Niskanen Center

# Next-generation geothermal power

## A COMMERCIAL READINESS ASSESSMENT

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The Niskanen Center is a 501(c)3 issue advocacy organization that works to change public policy through direct engagement in the policymaking process.
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# Executive summary

## BACKGROUND

Next-generation geothermal (NGG) technology has advanced significantly in recent years, resulting in cost reductions and a strong cohort of startup companies seeking to develop projects that produce electricity at grid scale. The potential amount of power that could be generated by a mature geothermal industry, and the geographic flexibility of the technology, could significantly alter the generation mix across the United States. As a carbon-free power option drawn from an inexhaustible energy source with a small land use footprint, NGG's commercialization and wide adoption would help meet many energy sector objectives, such as domestic supply diversity, emissions reductions, and round-the-clock power generation for reliability needs. These attributes have earned NGG bipartisan support. Nonetheless, continued advancement and scaling are far from inevitable.

## METHODOLOGY

To understand the commercial barriers NGG faces in the near term, we assessed the current status of the technology across a full spectrum of adoption risks. Specifically, we performed an evidence-based evaluation of the risks next-generation geothermal technologies face in the marketplace using the Department of Energy's Commercial Adoption Readiness Assessment Tool (CARAT)[1]. CARAT assigns risk levels for 17 distinct dimensions that address the technology's value proposition to users, the demand it gains in the marketplace, the maturity of supply-side inputs, and the social license to operate. More broadly, as a research tool, CARAT provides a common language for market risks, spotlights commercial readiness objectives, identifies metrics for tracking progress, and helps manage risk across projects.[2] Table 1 details the scope of our assessment.

TABLE 1: CARAT SCOPE OF ASSESSMENT FOR NEXT-GENERATION GEOTHERMAL TECHNOLOGY

| | |
|---|---|
| Technology scope | Enhanced geothermal systems (EGS) and advanced geothermal systems (AGS) for large-scale electricity production |
| Value chain scope | Complete chain from raw materials to power plant operation |
| Timeline for evaluation | 2025–2030 |
| Policy environment | Federal and state policy as of October 2025 |

We reviewed publicly available literature and interviewed geothermal practitioners to evaluate risks across CARAT's 17 dimensions. We considered both EGS and AGS within each risk dimension. Where the evidence supported different risk levels, we note the difference in our results; elsewhere, we provide a single risk designation.

EGS uses engineering to link geothermal wells and allow fluid circulation, typically boosting circulation through hydraulic or chemical stimulation of hot but low-permeability rock. AGS uses sealed wells to circulate fluid within hot subsurface environments without direct fluid contact with the rock, thus obviating rock permeability.[3] AGS technologies are sometimes referred to as "closed-loop geothermal," or CLG.

## RESULTS AND CONCLUSIONS

| | | | | | | |
|---|---|---|---|---|---|---|
| Value proposition | Delivered cost (EGS)<br>Delivered cost (AGS) | | Functional performance | | Ease of use/complexity | |
| Market acceptance | Demand maturity (EGS)<br>Demand maturity (AGS) | | Market size | | Downstream value chain | |
| Resource maturity | Capital flow | Project development | Infrastructure (EGS)<br>Infrastructure (AGS) | Manufacturing and supply chain | Materials sourcing | Workforce |
| License to operate | Regulatory | Policy environment | Permitting and siting | Environmental (EGS)<br>Environmental (AGS) | Community perception | |

Red = high risk Yellow = medium risk Green = low risk

With a very large potential market, attractive round-the-clock power generation profile, increased cost competitiveness, and favorable supply chain conditions, NGG is positioned for accelerated growth. However, it faces serious headwinds, including limited large-scale project experience; a lack of capital for project development; broad power-system infrastructure limitations; and challenging regulatory, permitting, and policy environments. Nevertheless, policy reforms could mitigate many of these key risks, creating positive momentum for building more projects and delivering the benefits that come from learning effects.

# Delivered cost

Risks associated with achieving delivered-cost competitiveness when produced at full scale, including amortization of incurred development and capital costs, and accounting for switching costs (if any)

## STATE OF PLAY

- Natural gas combined cycle power plants are the best comparison for cost parity for next-gen geothermal. The U.S. Energy Information Administration (EIA) projects that these plants will cost $55–$80/MWh in 2030.[4]
- For both EGS and AGS, cost projections are indicative engineering estimates. Uncertainty remains because there are no commercial-scale next-gen geothermal plants operating today in the U.S.[5] to provide an empirical basis for analysis.

## TRENDS

The segment of the EGS supply curve that has 100+ GW deployment potential in the U.S. is expected to cost $64–$111/MWh[6] by 2030 with tax credits.[7]

Multiple technology[9] and permitting improvements[10] could reduce EGS levelized cost of electricity (LCOE) to $45/MWh without tax credits by 2035.

Recent modeling[8] identified some EGS sites below $50/MWh, underscoring the potential for ongoing rapid cost reductions.

Compared with EGS, AGS is expected to have a higher capital expenditure (capex)[11] and has an uncertain path to cost parity with incumbents.

## ASSESSMENT

Next-gen geothermal technologies are more than five years away from cost parity with incumbent round-the-clock natural gas power plant technology, but technology advances and permitting improvements are possible pathways to parity for EGS.

### LOW RISK

Technology solution is either: a) currently more cost-effective than the incumbent or competing technology; or b) close to cost parity and on a clear cost curve to achieve cost parity within 3 years, and fundamental cost components (e.g., cost of critical inputs) are not at risk of significant market swings.

### MEDIUM RISK

Technology solution is more than 5 years away from cost parity with incumbent or competing technology but is on a clear path to be more cost effective; and/or there are some fundamental cost components that are at risk of market swings.

EGS

### HIGH RISK

Technology solution is more expensive than the incumbent or competing technology and there is no clear path to cost competitiveness without substantial R&D advances.

AGS

# Functional performance

Risks associated with the ability of the technology solution to meet or exceed the performance and feature set of incumbent solutions or to create new end-use markets

## STATE OF PLAY

- Conventional geothermal has a multidecade track record for continuous power output.[12] However, NGG's limited operational history creates performance uncertainty.
- NGG's round-the-clock performance capabilities are comparable to natural gas combined cycle (NGCC), and nuclear, while offering functionality benefits that include (depending on technology comparison) a fuel-free renewable energy resource base, zero carbon emissions, comparable or lower land and water impacts, and higher modularity.[13]

## TRENDS

A 2021 review of 64 EGS projects documented numerous difficulties, such as drilling issues, seismicity, and reservoir development. Even so, 29 projects are generating more electricity after EGS technology implementation.[14]

AGS has reached early commercial deployment, with Eavor's Munich-area facility delivering electricity to the German grid at Geretsried in December 2025[16] and aiming to scale output to 8 MW.[17]

More recently, Fervo Energy's 3.5 MW Project Red EGS plant in Northern Nevada has published a year of operational data showing no production decay for the period.[15] Fervo's Project Cape in Southwestern Utah is scheduled to begin operation in 2026 with 100 MW of generation.

Together, these examples suggest an NGG Technology Readiness Level[18] of 6–8, corresponding to testing conditions ranging from pilot-scale demonstration to full-scale operation in expected conditions.

## ASSESSMENT

NGG could perform equivalent to round-the-clock power technologies such as natural gas, but its limited operational history makes its performance uncertain. Compared with its competitors, NGG technologies have functionality advantages relative to size and environmental impacts.

### LOW RISK

Technology solution provides sustained improved performance and/or benefits that justify a premium (if any) in an existing end-use case or value in a new end-use case.

### MEDIUM RISK

Technology solution provides equivalent functionality to existing products (i.e., same performance on all key parameters); or improved performance does not justify current premium; or performance differential will not be sufficiently sustained (e.g., lack of fundamental competitive advantage or weak IP protection allows incumbent or competitors to reduce differential quickly).

AGS EGS

### HIGH RISK

Technology solution provides poorer functionality than solutions currently in place.

# Ease of use/complexity

Risks associated with operational switching costs; the ability of a new user (individual, company, or system integrator) to adopt and operationalize the technology with limited training, few new requirements, or special resources (e.g., tools, workforce, contract structures)

## STATE OF PLAY

→ Basic power turbine-generator technologies underpin NGG power plants,[19] similar to long-dominant fossil/nuclear power equipment but using Organic Rankine Cycle[20] technology.

## TRENDS

93 geothermal power plants operate across 8 states in organized wholesale markets and nonregional transmission organization (RTO) grids, spanning a variety of utility offtakers and plant operators such as Calpine, Ormat, Pacificorp, and Northern California Power Agency.[21]

## ASSESSMENT

Geothermal power plants use familiar turbine-generator technology, and numerous utilities and third-party market participants have direct, long-term experience with these facilities, providing entry points and pathways of diffusion through peer exchange that make NGG essentially plug and play with current infrastructure and markets.

### LOW RISK

Technology solution is easy for a typical user/operator to use/operate and to maintain (e.g., highly intuitive with little need for additional training, or similar to existing systems, and is plug and play with current infrastructure/ equipment).

AGS EGS

### MEDIUM RISK

Technology solution can be operated and maintained by a typical user/operator after some training, and allows for interoperability with existing infrastructure/equipment with minor adjustments.

### HIGH RISK

Technology solution deployment requires extensive operations and maintenance training of personnel and/or there are meaningful integration costs to successfully use/integrate the product.

# Demand maturity/market openness

Risks associated with demand certainty and access to standardized sales and contracting mechanisms (if required), as well with natural (e.g., network effects, first-mover advantages) and/or structural (e.g., existing monopolies/oligopolies) barriers to entry in the market(s) to which the technology solution can be applied

## STATE OF PLAY

- Utilities and merchant generators that own coal, gas, and nuclear power plants dominate the sector,[22, 23] but wind and solar have overcome barriers to entry,[24] illustrating alternatives' viability.
- Competitive wholesale markets offer low barriers to entry where there is demand from large customers.

## TRENDS

There are 780 MW of executed letters of intent and power purchase agreements for NGG[25] and an expanding list of customer supply options designed for geothermal, such as NV Energy's Clean Transition Tariff.[26]

The cost premium of AGS compared with EGS is a significant obstacle to AGS's demand maturity.

## ASSESSMENT

Although competing technologies and incumbent generation providers present barriers to entry, solar and wind successfully entered the market and grew, illustrating that alternatives can be viable. Letters of intent, long-term PPAs, and geothermal-friendly tariffs demonstrate offtake avenues and market interest for NGG.

### LOW RISK

There is a clear path for the technology solution to be introduced in a target market and gain initial traction; and there is standardized offtake (e.g., long-term agreements, hedgeable commodity market, accessible consumer market).

### MEDIUM RISK

Technology solution would need to overcome substantial barriers to market entry posed by competing technologies but has a clear path to do so; and there is a developing standardization of offtake.

EGS

### HIGH RISK

Technology solution's ability to enter the market is limited due to incumbent advantages; or offtake is not easy/standardized and does not meet the needs of technology solution deployment.

AGS

# Market size

Risks associated with the overall size of the market that the technology can serve, and the level of uncertainty with which the market will materialize



## TRENDS

U.S. electricity demand is expected to grow by 800 TWh from 2025–2030.[27] An early commercialization buildout of NGG totaling 2–5 GW of capacity would generate 13–33 TWh of electricity (assuming a 75% capacity factor). Thus, capturing even a tiny market share would drive a major NGG buildout.

The location of load growth[28] and NGG supply[29] frequently overlap — e.g., in Texas, Nevada, California, Oregon, Idaho, Arizona, and Louisiana — mitigating the constraints of long-distance transmission availability. Significant behind-the-meter potential exists as well for NGG.[30]

Overall, despite load growth uncertainty and market fragmentation, the sheer size of the U.S. electricity market provides a wide canvas for NGG deployment.

## ASSESSMENT

The scale of an early commercialization buildout of NGG is tiny relative to U.S. electricity consumption, and NGG supply locations align well with demand growth across multiple regions. Market conditions position NGG to compete in many regions, in both front- and behind-the-meter configurations.

### LOW RISK

Technology solution is well-positioned to compete strongly in a large and existing market or dominate in a small and existing market; technology solution can be broadly adopted across geographies.

AGS EGS

### MEDIUM RISK

Technology solution addresses only a moderately sized existing market opportunity, and/or there is moderate uncertainty whether the market will materialize; technology solution may be limited to select markets because of geographic or other constraints.

### HIGH RISK

Technology solution is limited to small markets, and/or relies on a market that has yet to materialize.

# Downstream value chain

Risks associated with getting the product from a producer to a customer along the value chain (e.g., considering split incentives, technology acceptance, business model changes)

## STATE OF PLAY

- Business models must work and there must be technology acceptance at each step along the chain of intermediaries between a geothermal power producer and electricity consumers, including utilities and grid operators, as well as aggregators, power marketers, and retail choice providers.[31]
- Project developers can increase technology acceptance among intermediaries and consumers by demonstrating project success. Policymakers can enable successful business models by reforming power-sector market design and planning parameters.

## TRENDS

Incumbent firms, market rules (e.g., RTO capacity market design), and long-term planning processes (e.g., utility integrated resource plans) are generally oriented around mature, established technologies and can overlook newer technologies, misaligning incentives for adoption of NGG.[32, 33, 34]

Performance elements such as a carbon-free footprint, low land and water impact, and modularity often go unrecognized in the value chain.

## ASSESSMENT

Power-market rules, planning processes, and key value chain players favor established technologies, disadvantaging NGG in the marketplace. However, reforms that recognize NGG's viability and value, along with a growing list of project success stories, can level the playing field and enable NGG expansion.

### LOW RISK

Path to market is clear; business proposition and technology solution features work within existing incentives/business models or the technology newly aligns incentives for stakeholders along the value chain.

### MEDIUM RISK

Path to market requires realigning value chain; business model and technology acceptance level are not clear for one or more participants in current value chain.

AGS EGS

### HIGH RISK

Value chain is nonexistent, highly fragmented, and/or technology solution benefits do not accrue to critical decision makers/gatekeepers across value chain.

# Capital flow

Risks associated with the availability of capital needed to move the technology solution from its current state to production at scale, including total investment required, availability of willing investors, availability of associated financial and insurance products, and the speed of capital flow

## STATE OF PLAY

→ DOE analysis indicates that approximately $20 billion–$25 billion in cumulative capital is required to support 2–5 gigawatts of NGG deployment across multiple states (including $5 billion for first-of-a-kind projects).[35]

## TRENDS

Roughly $900 million in private capital has entered the sector since 2020,[36] supplemented by very limited DOE demonstration funding.[37]

Exploration insurance and risk-sharing mechanisms remain scarce, raising perceived investment risk and limiting commercial debt access.[44]

As of 2025, there were approximately 18 recorded investments totaling $1.5 billion made between 2021 and 2025.[38, 39, 40, 41, 42, 43]

Executed offtake agreements (e.g., Google[45] and Clean Power Alliance[46] with Fervo) improve credibility but have not yet scaled institutional investor participation in the NGG sector.

## ASSESSMENT

Overall, capital availability — particularly equity — is improving, yet scaling still requires concessional financing and public participation. Exploration uncertainty, limited risk-mitigation mechanisms, and ongoing bankability concerns continue to constrain near-term financing for NGG projects.

### LOW RISK

Institutional investors confirm that the technology solution's return profile is commercially competitive with holdings in their broader portfolios. Deal flow/risk profile is sufficient to develop regular equity and debt approval processes at relevant investment institutions and ratings agencies. Major risks are insurable.

### MEDIUM RISK

There exist one or more "valleys of death" along the required capital stack to full deployment, but hurdles can be overcome, and capital flow and financial and insurance availability are beginning to increase.

### HIGH RISK

Significant additional investment from sources of concessionary/patient/high-risk pools of capital (e.g., public sector, philanthropic, and catalytic venture capital) required to achieve deployment.

# Project development

Risks associated with the processes and capabilities to successfully and repeatably execute projects using the technology solution

## STATE OF PLAY

- Next-generation geothermal draws on established expertise in drilling, subsurface engineering, and large infrastructure delivery.[47]
- Standardized engineering, procurement, and construction (EPC) processes, contracting templates, vendor experience, and permitting playbooks are still forming, given the limited number of NGG projects under development (Fervo, the leading NGG firm, has 4 projects[48]).

## TRENDS

DOE programs such as FORGE[49] have implemented and validated key drilling and stimulation techniques since 2021.

NGG startups such as Fervo[50] and Eavor[51] reached commercial pilots in 2022, but none has operated multiyear at full scale.

## ASSESSMENT

Demonstration successes show technical feasibility, but project numbers are too modest to build repeatable, on-budget, on-schedule delivery of full-scale geothermal projects.

### LOW RISK

Mature processes and capabilities exist (e.g., within EPC contractors) to develop, integrate, and manage full projects using the technology solution; demonstrated by a track record of on-budget, on-time projects using the technology solution or comparable projects.

### MEDIUM RISK

Some processes and capabilities exist to develop, integrate, and manage full projects using the technology solution, but these remain unproven.

### HIGH RISK

Deployment of the technology solution requires building new or significantly improved project development, integration, and management processes and capabilities compared with the industry status quo; demonstrations and deployments at scale face substantial budget and timeline risks as a result.

AGS EGS

# Infrastructure

Risks associated with the physical and digital large-scale systems needed to support, enable, or facilitate deployment at full scale (e.g., pipelines, transmission lines, roads and bridges, etc.)

## STATE OF PLAY

- Grid interconnection queues, driven by limited infrastructure, present a significant timing risk, an issue common across new generation sources.[52]
- AGS's lower water use and seismicity risk loosen its siting limitations compared with EGS, which softens AGS's infrastructure risk due to higher potential to make use of existing transmission lines.

## TRENDS

Power projects built in 2024 took 55 months on average from the interconnection request to commercial operations.[53]

As noted previously, the location of load growth[54] and NGG supply[55] frequently overlaps at the state level; at the same time, much of the best NGG resource lies far from load centers. Broad siting potential would require new or upgraded transmission lines, and in some locations could require site-access roads and communication and water systems.[56]

## ASSESSMENT

Remote resource locations and transmission congestion present notable siting and interconnection hurdles, creating high risk to broad NGG deployment prospects.

### LOW RISK

Technology solution can be broadly deployed within existing large-scale physical and digital infrastructure.

### MEDIUM RISK

Technology solution can be broadly deployed with minimal investment in large-scale infrastructure (i.e., existing infrastructure can be adapted to use with new technology solution) or there exists a clear and economically viable path for investors and developers to build required infrastructure.

AGS

### HIGH RISK

Technology solution can be broadly deployed only with additional significant investments in new large-scale infrastructure, and path to required infrastructure remains unclear.

EGS

# Manufacturing and supply chain

Risks associated with all the entities and processes to produce the end product, including integrators, component, and subcomponent manufacturers and providers

## STATE OF PLAY

- NGG wells use land-based rigs and supporting hardware similar to those deployed for oil and gas production. Adaptations such as enhanced drill bits, high-temperature tools, and cooling systems can address distinctive geothermal needs.[57]
- Turbines and heat exchangers draw from established power-sector suppliers such as Turboden and Ormat,[58] using processes comparable to fossil plants.[59] Although the global market is small, modest manufacturing expansion could supply GWs over several years.
- While specialized components exist, no entirely new manufacturing ecosystem is required.

## TRENDS

The U.S. currently operates approximately 580 active oil and gas land rigs,[60] substantially below recent peaks, indicating available capacity within the drilling equipment supply chain.

## ASSESSMENT

Next-gen geothermal can leverage mature oil-and-gas and power supply chains, using off-the-shelf or adaptations of existing products, making manufacturing risk low for early scale deployment.

### LOW RISK

Technology solution deployment relies on off-the-shelf or simple adaptation of existing supply base products and existing manufacturing capabilities.

AGS EGS

### MEDIUM RISK

Technology solution deployment requires new components or products that are aligned with existing supply base capabilities but that may require minor upgrades or retooling of manufacturing and other processes.

### HIGH RISK

Technology solution deployment requires creation of new manufacturing processes or supply chain components that are not currently in place, or deployment will overwhelm existing supply chain capacities.

# Materials sourcing

Risks associated with the availability of critical materials the technology requires (e.g., rare earths)

## STATE OF PLAY

- Nickel and chromium alloys used for high-temperature, corrosion-resistant power plant equipment present a notable sourcing exposure.[61] The same temperature and chemistry environments can affect casings, cement, and instrumentation.[62] Depending on site geology, temperature, and project design, developers may pursue significant critical mineral content.
- Geothermal shows low dependence on copper, lithium, cobalt, zinc, and rare earths, reducing exposure relative to some of the constrained components of wind, solar, and battery supply chains.[63]

## TRENDS

About 120 metric tons per megawatt of nickel and 60 metric tons per megawatt of chromium are required for geothermal facilities.[64]

For a 2–5 gigawatt deployment in the 2025–2030 timeframe, nickel and chromium requirements would each represent under 5% of cumulative global production over five years at current levels.[65]

## ASSESSMENT

NGG relies on materials that are distinct from those used in other energy technologies, and low volume requirements relative to global supply should avoid significant risk.

### LOW RISK

Technology solution relies on materials that are readily available in a competitive and distributed market and can be procured off the shelf with little to no geopolitical risk.

AGS EGS

### MEDIUM RISK

Technology solution relies on materials that are abundantly available but may face some risks (e.g., rely on new processing methods to make suitable for the application, geographic concentration).

### HIGH RISK

Technology solution relies on materials that are limited in supply relative to demand, may be difficult to obtain, may face geopolitical risks, or are very costly to produce in the needed quantities.

# Workforce

Risks associated with the human capital and capabilities to design, produce, install, maintain, and operate the technology solution at scale

## STATE OF PLAY

- 75% of geothermal project investment relates to activities that significantly overlap with skills and expertise in the oil and gas sector.[66]
- Across both subsurface expertise (geoscientists and drillers) and surface (power plant engineers, construction, and operation), DOE estimates there is an existing workforce with transferable skills comparable in size to the needs of a fully scaled geothermal industry.[67]

## TRENDS

However, degrees issued in mining and petroleum engineering programs have declined 47% and 73% since 2016 and 2018, respectively.[68]

Training programs such as the Fervo-Southern Utah University apprenticeship offer a model for building workforce paths that enable oil and gas workers to apply their skills in the geothermal sector[69] but requires scaling.

## ASSESSMENT

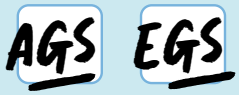
A strong labor base from the oil and gas and power sectors can readily support early projects if geothermal training and successful recruitment efforts scale up with NGG deployment.

### LOW RISK

Existing workforce has the necessary skills to manufacture and deploy technology solution with little additional training or significant scale-up.

### MEDIUM RISK

Existing workforce requires additional training to either manufacture or deploy/ install technology solution; workforce training pipelines exist but may need to be scaled.




### HIGH RISK

Workforce is nearly nonexistent; significant training is required for initial technology solution introduction and scale-up.

# Regulatory environment

Risks associated with local, state, and federal regulations or other requirements/standards that must be met to deploy the technology at scale

## STATE OF PLAY

- State regulation can significantly affect geothermal project development whether on federal, state, or private land.[70]
- Federal regulations encompass land leasing and a variety of environmental reviews involving numerous agencies.[71]

## TRENDS

In 14 states, geothermal regulations are being modified or are otherwise untested by actual project development, and 27 states have no geothermal regulations at all.[72] Only 17 states clearly identify the owner of geothermal resources on private land.[73]

At the federal level, National Environmental Protection Act processes can trigger up to 6 separate reviews for a geothermal project.[74] New categorical exclusions have reduced the regulatory burden but have limited scope.[75]

Because state regulations vary widely, individual states have opportunities to lead by streamlining rules and processes.

## ASSESSMENT

Gaps in state regulations and complex, uncoordinated federal regulations spanning many agencies seriously challenge the broad deployment potential of NGG.

### LOW RISK

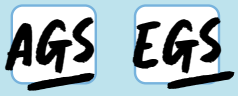
Technology solution can be broadly deployed within existing regulatory framework and standards, and those frameworks and standards are applied in a well-understood and fast-moving process with minimal risk of delays.

### MEDIUM RISK

Technology solution can be broadly deployed with minor changes to regulations and standards, and/or regulatory hurdles are well-understood but time-consuming and at risk of delays.

### HIGH RISK

Technology solution can be broadly deployed only with major changes to regulations and standards or entirely new regulations and standards; or there are significant challenges to navigating existing regulations and standards.



# Policy environment

Risks associated with local, state, and federal government policy actions that support or hinder the adoption of the technology at scale

## STATE OF PLAY

- At the federal level, the Energy Act of 2020[76] and Infrastructure Investment and Jobs Act[77] provided demonstration-project funding; the Inflation Reduction Act and the One Big Beautiful Bill Act provided geothermal-eligible tax credits;[78] and federal agencies have promulgated categorical exclusions to streamline permitting for exploration activities.
- Several states — California[79] and New Mexico,[80] for example — have enacted policies and programs such as capital provision and clean firm procurements supporting geothermal. Texas[81] and West Virginia[82] have recently clarified ownership and established regulations.

## TRENDS

While helpful, existing federal and state policies have not removed enough of the commercialization risks for broad NGG deployment, as evidenced by the very limited flow of projects in the development pipeline and the many high- and medium- risk dimensions herein. Several key policy wins, however, could reverse this.[83]

## ASSESSMENT

Despite significant political momentum and several important policy interventions, policymakers have given NGG limited targeted attention and provided only modest support mechanisms. To achieve broad deployment, policymakers must implement significant additional interventions to overcome hurdles and clearly signal a desired role for NGG.

### LOW RISK

Technology solution requires minimal additional policy intervention to encourage adoption as a preferred solution; policymakers are well-aligned with any changes needed to encourage adoption.

### MEDIUM RISK

Technology solution requires moderate policy intervention for broad deployment and is well-aligned with current governmental policies.

### HIGH RISK

Technology solution requires significant policy intervention to achieve and/or sustain broad deployment; and/or policymakers are not aligned with implementing required intervention to encourage adoption.

# Permitting and siting

Risks associated with the process to secure approvals to site and build equipment and infrastructure for deploying the technology at scale

## STATE OF PLAY

→ The interconnection authorizations[84] and local permitting decisions[85] that encumber energy project development broadly, and that can delay other authorization steps, are also potential bottlenecks for NGG.

## TRENDS

Geothermal project development timelines can take 7–10 years under the serial NEPA permitting regime[86] and due to federal staffing limitations and agency coordination challenges from overlapping responsibilities.[87] New categorical exclusions are only expected to reduce permitting timelines by 1 year for certain geothermal projects.[88]

State-level permits are often required for geothermal resource extraction, various project environmental impacts, and power-infrastructure siting.[89]

Federal and state permitting actions can be duplicative and/or lack coordination.[90]

## ASSESSMENT

Multiple layers of permitting and a lack of government capacity and coordination create a complex, lengthy, unpredictable landscape for geothermal project development.

### LOW RISK

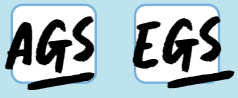
Permitting and siting process is easy, well-understood, timely, and repeatable.

### MEDIUM RISK

Permitting and siting can be time-consuming, but jurisdiction is clear, and complexity is low. Speed can be achieved with repetition.

### HIGH RISK

Permitting and siting are highly complex and time consuming, with multiple overlapping jurisdictions in play.



# Environmental and safety

Risks associated with the potential for hazardous side effects or adverse events inherent to the production, transport, or use of the technology solution or end product in the absence of sufficient controls

## TRENDS

NGG is a carbon-free electricity source with a smaller land footprint than most power technologies.[91] Best practices are well known for minimizing various environmental impacts from geothermal development activities.[92]

NGG reservoirs are located far deeper in the subsurface than drinking water supplies, and well casings protect shallow water and soil, posing minimal contamination potential.[93] AGS uses a closed fluid cycle equating to minimal water use, whereas EGS loses fluid equating to water use similar to coal, gas, and nuclear plants but with potential to use nonfresh water.[94] EGS uses fracking fluids whereas AGS does not; chemical composition of fluids is typically lower than for oil and gas,[95] potentially boosting license to operate.

Induced seismicity risk is lower for NGG than for widespread oil and gas activities and can be managed through processes such as the DOE's Induced Seismicity Protocol. AGS has lower seismicity risk than EGS, but both seek to maintain reservoir pressure to keep production steady, which also avoids seismicity.[96]

## ASSESSMENT

NGG is a zero-carbon resource with a small land footprint. Induced seismicity and water impacts are noteworthy but manageable risks for EGS and are minimal for AGS.

### LOW RISK

Technology solution has minimal inherent environmental or safety risk; results in net zero carbon or negative carbon solution.

AGS

### MEDIUM RISK

Technology solution has potential for environmental degradation and for safety concerns, but the risks can be managed through current processes and/or anticipated future processes or solutions.

EGS

### HIGH RISK

Technology solution has potential to create significant environmental degradation or increases carbon emissions over currently fielded solutions, and/or poses significant safety concerns that are challenging to mitigate.

# Community perception

Risks associated with the general perception by global and local communities of the technology solution and its risks or impact, whether founded or unfounded

## STATE OF PLAY

- Public awareness of geothermal technologies is low,[97] which could present a challenge to community acceptance.
- Early outreach can boost community openness.[98]
- Low visibility and low to modest air and water impacts relative to other power technologies are assets for public acceptance of NGG.

## TRENDS

Association with oil and gas drilling and fracking without an understanding of NGG differences could provoke significant opposition.[99]

On the other hand, widespread oil and gas infrastructure[100] and significant geothermal operations in 8 states[101] suggest potential for overall acceptance and local alignment in many communities.

## ASSESSMENT

Pockets of resistance may arise, but the presence of geothermal or oil and gas operations in many communities bodes well for public alignment in key development locations. With community involvement, NGG's advantages could inspire positive public reception.

### LOW RISK

Technology solution is likely to be favorably received by the public.

### MEDIUM RISK

Technology solution may create pockets of public resistance but enjoys a strong level of support overall. No systemic challenges are anticipated, and local communities accept deployment in key locations.

AGS EGS

### HIGH RISK

Technology solution is likely to generate negative public or community reactions that could derail or significantly delay deployment.

## ACKNOWLEDGEMENTS

The authors would like to thank the following individuals for their contributions to this research project. Niskanen interns Chelsey Gilchrist, Isabella Cho, and Swad Sathe provided research support. Dr. Roland Horne at Stanford University, Dr. Michael Matson at Boston Consulting Group, and Alice Wu at the Federation of American Scientists provided valuable comments on the manuscript draft; manuscript review does not imply endorsement. We would also like to thank our interviewees for insightful discussions on NGG technology deployment.

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