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Geothermal Energy and U.S. Competitive Advantage: Drill, Baby, Drill

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Introduction

The United States and the rest of the world sit at the intersection of potentially destabilizing trends. Great power competition, climate change, intensifying geopolitical uncertainty, the economy's potential deglobalization, and the potential massive increase in energy demands arising from artificial intelligence (AI) are creating challenges for U.S. national energy policy. A foremost concern is the vulnerability of energy supply chains to interference from or control by a hostile power.

In this dynamic context, U.S. energy policy has evolved significantly in terms of markets, supplies, regulation, and legislation. The country's success in using fracking technology and exploiting abundant shale reserves have made it the world's largest producer of hydrocarbons and a major exporter, especially of natural gas.[1] Further, as national and international concerns about climate change have grown, U.S. energy policy has become more aligned with transitioning to renewable sources. So far, the focus of clean energy additions has been on wind, solar, and nuclear power. Beginning in the mid-2000s, the United States issued legislation and policies raising renewable energy to the level of industrial policy. Among those were the Energy Policy Act (2005), the American Recovery and Reinvestment Act (2009), the Infrastructure Investment and Jobs Act (IIJA) (2021), the CHIPS and Science Act (2022), and the Inflation Reduction Act (IRA) (2022).

However, geothermal energy—which uses the heat of the earth's crust for power—has been largely left out of U.S. industrial policy. This is despite the facts that utilizing this source of renewable energy requires some of the same technologies that have made the United States the world's top oil and gas producer and that geothermal has the potential to provide clean, dispatchable power that does not rely on weather conditions.

With U.S. clean firm power demand expected to increase by approximately 700–900 gigawatts by 2050,[2] the United States needs to dramatically increase capacity while reducing or eliminating net carbon output and insulating its energy supply from dependence on international supply chains. The question for the country now is: how should public and private resources be directed to provide the United States with an energy system optimized for the current national and international environment?

This paper argues that recent advances in geothermal power have made it the technology with superior characteristics for future U.S. energy system development. With its comparative advantages, geothermal power merits an urgent, intense, and dedicated reorientation of U.S. industrial policy, legislation, and resources.

Geothermal Energy: Background

There are three common uses of geothermal energy systems: direct use (such as through hot springs and district heating systems), heat pumps for individual buildings, and electricity generation. Geothermal electricity generation technologies can be divided into two classes: conventional hydrothermal systems and next generation geothermal systems.[3] Next generation systems are further classified by technique into enhanced geothermal systems (EGS), which require drilling (fracking) to create a reservoir, and advanced geothermal systems (AGS), which use a closed loop system instead of a fracked rock reservoir system.[4]

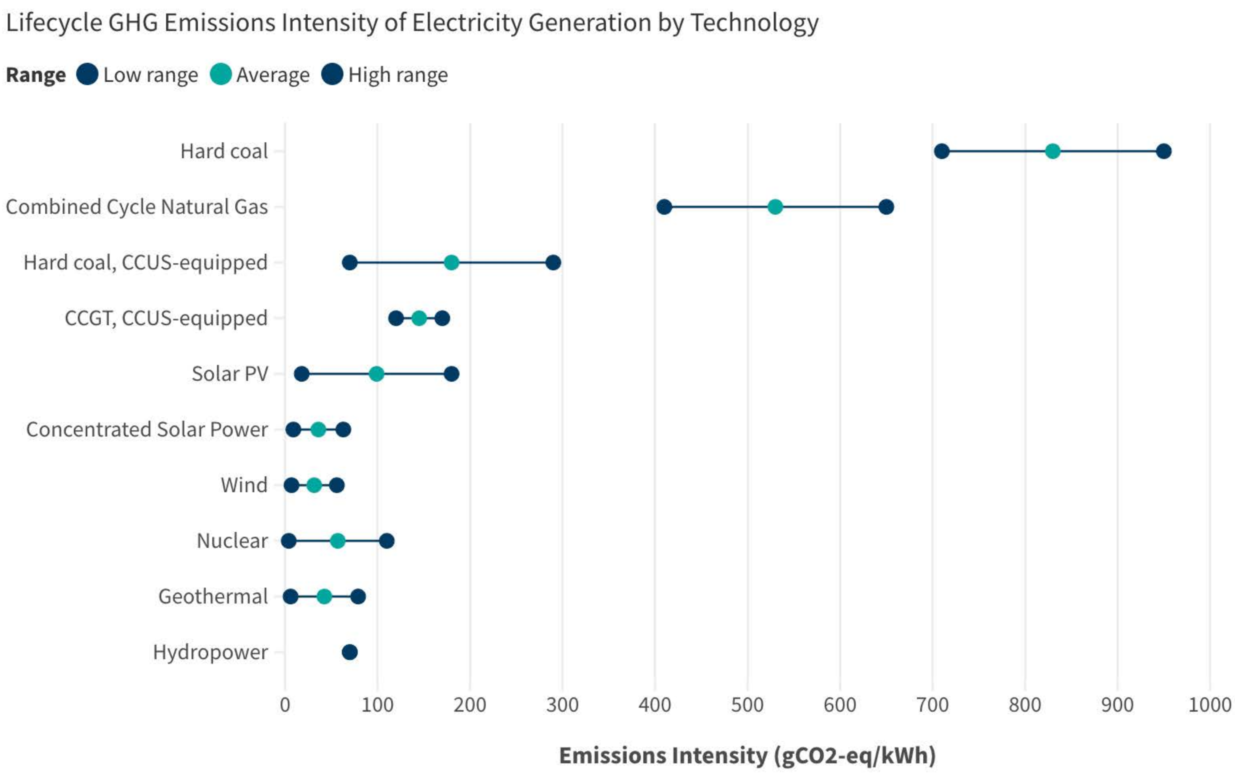
Up to the 2010s, U.S. geothermal production relied on conventional hydrothermal systems. This type of production is extremely limited because it can only occur in geographic areas with specific conditions, for instance, where hot rocks are close to the surface in volcanically active areas. The United States has an estimated 40 gigawatts of total potential for conventional systems, of which 9 gigawatts are identified and 3.7 gigawatts in operation.[5] Next generation geothermal (EGS/AGS), on the other hand, is available at varying depths throughout the country and the world. In the United States, there is potential nationwide, with the highest potential availability in the West.[6] Per the U.S. Department of Energy (DOE), EGS/AGS represents an opportunity to produce over 5 terawatts of U.S. electricity generation capacity, approximately five times the nameplate capacity of all U.S. utility scale electricity generation plants in 2023.[7]

With EGS/AGS development in competition with other energy sources for public and private funding and resources, government policy should take into consideration the relative advantages and disadvantages of each.

What Geothermal Has to Offer

Geothermal energy compares favorably in various ways to other methods of energy production. Most importantly, it does not produce significant greenhouse gas emissions (GHG). According to the National Renewable Energy Laboratory (NREL), life cycle GHG emissions from geothermal systems are slightly lower than those from utility scale solar photovoltaic (PV) systems, although this study found that geothermal systems produced slightly more emissions than other low-carbon sources such as wind power (see figure 1).[8] In EGS, emissions are primarily created or released during the drilling phase and when stored carbon in subsurface strata is released.[9]

Figure 1. Geothermal's Emissions Edge



Source: Intergovernmental Panel on Climate Change, "Chapter 7: Energy Systems," in Assessment Report 5, December 2013, pages 34-36, https://archive.ipcc.ch/pdf/assessment-report/ar5/wg3/drafts/fgd/ipcc_wg3_ar5_final-draft_fgd_chapter7.pdf.

But geothermal power still has some advantages over other low-carbon energy sources. It provides firm dispatchable power, unlike wind and solar, which operate intermittently and thus require significant energy storage. According to the International Energy Agency (IEA), global geothermal capacity had an average utilization rate—the ratio of its actual power generation compared to its maximum possible generation over a period of time—of over 75 percent in 2023, whereas solar PV had less than 15 percent and wind power less than 30 percent.[10] This makes it suitable to power, for example, data centers that need firm power for the AI revolution; current plans to power these centers with new gas generation are a worrying sign for global emissions and demonstrate the urgency of offering low-carbon options such as nuclear or geothermal.[11]

In its firmness and ability to produce medium-temperature heat for buildings, district heating, and industrial processes, EGS/AGS is comparable to nuclear power.[12] But unlike nuclear, it does not produce highly radioactive waste that requires specialized and expensive management; next generation geothermal produces primarily solid waste from drilling and some waste associated with the power plants.[13] While it requires about a third more land than nuclear power (not considering radioactive waste disposal land requirements), its projected land use footprint in 2030 is approximately 10 percent of that of wind.[14]

Crucially, geothermal also builds on existing U.S. strengths and circumvents U.S. weaknesses. Drilling into the ground for clean heat requires many of the same technologies and capacities required to exploit oil and gas resources. U.S. firms and workers have an abundance of these technologies and skills, and 80 percent of hydrocarbon skills are transferable to geothermal, according to the IEA.[15] Oil and gas workers who are interested in working in a low-carbon industry could bring their subsurface skills to a fast growing industry. The DOE estimates that getting EGS/AGS to scale would create or preserve about 60,000 permanent jobs with transferable skills from oil and gas extraction.[16] EGS/AGS is also poised to preserve and expand employment for those currently in the hydrocarbon sector of electricity generation.[17] As the United States' electricity generation capacity continues to build and evolves away from carbon-based generation to renewable sources, the development of EGS/AGS can be expected to preserve the existing oil and gas employment pool.

U.S. firms could also take advantage of a growing international market: the IEA projects that geothermal energy could meet 15 percent of global electricity demand growth to 2050, producing almost 6,000 terawatt hours per year, as much electricity as the U.S. and India consume today combined.[18] That corresponds to potentially $140 billion in yearly investments globally. The United States will benefit if some of that money is spent on hiring American firms and workers to build geothermal systems around the world, in partnership with local engineers.

What's more, geothermal supply chains do not have the same weaknesses as those that plague other major low-carbon sources with growth potential. Solar power has a large supply chain vulnerability, with 80 percent or more of world production capacity in China,[19] versus

2 percent in the United States.[20] Despite the recent boom in solar manufacturing in the United States, solar power is still highly reliant on panels from Southeast Asia, which often use Chinese inputs.[21]

Nuclear power is not dependent on external technology providers; the only nuclear power plant under construction in the United States is being built by an American company.[22] But nuclear power does depend on external suppliers for fuel, with only 5 percent produced in the country and 95 percent from international supply chains.[23] Approximately half of all supplies come from Kazakhstan (25 percent), Russia (12 percent) and Uzbekistan (11 percent) combined, according to 2022 data.[24] In 2024 the United States enacted a bipartisan bill banning the import of Russian uranium, which should encourage the development of a stronger domestic nuclear fuel supply chain, though this will take time.[25]

Only two currently available technologies—hydroelectric and EGS/AGS—are essentially independent of supply chain vulnerabilities.

Cost Considerations

To determine the economic viability of EGS/AGS versus other renewable energy systems, this paper compares the energy systems' economic efficiency and financial risk by focusing on the levelized cost of energy (LCOE) and upfront capital costs per unit of energy.

The LCOE represents "the present value of the total cost of building and operating a generating plant over its economic life, converted to equal annual payments, and adjusted for inflation."[26] Lazard, a leading financial advisory and asset management firm, has found that the LCOE of unsubsidized conventional hydrothermal power generation is in the same range as coal, combined cycle gas plants, and some solar and onshore wind, in particular those with four hours of storage capacity. Conventional geothermal's LCOE is superior to nuclear, gas peaking plants, and offshore wind.[27]

Yet Lazard does not account for "firming costs,"[28] which helps explain the continued expansion of fossil generation around the world despite wind and solar having lower average LCOE.[29] These costs are associated with using other firm energy sources or batteries to fill in the capacity shortfalls caused by the intermittencies of wind and solar. With this taken into account, conventional geothermal's LCOE range of $64–$106 per megawatt-hour (MWh) is comparable to offshore wind and combined cycle gas in most U.S. regions.[30]

EGS/AGS, as an incipient technology, does not yet have comparable, repeatable data to generate its commercial LCOE. But based on data from NREL, the DOE estimates that the current LCOE for first of a kind EGS is about $200 per MWh, or 50–100 percent above the LCOE of firmed wind and solar and equivalent to the high end of gas peaking plants' range.[31] And the U.S. government intends to help drive it much lower: the DOE Enhanced Geothermal Shot initiative's objective is to reduce the LCOE of unsubsidized EGS/AGS to $45 per MWh by 2035.[32]

If EGS/AGS can achieve comparable cost reductions to solar power—whose LCOE fell 89 percent from 2009 to 2023—the technology could become a serious, economical competitor to firmed solar and wind.[33] The shift from conventional geothermal to EGS/AGS could make that possible. Changing focus would open the potential geography from 4 percent of the country to virtually 100 percent. With that change would come a shift in the main locus of expense from resource exploration (finding favorable geography) to resource creation (using advanced techniques to deploy the technology nearly anywhere).[34] In fact, some literature has found that EGS has an even higher learning rate than solar, if on a much smaller scale: the U.S. firm Fervo Energy's horizontal drilling for EGS wells achieved a learning curve of 35 percent.[35]

U.S. Industrial Policy Has Neglected Geothermal

Solar and wind energy did not achieve their levels of cost effectiveness based on the altruistic motivations of their developers. Instead, they came as a result of almost two decades of increasingly aggressive public policy and financial incentives. Beginning with the Energy Policy Act of 2005, the U.S. government has deployed increasingly broad and ever larger sums for the development of clean energy resources. Data from 2016–2022 are demonstrative (see table 1).[36]

The table shows that of the $61 billion in government support over the time period, a majority in utility scale green energy went to solar (60 percent) and wind (31 percent). That is to be expected in some ways because nuclear confronted social and political resistance, and hydropower, biomass, and traditional hydrothermal geothermal had well-known natural limits to their potential growth. EGS/AGS was only just under development during this period.

Figure 2 further depicts how geothermal has been left out of previous U.S. government funding packages. But it is also misleading because only one of the alternatives to geothermal presented—nuclear—actually produces power. Hydrogen is a derivative fuel, and the others require additional costs for "greening" existing carbon-based fuels. The demonstration funding provided therefore neither adds to the power supply nor improves economic efficiency.

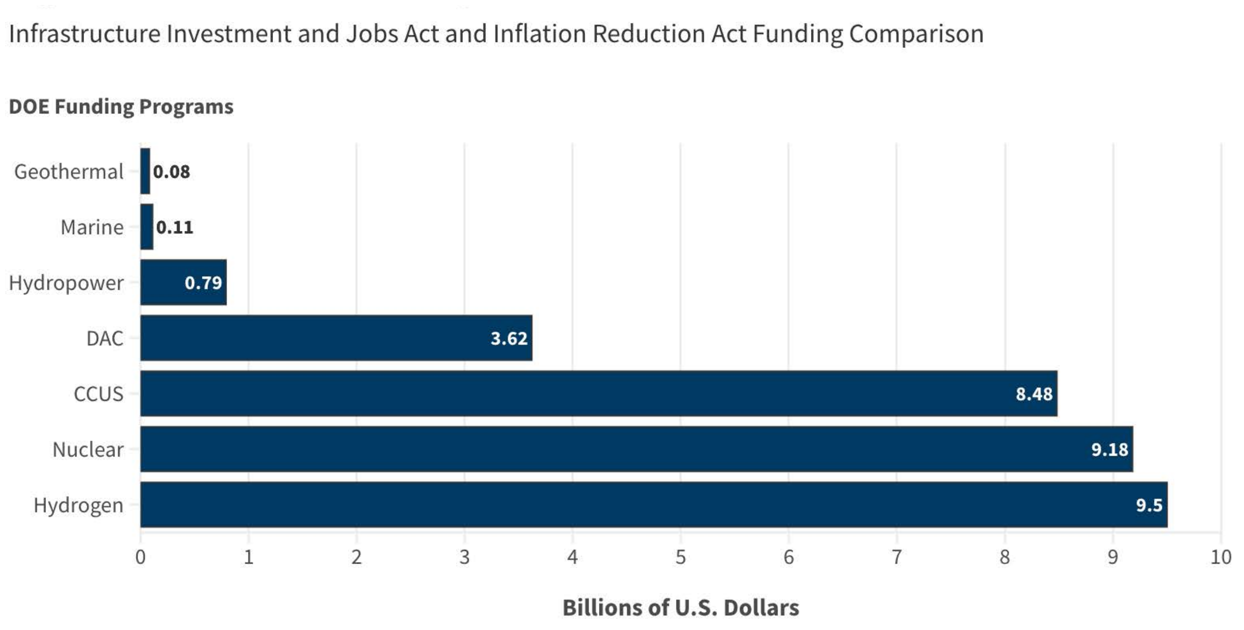
Table 1. Total Subsidies, Utility Scale Energy in Millions of U.S. Dollars, 2016–2022

Year	Coal	Oil and Gas	Nuclear	Biomass	Hydro	Solar	Wind	Geothermal	Total Green
2016	1,821	-921*	415	33	26	3,036	846	19	4,375
2017	2,620	-938	463	57	83	3,437	899	25	4,964
2018	2,578	2,065	354	113	22	4,054	2,248	127	6,918
2019	2,400	2,966	313	146	35	4,418	3,201	299	8,412
2020	2,348	1,701	355	232	46	6,982	4,021	141	11,777
2021	2,622	2,100	563	228	53	7,028	3,858	151	11,881
2022	873	2,304	390	312	41	7,522	3,592	353	12,210
Total	**15,262**	**9,277**	**2,853**	**1,121**	**306**	**36,477**	**18,665**	**1,115**	**60,537**

Note: The Department of the Treasury explains that subsidies may take on a negative value in some years because of economic conditions and other factors.

Source: "Federal Financial Interventions and Subsidies in Energy in Fiscal Years 2016-2022," Energy Information Administration

Figure 2. U.S. Industrial Policy Underfunds Geothermal



Source: "Infrastructure Programs at Department of Energy," U.S. Department of Energy, accessed January 16, 2024, https://www.energy.gov/infrastructure/infrastructure-programs-department-energy.

The focus on solar and wind, in combination with learning effects in foreign markets such as Germany and China, has had the intended effect of reducing solar PV's LCOE by almost 90 percent and onshore wind by almost 70 percent between 2010 and 2023.[37] The result has been to make unfirmed utility scale solar and wind more cost competitive than fossil fuels in utility scale electricity production.[38]

The IRA of 2022 became potentially the most impactful legislation for the wind and solar sectors, making available $369 billion for renewable energy, pollution reduction, and environmental justice.[39] The success of subsidies to date, however, raises important policy questions: With solar and onshore wind having achieved LCOEs below those of fossil fuels, why would continued and vastly expanded subsidies be necessary to incentivize further development? Does the private sector still lack the economic incentive to continue development?

One possible explanation is that wind and solar have already developed in the easiest and most productive geographies and that further infill in resource-dense zones is complicated by limited availability of suitable land. Subsidies can therefore potentially aid in expanding into less favorable areas. However, other analyses suggest that is not the case. Lazard analysis suggests that the extension of the Investment Tax Credit (ITC) and Production Tax Credit (PTC) in the IRA will drive further decreases in low-end LCOE for wind from $26 to $9 per MWh and for solar from $29 to $28 per MWh.[40] That suggests developers in those areas would reap a benefit not related to carbon reduction (as they already have a cost advantage incentive to develop). It also suggests that such a use of funds is inefficient and ineffective public policy.

How EGS/AGS Can Strengthen U.S. Competitive Advantage

Next generation geothermal has the potential to strengthen the United States' geopolitical, diplomatic, and economic power in the following ways:

- **Enhance U.S. Geoeconomic Power:** Next generation geothermal energy has the potential to equally impact both U.S. national and international energy supplies. Given geothermal energy's near universal availability and inherent advantages over wind and solar, U.S. dominance in a fully developed geothermal energy segment could enhance the country's geopolitical and diplomatic power. For example, U.S. companies and agencies could provide an opportunity for vastly increased U.S. participation in building energy system resilience in vulnerable geographies, including

Europe, which still imports Russian oil and gas,[41] and Taiwan, which is exposed to Chinese aggression. Geothermal could provide win-win opportunities for the United States and partner countries.

- **Enhance the U.S. Military's Base Resilience, Efficiency, and Projection of Power:** For U.S. military bases, overseas energy represents an important component of direct and logistical expenses, as well as a significant vulnerability. EGS/AGS could provide greater energy supply reliability, economy, and resilience to U.S. overseas military installations, strengthening their strategic planning.

- **Provide Economic Opportunities:** U.S. corporations have an unequalled capacity in the subsurface technologies on which EGS/AGS depends, and the foremost developers in the sector are American companies. While the sector is still in a nascent state, companies such as Fervo, Quaise Energy, GreenFire Energy, and others have begun to explore projects in Taiwan, Japan, Western Europe, and West Africa.[42] Export earnings from a fully developed EGS/AGS segment would accrue principally to U.S. companies.

Pathway for Future Policy Development

Given its favorable characteristics relative to other energy systems, EGS/AGS can presumably become a major—if not the major—pillar of U.S. green energy. The question that needs addressing is what is required to achieve that. The current and subsequent Congresses should determine whether and how U.S. renewable energy industrial policy can be reassessed and reoriented to make room for EGS/AGS.

The DOE's road map for next generation geothermal, published in March 2024, seeks a 68 percent reduction from an estimated overnight (interest rate independent) capital cost of approximately $14,700 per kilowatt hour in 2023 to a low-end of $4,700 per kilowatt hour, or $60 per MWh, in 2030.[43] That 68 percent reduction could come from three basic sources: improved data collection and analysis on subsurface geologic conditions, leading to the need to drill fewer exploration wells; reduced well and reservoir construction costs as industry experience progresses; and lower power plant costs as the first two lead to higher fluid flow rates.[44] The road map then suggests a further 20 percent reduction of 2030 costs by 2050 given continuous marginal improvements on all of the above.[45]

The upfront investment required for EGS/AGS is extremely high in terms of drilling costs. For tax credits and other subsidies to be effective, investors need a reasonable belief that development costs can be offset by production. Those costs have two risk factors: the drilling time required (the most directly related indicator of cost) and the unknown nature of the subsurface geology in a given site. While it is possible to drill and access the earth's heat anywhere, the type of rock that must be drilled through is an important factor for the cost of power delivery. Better mapping and understanding of subsurface geology can therefore help predict costs. As for drilling times, early indications from the DOE's Frontier Observatory for Research in Geothermal Energy (FORGE) research and development site in Utah show that these can be vastly reduced, having dropped by more than 500 percent from when the first well was drilled in 2017 until 2024. Similarly, Fervo's drilling rates have reportedly shown a 300 percent increase in a period of six months over six wells.[46]

It is important to note that the costs per megawatt hour cited in the road map are unsubsidized LCOE equivalents. They do not take into account potential tax credits and other subsidies in U.S. industrial policy legislation. Subsidies—which could be stacked by up to 70 percent of upfront costs—could make EGS/AGS highly competitive as a firm energy technology.[47] The greatest issue it faces is that while it has been proven a viable technology, it does not yet have a profile of known, repeatable, and dependable costs. That leaves the technology needing equity-only financing, as institutional debt will not be available in the absence of a proven risk profile. Of the estimated $20–25 billion investment needed by 2030 to prove the market opportunity, the DOE plan envisions a portfolio of ten first-of-a-kind demonstration projects at a total cost of about $4.5 billion.[48] An investment of that nature would be on the low-end of funding allocated to other nascent technologies under the industrial policy acts cited above (see figure 2).[49]

In sum, while the potential of EGS/AGS is large and the progress on cost optimization is promising, the lack of reliable repeatability and uncertain resulting production create a risk profile that inhibits large-scale investment. Given that subsurface geology and drilling optimization are the two gateway risks to mitigate, the DOE road map divides the investment ramp into two periods: "liftoff/proving" the market opportunity by 2030 and "achieving scale" by 2050.[50]

Policy and Legislative Recommendations

Given all the factors discussed above, next generation geothermal has at least as much potential as wind and solar to be an important pillar of the U.S. energy system by 2050. In the event the DOE road map's objectives are realized, it would also represent a clean energy source that improves economic efficiency relative to current carbon-based generation. The most important question is how public policy and private investment can combine to explore and then realize the opportunity.

The DOE road map proposes an initial investment of $4.5 billion for ten demonstration projects. The potential benefits outlined in this paper seem to easily justify such an investment by the government itself, given the amounts it has already allocated to demonstration projects for other energy sources. With geothermal supporters like Energy Secretary Chris Wright and Interior Secretary Doug Burgum newly confirmed to run the DOE and the Department of the Interior, respectively, there are leaders in the Donald Trump administration ready to advocate for and work with Congress to support the development of geothermal energy resources.

Short of appropriating more funding for geothermal energy and new legislation,[51] Congress, the Department of Energy, and the Department of Defense could take the following actions, as applicable, to provide the resources for demonstration projects:

- As of January 2024, the Loan Programs Office had a total of approximately $85 billion of investable funding that is applicable to EGS/AGS.[52] The Department of Energy could segregate a portion of those funds for EGS/AGS demonstration project purposes.

- Likewise, the DOE's Office of Clean Energy Demonstrations could reallocate any remaining money in the IIJA and IRA demonstration project funding chart above to EGS/AGS liftoff. The DOD could complement these efforts by continuing to develop geothermal demonstration sites.

- The DOD's Innovation Unit has been the most active single next generation developer of EGS/AGS, with seven projects currently under development on military bases in five states.[53] As a resilient, behind-the-meter energy source, next generation geothermal represents an attractive option for base development domestically and especially internationally. The DOD has dedicated funding to the effort. Because of its manageable footprint, fuel independence, and lack of waste management issues, as is the case for modular nuclear reactors, EGS/AGS has become the main focus of DOD clean and independent energy production.[54] Given this activity, Congress could direct money destined for DOD for demonstration projects at greenfield sites through the annual appropriations process.

- The IRA established an enhanced use of the Defense Production Act (DPA), allocating $500 million for critical minerals and heat pumps.[55] The DPA could likewise be used as a vehicle for funding, for example for manufacturing of the organic Rankine cycle turbines that turn geothermal heat into electricity.[56]

- The Chips and Science Act established the Foundation for Energy Security and Innovation (FESI) to "accelerate the commercialization of new and existing energy technologies by raising and investing funds through engagements with the private sector and philanthropic communities."[57] FESI is a nonprofit 501(c)(3) organization independent of but in coordination with DOE that has a nonvoting member on the Board of Directors. That board is now active, having held its first meeting May 1, 2024.[58] Like the DPA, FESI could serve as an established vehicle for creating a joint fund with private capital, including an aggregation of high intensity offtake companies (such as data centers), oil and gas companies, and large financial funds with an interest in EGS/AGS development.

- Congress could direct some of the annual appropriations for DOE's laboratory system and/or other departments and agencies, such as Bureau of Land Management or the U.S. Geological Survey (USGS), to defray some of the upfront subsurface characterization costs of government, private, or public-private-partnership demonstration projects.

- Agencies such as the Development Finance Corporation, Millennium Challenge Corporation, and the Export-Import Bank should explore opportunities with U.S. firms to provide finance for bankable projects in priority foreign countries to develop their own geothermal energy sectors. The need to reauthorize DFC (by September 2025) and EXIM (by December 2026) provides opportunities to get these organizations to focus on next-generation geothermal.

Conclusion

Much like for wind and solar fifteen years ago, it is a rational and imperative choice for Congress and the executive branch to provide a risk-mitigating safety net to get EGS/AGS development beyond its valley of death demonstration stage. Because EGS/AGS is an incipient technology that lacks a track record of repeatable financial performance, it is at a disadvantage in competition for private institutional funders attracted to federal subsidies under the IRA and other recent industrial policy legislation.

U.S. industrial policy has poured hundreds of billions of dollars into wind, solar, and nuclear power, as well as for manufacturing batteries and providing consumer-side subsidies for electric vehicles and residential energy upgrades. Yet it has essentially ignored next generation geothermal, despite its promise to provide firm, low-carbon power and heat without the supply chain vulnerabilities that bedevil other important clean power sources. In the interest of U.S. economic strength, environmental quality, and national security, funding EGS/AGS development is a rational imperative. The objective should be to de-risk upfront EGS/AGS capital costs and reduce its LCOE so it can take its rightful place as a pillar of the United States' and the global low-carbon energy system.

About the Authors

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Notes

1 “United States Produces More Crude Oil than Any Country, Ever,” U.S. Energy Information Administration, March 11, 2024, https://www.eia.gov/todayinenergy/detail.php?id=61545. Brad Plumer and Nadja Popovich, “How the U.S. Became the World’s Biggest Gas Supplier,” *New York Times*, February 3, 2024, https://www.nytimes.com/interactive/2024/02/03/climate/us-lng-natural-gas-leader.html.

2 Arthur Blankenship et al., “Pathways to Commercial Liftoff: Next-Generation Geothermal Power,” U.S. Department of Energy, Geothermal Technologies Office, March 2024, https://liftoff.energy.gov/wp-content/uploads/2024/03/Liftoff_DOE_NextGen_Geothermal.pdf.

3 Blankenship et al., “Pathways to Commercial Liftoff,” 10.

4 Blankenship et al., “Pathways to Commercial Liftoff,” 10.

5 Blankenship et al., “Pathways to Commercial Liftoff,” 10.

6 “Geothermal - Energy Kids: U.S. Energy Information Administration (EIA),” accessed May 1, 2024, https://www.eia.gov/kids/energy-sources/geothermal.

7 Blankenship et al., “Pathways to Commercial Liftoff,” 10; and Lindsey Buttel, “America’s Electricity Generating Capacity 2023,” American Public Power Association, May 2023, https://www.publicpower.org/system/files/documents/Americas_Electricity_Generating_Capacity_2023_Update.pdf.

8 Annika Eberle et al., “Systematic Review of Life Cycle Greenhouse Gas Emissions from Geothermal Electricity,” National Renewable Energy Laboratory, September 29, 2017, https://doi.org/10.2172/1398245, 9 and appendix A.

9 Thomas Fridriksson et al., “Greenhouse Gas Emissions from Geothermal Power Production,” World Bank, February 13, 2017, https://documents1.worldbank.org/curated/en/875761592973336676/pdf/Greenhouse-Gas-Emissions-from-Geothermal-Power-Production.pdf.; and T. Bruckner et al., “2014: Energy Systems,” in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press: Cambridge, United Kingdom and New York, NY), https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf.

10 International Energy Agency, “The Future of Geothermal Energy,” December 2024, https://www.iea.org/reports/the-future-of-geothermal-energy.

11 Matthew Zeitlin, "Investors Are Expecting a Natural Gas Boom. Will They Get It?," Heatmap, December 10, 2024, https://heatmap.news/economy/ge-vernova-natural-gas-ai.

12 Geothermal Technologies Office, "What Is an Enhanced Geothermal System?," U.S. Department of Energy, May 2016, https://www.energy.gov/sites/default/files/2016/05/f31/EGS%20Fact%20Sheet%20May%202016.pdf.

13 "Enhanced Geothermal Systems: Introduction and Issues for Congress," Congressional Research Service, September 29, 2022, https://crsreports.congress.gov/product/pdf/R/R47256.

14 Natanael Bolson, Pedro Prieto, and Tadeusz Patzek, "Capacity Factors for Electrical Power Generation from Renewable and Nonrenewable Sources," *Proceedings of the National Academy of Sciences* 119, no. 52 (December 27, 2022): https://doi.org/10.1073/pnas.2205429119, e2205429119; and Alexander Richter, "Geothermal Energy Is Least Land-Use Intense Source of the Renewable Energy Technologies," ThinkGeoEnergy, Geothermal Energy News (blog), January 22, 2021, https://www.thinkgeoenergy.com/geothermal-energy-is-least-land-use-intense-source-of-the-renewable-energy-technologies.

15 International Energy Agency, "The Future of Geothermal Energy."

16 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 18.

17 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 18.

18 International Energy Agency, "The Future of Geothermal Energy."

19 International Energy Agency, "The World Needs More Diverse Solar Panel Supply Chains to Ensure a Secure Transition to Net Zero Emissions," July 7, 2022, https://www.iea.org/news/the-world-needs-more-diverse-solar-panel-supply-chains-to-ensure-a-secure-transition-to-net-zero-emissions.

20 Eric Wesoff, "Can the US Manufacture Enough Solar Panels to Meet Its Surging Demand?," Canary Media, June 7, 2023, https://www.canarymedia.com/articles/solar/can-the-us-manufacture-enough-solar-panels-to-meet-its-surging-demand.

21 Quill Robinson and Ryan Featherston, "Assessing the United States' Solar Power Play", Center for Strategic and International Studies, July 1, 2024, https://www.csis.org/analysis/assessing-united-states-solar-power-play.

22 U.S. Energy Information Administration, "U.S. Nuclear Industry," accessed May 1, 2024, https://www.eia.gov/energyexplained/nuclear/us-nuclear-industry.php.

23 "Uranium Marketing Annual Report," U.S. Energy Information Administration, accessed March 1, 2025, https://www.eia.gov/uranium/marketing/

24 "Where Our Uranium Comes From," U.S. Energy Information Administration.

25 Backgrounder on uranium import ban. (n.d.). NRC Web. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/uranium-import-ban.html

26 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 11.

27 George Bilicic and Samuel Scroggings, "2024 Levelized Cost of Energy+," Lazard, June 2024, https://www.lazard.com/research-insights/levelized-cost-of-energyplus.

28 George Bilicic and Samuel Scroggins, "2023 Levelized Cost of Energy+," Lazard, April 12, 2023, https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus, 8.

29 International Renewable Energy Agency, "Renewable Power Generation Costs in 2023," September 2024, https://www.irena.org/Publications/2024/Sep/Renewable-Power-Generation-Costs-in-2023.

30 Bilicic and Scroggings, "2024 Levelized Cost of Energy+"

31 George Bilicic and Samuel Scroggins, "2023 Levelized Cost of Energy+," Lazard, April 12, 2023, https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus, 9.

32 "Enhanced Geothermal Shot," U.S. Department of Energy, accessed on February 2, 2025, https://www.energy.gov/topics/enhanced-geothermal-shot.

33 Beatriz Santos, "Average Solar LCOE Increases for First Time This Year," pv magazine, April 14, 2023, https://www.pv-magazine.com/2023/04/14/average-solar-lcoe-increases-for-first-time-this-year.

34 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 24.

35 Kareem El-Sadi et al., "Review of Drilling Performance in a Horizontal EGS Development," Stanford University, February 12, 2024, https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2024/Elsadi.pdf.

36 U.S. Energy Information Administration, "Federal Financial Interventions and Subsidies in Energy in Fiscal Years 2016-2022," August 2023, https://www.eia.gov/analysis/requests/subsidy/pdf/subsidy.pdf, 20–24.

37 Santos, "Average Solar LCOE Increases for First Time This Year."

38 International Renewable Energy Agency, "Renewable Power Generation Costs in 2022," 17.

39 "Treasury Announces Guidance on Inflation Reduction Act's Strong Labor Protections," U.S. Department of the Treasury, November 29, 2022, https://home.treasury.gov/news/press-releases/jy1128.

40 George Bilicic and Samuel Scroggings, "2024 Levelized Cost of Energy+," 10.

41 "EU imports of Russian fossil fuels in third year of invasion surpass financial aid sent to Ukraine," Centre for Research on Energy and Clean Air, (2025, February 26), https://energyandcleanair.org/publication/eu-imports-of-russian-fossil-fuels-in-third-year-of-invasion-surpass-financial-aid-sent-to-ukraine/.

42 Carlo Cariaga, "EAVOR targets geothermal power production at Gerestried site by 1H 2025," Think GeoEnergy, January 7, 2025, https://www.thinkgeoenergy.com/eavor-targets-geothermal-power-production-at-gerestried-site-by-1h-2025/; "Kenya Electricity Generating Company approves GreenFire Energy Inc. to commence implementation of greenfire's GreenLoop®," GreenFire Energy, April 4, 2024, https://www.greenfireenergy.com/kengen2024/.

43 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 27.

44 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 27.

45 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 27.

46 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 25.

47 Kenneth Vincent, "Energy, Climate and National Security" class discussion, Bush School of Government and Public Service, April 9, 2024, attended by one of the authors.

48 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 39.

49 "Infrastructure Programs at Department of Energy," U.S. Department of Energy, accessed January 16, 2024, https://www.energy.gov/infrastructure/infrastructure-programs-department-energy.

50 Blankenship et al., "Pathways to Commercial Liftoff: Next-Generation Geothermal Power," 32.

51 Author interviews with Jigar Shah of the DOE's Loan Programs Office, Congressman Russ Fulcher and staff, Congressman Dan Crenshaw and staff, Congressman Pete Sessions and staff, and others in the Texas congressional delegation in November and December 2024.

52 Loan Programs Office, "LPO Year in Review 2024," U.S. Department of Energy, January 17, 2025, https://www.energy.gov/lpo/articles/lpo-year-review-2024.

53 Author interview with Kenneth Wisian (Director of the Bureau of Economic Geology, University of Texas), April 3, 2024.

54 Author interview with Wisian, April 3, 2024.

55 "Inflation Reduction Act Summary: Energy and Climate Provisions," Bipartisan Policy Center, August 4, 2022, https://bipartisanpolicy.org/blog/inflation-reduction-act-summary-energy-climate-provisions, 18.

56 Advait Arun, "The Natural Gas Turbine Crisis," Heatmap News, February 26, 2025, https://heatmap.news/ideas/natural-gas-turbine-crisis.

57 "DOE Launches Foundation for Energy Security and Innovation," U.S. Department of Energy, February 9, 2023, https://www.energy.gov/articles/doe-launches-foundation-energy-security-and-innovation.

58 Author interview with Michael O'Connor (Sector Strategist, Office of Clean Energy Demonstrations), April 23, 2024.

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