Glass Buttes Geothermal Exploration Project – Environmentally Sensitive Area Impacts

The Glass Buttes Geothermal Exploration Project in Burns, Oregon, proposed to drill 13 exploratory wells[6] (3 slim wells, 10 full-diameter wells) on 13 well pads requiring NOIs and GDPs and the completion of an EA. The EA identified about 59 acres of surface disturbance on BLM-managed public lands and 13 acres on adjacent private land (BLM 2011b). The EA noted that the project area included up to 60.36 acres of potential wetlands based on the National Wetland Inventory and USGS National Hydrography Database (BLM 2011b).

5.3.2 Glass Buttes Geothermal Exploration Project – Environmentally Sensitive Area Mitigation Measures

The Glass Buttes Geothermal Exploration Project EA noted that the wetlands located within the project area would not experience disturbance due to project activities (road and well-pad construction). As a result, the EA did not include any mitigation measures for wetland impacts (BLM 2011b).

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[6] The project proposal also included drilling up to three wells on private land.

5.4 Cultural Resources

Cultural resources may be difficult to identify at the outset of a geothermal project. A cultural inventory can identify known cultural and historic resources in the project area; however, subsurface discoveries of previously unidentified cultural resources may occur during project activities. In addition, geothermal resource exploration and resource confirmation has the potential to affect a site's eligibility for the National Register of Historic Places if not conducted responsibly.

5.4.1 McCoy II Geothermal Exploration Project – Cultural Resources Impacts

The McCoy II Geothermal Exploration Project in Churchill County, Nevada, proposed to drill up to 57 wells (temperature-gradient wells, observation wells, and full-diameter wells) on 19 well pads. The EA identified a maximum total surface disturbance of 69 acres, including about 30 acres for road improvement and 39 acres for well pads (BLM 2011c). In furtherance of the project, a cultural resources inventory was conducted that evaluated 20 sites and 16 isolates. The EA noted that project construction could affect some of the cultural sites having National Register of Historic Places eligibility, which would constitute a significant impact. However, the EA stated that most of the proposed activities within the project area were located away from the eligible sites and historic properties (BLM 2011c).

5.4.2 McCoy II Geothermal Exploration Project – Cultural Resources Mitigation Measures

To effectively mitigate the potential impact on cultural resources in the project area, the EA listed a series of mitigation measures, including:

- Avoid known eligible or potentially eligible cultural resource sites during construction and operation.
- Establish a 100-foot buffer zone around eligible or potentially eligible cultural resource sites.
- Engineer the project area to avoid run-off that could affect adjacent cultural resources.
- Where project activities could impact cultural resources, retain a qualified archaeologist to serve as a cultural monitor during construction.
- Limit vehicle travel to established roads within the project area.
- Cease all operations upon discovery of any cultural resources and notify the BLM field manager.

5.5 Water Quality and Use

Generally, geothermal exploration and resource confirmation drilling projects may include impacts to both surface water and groundwater as well as require some level of water consumption. Although these impacts are typically temporary and localized, more severe impacts can occur as a result of well blowout, accidental release of hazardous materials to the environment, and disturbance or alteration of the subsurface aquifers.

5.5.1 Salt Wells Geothermal Drilling Project – Water Quality and Use Impacts

The Salt Wells Geothermal Drilling Project in Churchill County, Nevada, proposed to drill up to ten 8.5-inch-diameter wells, on 10 well pads requiring an NOI and, if a productive resource was discovered, proposed drilling full-size wells requiring a GDP and the completion of an EA (BLM 2007). The EA identified a maximum surface disturbance of 56 acres, including 38 acres for well pads and 18 acres for access roads if the developer implemented the full proposal, including drilling full-size wells. Surface water impacts included the potential for flooding, the release/runoff of substances used in the construction process (e.g., fuels and hydraulic fluid), and pipe or storage-tank rupture affecting water quality. In addition, noted groundwater impacts included decreasing the local groundwater aquifer through proposed use of a water well and groundwater quality impacts if cooling-water evaporation ponds recharge shallow groundwater (BLM 2007).

5.5.2 Salt Wells Geothermal Drilling Project – Water Quality and Use Mitigation Measures

To effectively mitigate the potential impacts on surface water and groundwater in the project area, the EA included a series of mitigation measures. For surface-water impacts, the EA provided containment and cleanup standards for spills of substances, a stormwater pollution prevention program as required under the Clean Water Act, and proper maintenance and monitoring of pipes and storage tanks to avoid ruptures. For groundwater impacts, the EA stated that groundwater withdrawals would be limited based on county temporary water-use permits to avoid permanent adverse effects on the groundwater aquifer, and a National Pollution Discharge Prevention System permit would require the developer to demonstrate that cooling-water discharges would not degrade groundwater quality (BLM 2007).

5.6 Safety

Safety concerns included fire prevention and H_2S monitoring. In addition, exploratory and resource confirmation drilling involves the use of equipment that creates sparks (e.g., welding equipment, vehicles), which increases the potential for fires within the project area and may spread to surrounding areas.

5.6.1 Steamboat Geothermal Wells Project – Safety-Related Impacts

The Steamboat Geothermal Wells Project in Washoe County, Nevada, proposed to drill three wells (temperature-gradient well, observation well, and production well) from one well pad requiring a GDP and the completion of an EA (BLM and USFS 2014). The EA identified a maximum surface disturbance of 3.7 acres, including 2.8 acres for the well pad and 0.9 acre for road improvement. The EA noted a potential safety concern related to fires occurring at the drill site (BLM and USFS 2014).

5.6.2 Steamboat Geothermal Wells Project – Safety-Related Mitigation Measures

To effectively mitigate potential impacts caused by fires, the EA listed safety measures, including:

- Small fires occurring at the drill site should be controlled by drill rig personnel using on-site firefighting equipment.
- The developer should notify the BLM district office immediately of any wildfire.
- All vehicles and drill sites would need a shovel, 5 gallons of water, and a fire extinguisher.

- Catalytic converters on vehicles would be inspected often and cleaned of all flammable debris.
- Cutting and welding should occur in an area free or mostly free of vegetation.
- Compliance with BLM fire restrictions or closures.
- Smoking would be permitted only in designated areas (BLM and USFS 2014).

5.7 Noise and Visual Impacts

Noise and visual impacts (e.g., light, drill rig) may have impacts on both nearby human populations as well as species inhabiting the area. General impacts noted in projects reviewed for this analysis included noise from construction equipment, viewshed impacts, and use of lights when drilling at night.

5.71. Coyote Canyon/Dixie Meadows Geothermal Exploration Projects – Noise and Visual Impacts

The Coyote Canyon/Dixie Meadows Geothermal Exploration Projects in Churchill County, Nevada, proposed to drill up to 60 wells (temperature-gradient wells, observation wells, and production wells) on 20 well pads (BLM 2011d). The maximum total surface disturbance was 137 acres, including a maximum well-pad disturbance of 82 acres and nearly 35 acres for access roads. The EA noted several visual impacts, including temporary visual impacts related to the drill rig and use of lights to drill at night. The EA did not include any potential noise impacts (BLM 2011d).

5.7.2 Coyote Canyon/Dixie Meadows Geothermal Exploration Projects – Noise and Visual Impacts Mitigation Measures

To effectively mitigate the potential impacts caused by visual impacts to viewsheds, the EA listed mitigation measures, including:

- All drill rigs and well test facility lights would be limited to those required to safely conduct operations.
- All drill rig and well test facility lights should be shielded or directed in a manner to focus direct light on the immediate work area.
- Removal of equipment upon completion of drilling and testing the wells (BLM 2011d).

6. Conclusion

This analysis reviewed environmental concerns and mitigation measures for geothermal resource confirmation drilling activities to provide the BLM with background information to identify potential areas for reducing regulatory compliance and permitting timelines. Table 1 highlights findings of this analysis from the interviews, group teleconferences, an in-person workshop, and previous NEPA environmental review documents.

Table 1: Summary of Environmental Concerns and Mitigation Measures

Site Access			
Concerns **Concluded from Expert Team**	**Mitigation** **Concluded from Expert Team**	**Example** **Concerns**	**Example** **Mitigation**
• The presence of cultural, tribal, or paleontological resources; sensitive species and/or critical habitat, and environmentally sensitive areas along the access route. • The spread of noxious weeds and/or invasive species. • Fugitive dust emissions from transporting personnel and equipment along the access route.	• Complete a "desk review" to avoid any known cultural resources, sensitive species and/or critical habitat, and environmentally sensitive areas. • Complete an on-site review based on findings from a "desk review." • Power-wash all construction equipment prior to arrival at the drill site and inspect and treat employee clothing and shoes to prevent transportation of noxious weeds. • Employ standard dust-suppression strategies to prevent fugitive dust emissions.	The McCoy II Geothermal Exploration Project EA noted that project construction could affect some of the cultural sites having National Register of Historic Places eligibility, which would constitute a significant impact. However, the EA stated that most of the proposed activities within the project area are located away from the eligible sites and historic properties.	The EA lists the following mitigation measures: • Avoid known eligible or potentially eligible cultural resource sites during construction and operation. • Establish a 100-foot buffer zone around eligible or potentially eligible cultural resource sites. • Engineer the project area to avoid run-off that could affect adjacent cultural resources. • Where project activities could impact cultural resources, retain a qualified archaeologist to serve as a cultural monitor during construction. • Limit vehicle travel to established roads within the project area. • Cease all operations upon discovery of any cultural resources and notify the BLM field manager.
Drilling Site			
Concerns **Concluded from Expert Team**	**Mitigation** **Concluded from Expert Team**	**Example** **Concerns**	**Example** **Mitigation**
• Terrestrial and avian species getting into a well or sump. • The corrosiveness of and/or hazardous constituents in geothermal fluid and the potential for sump overflow to contaminate the surrounding area. • Grading of land, which may destroy vegetation and displace species. • Cumulative and connected impacts generally, including	• Establish seasonal restraints for breeding and migration. • Place grate over wellbore. Use fencing around, escape ladders in, and netting over sump to protect humans and terrestrial/avian species. • Place mats for vegetation at the drill site, particularly in wet climates to help avoid need for a Clean	The Tungsten Mountain Geothermal Exploration Project EA identified 131 acres of habitat loss for migratory birds in the area but noted that the habitat lost was small relative to the available habitat in the vicinity; also, the population viability for any individual migratory bird species was not expected to be in jeopardy as a result of the project.	Mitigation measures included suggesting project activities to occur outside of the migratory bird season. If project activities were to occur during migratory bird season, a qualified biologist would need to conduct bird surveys for nesting species prior to construction. If an active nest was identified during the study, a "no-activity" buffer of 200 feet would be established until the nest becomes inactive.

ancillary construction activities and pipelines.	Water Act Section 404 permit. • Limit/prevent new material being brought into the drill site without specific environmental analysis.		
Water Quality, Discharge, and Use			
Concerns **Concluded from Expert Team**	**Mitigation** **Concluded from Expert Team**	**Example** **Concerns**	**Example** **Mitigation**
• Effects to plant and animal species from briny, salty, corrosive, or scalding geothermal fluids. • Source of water use. • Sump, pipes, and tanks overflowing, leaking, or spilling and the potential contaminants in leaked fluids. • Use of toxic drilling muds.	• Use liners for sumps/pits if shallow groundwater is present. • Use separate pits for geothermal fluids and drill cuttings. • Maintain 2 feet of freeboard to prevent sump overflow. • Reinject geothermal fluids or use storage tanks. • Place impermeable protection under the rig to facilitate clean-up. • Use water-based and non-toxic geothermal drilling fluids.	The Salt Wells Geothermal Drilling Project EA identified several surface-water impacts, including the potential for flooding, the release/runoff of substances used in the construction process, and pipe or storage-tank rupture affecting water quality. In addition, noted groundwater impacts included decreasing the local groundwater aquifer through proposed use of a water well and groundwater-quality impacts if cooling-water evaporation ponds recharge shallow groundwater.	Mitigation measures for surface-water impacts included containment and clean-up standards for spills of substances, a stormwater pollution prevention program as required under the Clean Water Act, and proper maintenance and monitoring of pipes and storage tanks to avoid ruptures. For groundwater impacts, the EA stated that withdrawals would be limited based on county temporary water-use permits to avoid permanent adverse effects on the aquifer and a NPDES permit would require the developer to demonstrate cooling-water discharges would not degrade groundwater quality.
Safety			
Concerns **Concluded from Expert Team**	**Mitigation** **Concluded from Expert Team**	**Example** **Concerns**	**Example** **Mitigation**
• Improper storage of fuels or hazardous materials. • Release of H_2S. • Fires. • Dangers resulting from well blowout and very high-temperature geothermal fluids.	• Add containment around stored fuels and hazardous materials. • Use H_2S monitoring devices. • Place H_2S and fluid-temperature danger signs. • Store fire-safety equipment at the drill site and planning emergency escape/evacuation route.	The Steamboat Geothermal Wells Project noted a potential safety concern related to fires occurring at the drill site.	The EA listed the following safety measures: • Drill-rig personnel are to control small fires occurring at the drill site using on-site firefighting equipment. • Notify BLM district office immediately of any wildfire. • A shovel, 5 gallons of water, and a fire extinguisher in all vehicles and drill sites. • Catalytic converters on vehicles inspected often

	• Ensure adequate well design to control well and prevent blowout, including the use of a blowout preventer. • Wear protective clothing.		and cleaned of all flammable debris. • Cutting and welding should occur in an area mostly free of vegetation. • Comply with BLM fire restrictions or closures. • Permit smoking only in designated areas.
Noise, Light, and Proximity to Population			
Concerns **Concluded from Expert Team**	**Mitigation** **Concluded from Expert Team**	**Example** **Concerns**	**Example** **Mitigation**
• Noise and light impacts for specific species. • Noise related to transporting equipment and personnel to the site, 24-hour drilling, and well testing may impact species or nearby populations.	• Use sound barriers or blankets. • Shield light downward. • Place time and seasonal restrictions on drilling to protect species and nearby populations.	The Coyote Canyon/Dixie Meadows Geothermal Exploration Projects' EA noted several visual impacts, including temporary visual impacts related to the drill rig and use of lights to drill at night. The EA did not include any potential noise impacts.	The EA provided the following mitigation measures: • All drill rigs and well test facility lights would be limited to those required to safely conduct operations. • All drill rig and well test facility lights should be shielded or directed in a manner to focus direct light on the immediate work area. • Remove equipment upon completion of drilling and testing the wells.
Plugging and Abandoning Wells			
Concerns **Concluded from Expert Team**	**Mitigation** **Concluded from Expert Team**	**Example** **Concerns**	**Example** **Mitigation**
• The site stays un-reclaimed for an extended period of time. • Impacts to groundwater quality, such as those caused by liner degradation. • If the developer plans to revisit and continue work, plugging and abandoning a well may cause more environmental impacts than leaving it in place.	• Provide sufficient bonding amount to cover the cost of reclamation. • Ensure conditions of approval aimed at limiting the time period and well safety during that time period.	The Dixie Meadows Geothermal Exploration Project EA identified about 80 acres where the project would impact existing vegetation cover. Beyond the direct impacts of vegetation removal, the EA also noted the potential for cleared areas to become susceptible to the spread of invasive vegetation.	Mitigation measures included salvaging topsoil, which would reduce the effects of soil compaction during reclamation, as well the use of certified weed-free seed mixes during reclamation. The EA noted that implementing reclamation of the project area would occur within two years of project completion.

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APPENDIX

NEPA Documents

Deep Rose Geothermal Exploration Project EA - *EA-CA-650-2005-086*

Dixie Meadows Geothermal Exploration Project EA - *DOI-BLM-NV-C010-2011-0516-EA*

McCoy II Geothermal Exploration Project EA - *DOI-BLM-NV-C010-2011-0514-EA*

Salt Wells Geothermal Drilling EA - *EA-NV-030-07-05*

Salt Wells Geothermal Exploratory Drilling Program EA - *DOI-BLM-NV-C010-2009-006-EA*

San Emidio Geothermal Exploration Project EA - *DOI-BLM-NV-W030-2010-0006-EA*

Midnight Point and Mahogany Geothermal Exploration Projects, Glass Buttes Exploration EA - *DOI-BLM-OR-P040-2011-0021-EA*

Drum Mountains and Whirlwind Valley Geothermal Exploration Projects EA - *DOI-BLM-UT-W020-2010-042-EA*

Tungsten Mountain Geothermal Exploration Project EA - *DOI-BLM-NV-C010-2012-0029-EA*

Jersey Valley Geothermal Exploration Project FONSI - *DOI-BLM-NV-020-07-01-EA-FONSI*

Patua Geothermal Project Phase II EA - *DOI-BLM-NV-C010-2011-0501-EA*

Reese River Valley Geothermal Exploration Project FONSI - *NV063-EA06-098-FONSI*

Silver Peak Silver Peak Area Geothermal Exploration Project EA - *DOI-BLM-NV-B020-2012-0214-EA*

Soda Lake Geothermal Exploration Project FONSI - *DOI-BLM-NV-C010-2010-008-EA-FONSI*

Drum Mountain Temperature Gradient Exploration Project EA - *DOI-BLM-UT-W020-2009-028-EA*

Coyote Canyon and Dixie Meadows Geothermal Exploration EA - *DOI-BLM-NV-C010-2010-0010-EA*

Steamboat Geothermal Well(s) 16-32 Project EA and FONSI - *DOI-BLM-NV-C010-2014-0019-EA*

Leach Hot Springs Geothermal Exploration Project EA - *DOI-BLM-NV-W010-2011-0001-EA*

Wild Rose Geothermal Project FONSI - *DOI-BLM-NV-C010-2012-0050-EA-FONSI*

Gabbs Valley and Dead Horse Wells Geothermal Exploration EA - *NV-C010-2010-006-EA*

Coyote Canyon South Geothermal Exploration EA - *DOI-BLM-NV-C010-0051-EA*

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Question from Chairman Lisa Murkowski

Question: Oil and gas development has moved at a rapid pace since the shale boom. Many of the new technologies pioneered for shale development could be used for geothermal as well. What are the best ways the Department of Energy and the Department of the Interior could further foster cooperation between the oil and gas and geothermal energy sectors?

Response: Technology transfer from the oil and gas industries is one of the most compelling opportunities for opening up the significant geothermal energy resource outlined in the GeoVision study. In my career, I have worked both for the oil and gas sector and in the renewable energy sector, so I'm excited to provide perspective on how we can foster collaboration between these communities. There are many actions that can be taken by the Department of Energy (DOE) and the Department of Interior (DOI) to foster cooperation between the oil and gas and geothermal sectors.

First, the DOE and DOI can continue to provide a compelling vision of market potential and market certainty to attract private investment from the oil and gas sector. The GeoVision study is a great example of a DOE action that outlines the significant upside for geothermal and outlines a prize that will be compelling to the oil and gas sector. Similarly, the actions outlined in the report on regulatory actions would have a tremendous impact on attracting oil and gas interest. Oil and gas operators I engage with regularly bring up complexities and timelines of operating on federal land as a barrier to their interest in geothermal, so actions that clarify regulatory issues will have an immediate impact on private sector interest. As outlined in Ms. Kate Young's testimony, actions such as use of Categorical Exclusions for Resource Confirmation and creation of a dedicated BLM geothermal team would greatly improve clarity and timelines for permitting and catalyze significant interest in geothermal from the private sector.

Second, focusing resources on field level testing and validation would facilitate interest in collaboration in the oil and gas and geothermal communities. In oil and gas, engineers and investors tend to take ideas seriously only when they have been tested and proven at the field level. While basic science and lab-scale research is critical to the innovation ecosystem, field level results of new technology would catalyze significant interest from the oil and gas community. The DOE led Field Observatory for Research in Geothermal Energy (FORGE) is a great example of innovation at the field level that will have a major impact on geothermal innovation. Additional measures could include use of public-private partnerships through the Geothermal Technology Office or ARPA-E on first-of-a-kind field deployments of innovative technologies. Field-scale work would enable the field level results that will get the attention and drive investment from the oil and gas community.

Finally, targeting technologies and resources that have overlap and synergies with recent oil and gas innovations would facilitate rapid technology transfer. For example, dramatic increases in horizontal drilling have been one of the most important innovations underpinning the shale revolution in the United States, so focusing research on this area would leverage recent advancements familiar to the oil and gas industry into geothermal. Additionally, it is important that we select resources that share similarities with recent innovations in oil and gas to facilitate technology transfer. For example, temperatures in shale oil and gas reservoirs such as the Eagle Ford or Haynesville are often in the 150-180°C range, similar to

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many commercial geothermal resources. Focusing technology R&D on geothermal resources at or near this temperature window would enable many vital technologies to be adapted to geothermal from oil and gas on an accelerated timeline. For example, the FORGE project specifically targeted reservoir temperatures from 175-225°C, a window with significant overlap with current oil and gas operations. At these temperatures, technologies can be adapted from the oil and gas industry rapidly, without having to completely reinvent the wheel. Further, the resource potential in the US in this temperature range is massive. NREL estimates that there are 248 GW_e of geothermal energy available in the 175-225°C range shallower than 5 km.[1] Focusing attention on these resources would enable rapid technology transfer from oil and gas and open a significant resource for geothermal energy in the United States.

There has never been a better time for technology transfer from the oil and gas industry to geothermal. The shale revolution has brought unprecedented technology and productivity gains in drilling and completions. Oil and gas companies are eager to diversify their businesses in response to risks related to climate change. The DOE and DOI could play an important role in fostering collaboration by providing market potential and regulatory clarity, focusing investment on field level testing and validations, and targeting technologies and resources that share overlap with the oil and gas industry, such as horizontal drilling and geothermal resources in the 175-225°C temperature range.

Questions from Ranking Member Joe Manchin III

Questions: Fervo Energy is an example of one of DOE's best technology incubators doing its job – Lawrence Berkeley National Lab's Cyclotron Road. Cyclotron Road and other DOE-funded incubators are filling a critical financing gap for companies like Fervo.

What role did venture capital played in launching Fervo? How would you have launched Fervo without Cyclotron Road? What was the value Cyclotron Road provided to your company?

Response: How would we have launched Fervo without Cyclotron Road? With great difficulty or perhaps not at all. Companies like Fervo Energy face unique challenges in commercializing new technology. Unlike many traditionally venture backed companies, commercializing hard tech requires extended timelines, scientific risks, and large-scale project development. This kind of risk and timeline has proved ill suited for the traditional venture community to go alone, but innovative programs like Cyclotron Road show a roadmap to partnering with the private investment community to fill a gap that enables companies like Fervo to thrive.

Cyclotron Road is an entrepreneurial research fellowship that provides many unique benefits that catalyze hard technology innovations—those rooted in physical or biological sciences, as opposed to software. Two years ago, as we were exploring options for where to take our geothermal technology breakthroughs, we found very few options in the public or private sector that would provide a good home for us to succeed. In a world where permitting and project timelines can take years, common incubator terms of 2-3

[1] *Update to Enhanced Geothermal System Resource Potential Estimate*. Augustine, Chad. National Renewable Energy Laboratory. (2016)

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months wouldn't give us the space we need to succeed. Since many of our questions were technical in nature, we needed to find a place that could provide us with the right research advice, not just advice on company building. This left few private sector options to choose from. Many public sector options would have enabled us to continue our research, but would not have provided us with a connection to industry and the investment community, leaving us in the dark about if our work will matter. We needed a home that gave us the time and technical expertise to succeed and allow us to stay relentlessly focused on the marketplace. Cyclotron Road stood out as the ideal platform to launch Fervo Energy.

As soon as we joined Cyclotron Road, we knew we were in the right place. If crossing the "Valley of Death" for hard tech commercialization requires building a bridge across research and industry, it's hard to imagine a better embodiment for that bridge than a typical Thursday at Cyclotron Road:

- Our day starts with a weekly check in with our Principal Investigator, Dr. Pat Dobson, who serves as Lawrence Berkeley National Lab's Geothermal Systems Lead. With 30 years of public and private sector experience, Dr. Dobson serves as an invaluable guide for Fervo in the research community, identifying potential pitfalls before they happen or connecting us with the right research group at the right time. Thanks to our ties into the energy industry and investment community, we are able to provide Dr. Dobson useful information on market trends that help guide research work.
- Next we attend the Cyclotron Road weekly fellows' lunch, where world-class guest speakers cover topics as diverse as IP strategy or effective management. This is followed by dedicated meeting time with relevant visitors, which includes groups from investors to utilities to ARPA-E directors. In just one day, we can review our research plans with a world-class subject matter expert, learn relevant business skills tailored to the needs of a hard tech business, and connect with the right people throughout the research ecosystem.
- Cyclotron Road also provides a strong signal to the marketplace that enables us to establish credibility quickly. Because Cyclotron Road has a strong reputation and is highly competitive, outside stakeholders know by our association with the program that we have been thoroughly vetted and our ideas hold scientific merit. This is particularly helpful with the investment community, which may not have the bandwidth or internal expertise to become experts in every single sub-discipline they come across as an investment candidate.

Cyclotron Road, the flagship in the lab-embedded entrepreneurship program, ensures that fellows' innovations are screened by the right subject matter experts. This technology vetting capability is unique to lab-embedded entrepreneurship programs and sends a strong signal to the marketplace. Venture capital has provided a key role in Fervo Energy's scale up and we are thrilled to be working alongside innovative investors such as Breakthrough Energy Ventures and Baruch Future Ventures, and the strong signal and network provided by Cyclotron Road has been vital to our tapping into the venture capital community.

There is no way around it, hard tech innovation is hard. It always will be. But Cyclotron Road forges a path to make it possible.

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Question from Senator James E. Risch

Question: Idaho has been a world leader when it comes to developing geothermal resources and demonstrating new technologies. In the Geovision report, you note that technology improvements could go a long way in deploying additional geothermal resources. Can you please explain what technologies you think would be the most beneficial in developing additional geothermal resources in Idaho?

Answer: The Raft River Geothermal Project, which lies in southern Idaho, approximately 200 miles south-east of Boise, Idaho, is located on a former U.S. Department of Energy geothermal demonstration site which operated from 1974 to 1982 during which time over $40 million was invested in geothermal studies and production infrastructure. The world's first commercial-scale binary cycle geothermal power plant was constructed at Raft River. The 7MW dual-pressure system, built between 1980 and 1982, successfully generated electricity for several months on a test basis. Following the acquisition by U.S. Geothermal in 2002, construction of "Unit 1" which generates 10MW began in 2006 before being completed in January 2008 with plans for additional development of up to 36MW[1].

In addition to acquiring U.S. Geothermal in early-2018, Ormat was contracted to supply all major pumps, electrical components and other equipment for construction of the binary cycle system at the Raft River Geothermal Project. Binary plants are the ideal partner to pair with geothermal reservoirs in Idaho due to their ability to maximize sustainability, return on investment, and generate renewable baseload generation. Sustainability is maximized through responsible resource management which is achieved by reinjecting 100% of the geothermal fluid back into the reservoir in order to prevent premature cooling and maintain reservoir pressures. Return on Investment is amplified due to having much lower operating costs and a higher resilience to changing reservoir conditions which allows for the maintenance of higher efficiency over a longer term. Binary technology can be reliably dispatched on the wide range of geothermal resources found in Idaho, from those with low enthalpy to high, which has been demonstrated by the successful operation of "Unit 1" for more than a decade.

While the Raft River Geothermal Project is the most well-known developed geothermal resource in Idaho, the USGS, in its Assessment of Moderate-and High-Temperature Geothermal Resources of the United States, has identified an estimated 333MW of discovered yet undeveloped resources, an additional approximated 1,872MW of undiscovered geothermal, and nearly 68,000MW of geothermal generation should Enhanced Geothermal System techniques be applied to resources in Idaho. These vast amounts of clean, renewable, baseload geothermal generation can be realized more quickly at the federal level through streamlining the NEPA process and through the passage of H.R. 4568 which will promote timely exploration of geothermal resources. Please see below for a detailed breakdown of estimated available megawatts of geothermal generation produced by identified resources, undiscovered resources, and enhanced geothermal systems[2]:

[1] https://www.power-technology.com/projects/raftriver/
[2] https://pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf

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Table 1. Electric power generation potential in Megawatts-electric (MWe) from identified and undiscovered geothermal resources and Enhanced Geothermal Systems in the western United States.

[All electric power generation figures are calculated on a basis of 30 years of production. F95 represents a 95% chance of at least the amount tabulated; other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. N is the number of identified geothermal systems included in the estimate].

		Identified Resources (MWe)				Undiscovered Resources (MWe)				Enhanced Geothermal Systems (MWe)			
State	**N**	**F95**	**F50**	**Mean**	**F5**	**F95**	**F50**	**Mean**	**F5**	**F95**	**F50**	**Mean**	**F5**
Alaska	53	236	606	677	1,359	537	1,428	1,788	4,256	NA	NA	NA	NA
Arizona	2	4	20	26	70	238	775	1,043	2,751	33,000	52,900	54,700	82,200
California	45	2,422	5,140	5,404	9,282	3,256	9,532	11,340	25,439	32,300	47,100	48,100	67,600
Colorado	4	8	11	30	67	252	821	1,105	2,913	34,100	51,300	52,600	75,300
Hawaii	1	84	169	181	320	822	2,027	2,435	5,438	NA	NA	NA	NA
Idaho	36	81	283	333	760	427	1,391	1,872	4,937	47,500	66,700	67,900	92,300
Montana	7	15	51	59	130	176	573	771	2,033	9,000	16,100	16,900	27,500
Nevada	56	515	1,216	1,391	2,551	996	3,243	4,364	11,507	71,800	101,300	102,800	139,500
New Mexico	7	53	153	170	343	339	1,103	1,484	3,913	35,600	54,400	55,700	80,100
Oregon	29	163	485	540	1107	432	1,406	1,893	4,991	43,600	61,500	62,400	84,500
Utah	6	82	171	184	321	334	1,088	1,464	3,860	32,600	46,500	47,200	64,300
Washington	1	7	20	23	47	68	223	300	790	3,900	6,300	6,500	9,800
Wyoming	1	5	31	39	100	40	129	174	458	1,700	2,900	3,000	4,800
Total	248	3,675	8,356	9,057	16,457	7,917	23,739	30,033	73,286	345,100	507,000	517,800	727,900

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