Prepared Statement of Katherine R. Young
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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).

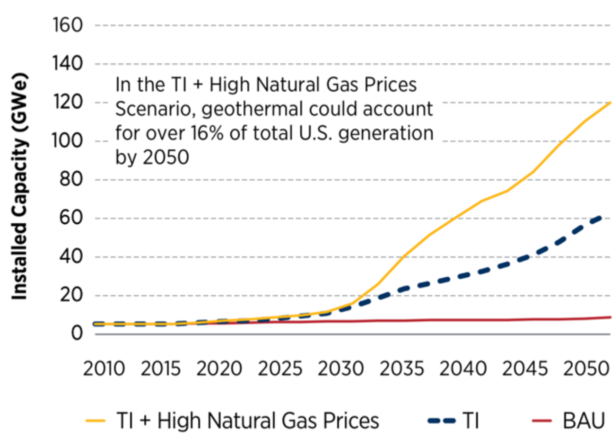

Figure 1. Installed geothermal capacity for GeoVision's *Technology Improvement (TI) scenario compared to a combined scenario and Business-as-Usual (BAU). The combined scenario considers the TI scenario in combination with the U.S. Energy Information Administration's High Natural Gas Prices. At the end 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.

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[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

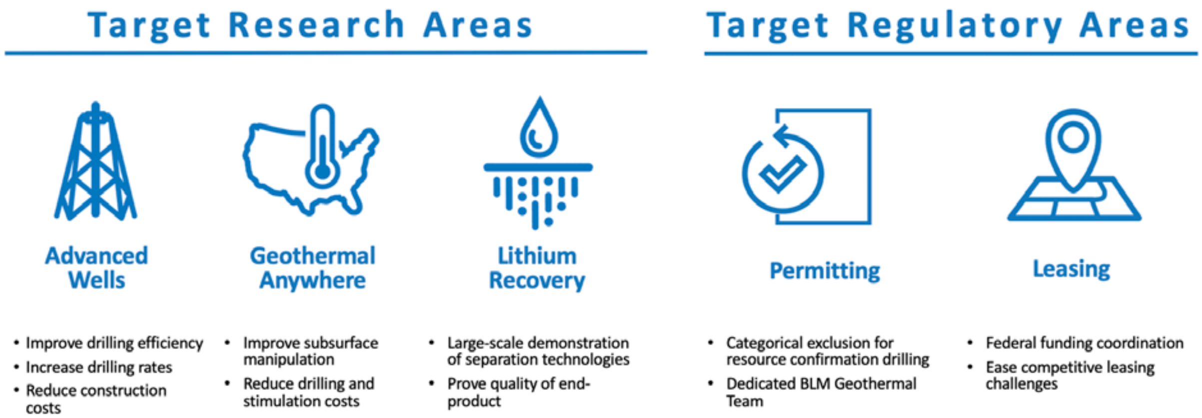


Figure 2. Target research and regulatory improvements that can help catapult the geothermal industry in the United States.

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

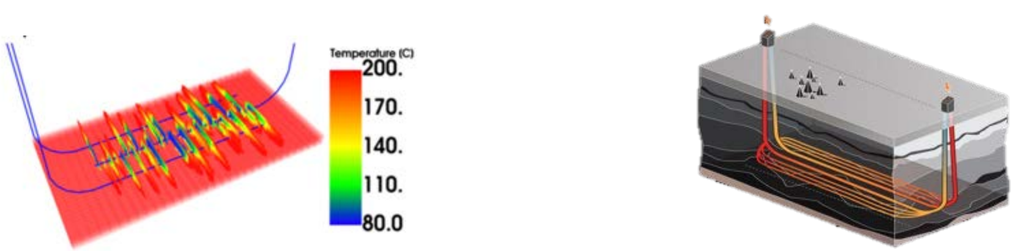
Well construction is a significantly high cost of developing a geothermal well field. Geothermal wells are larger, with a typical hole diameter more than twice the size of oil and gas wells, requiring more casing and cement to be used in construction. Additionally, because of the harsh environment, geothermal 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

[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].

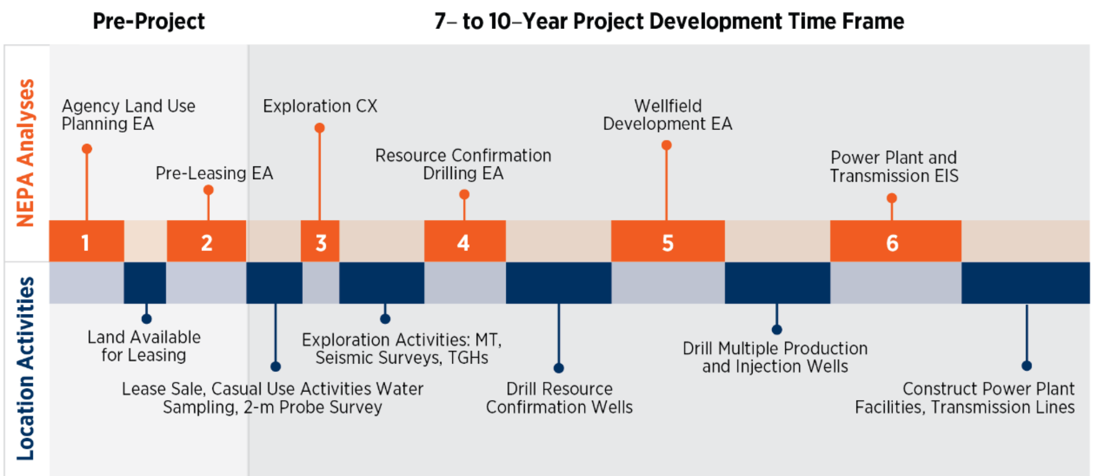


Figure 4. Example timeline of a geothermal project on federal lands, illustrating that a single location could trigger NEPA analyses six separate times. (Source: Young el al. 2014). EA = Environmental Assessment, EIS = Environmental Impact Statement, CX = Categorical Exclusions, MT = magnetotelluric,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

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[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.

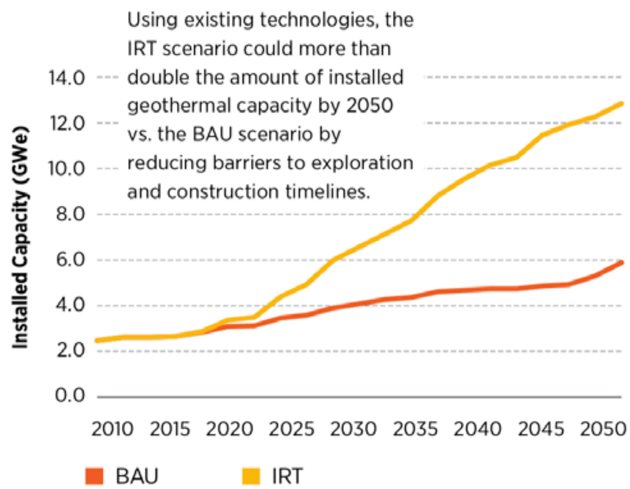

Figure 5. GeoVision's *Improved Regulatory Timeline (IRT) scenario results and comparison to the Business-as-Usual (BAU) scenario for conventional hydrothermal resources. The IRT scenario modeled the impact of 4-year regulatory timelines against the current average BAU regulatory timeline of 8 years 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

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[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

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[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.