Environmental Defense Fund

Climate Innovation Initiative

Workshop on Next-Generation Geothermal Systems

Environmental Defense Fund

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EDF's Climate Innovation Initiative recently convened a workshop on scaling Next Generation Geothermal systems (NGG) as a source of clean firm power. Pulling together experts from across the industry, academia, government, and non-profit spheres, the workshop aimed to identify key gaps and potential vulnerabilities in current technologies[1].

Key Takeaways:

- NGG represents a unique opportunity to provide scalable, resilient, decarbonized baseload energy that complements renewables and supports growing electricity demand.
- A lack of critical data for commercial-scale NGG development needs to be addressed via government and private funding for field data acquisition and dissemination to the public. This would also benefit other kinds of geothermal development. Oil and gas companies could play a large role by allowing access to some of their proprietary data. Pilot data-sharing agreements, metadata standards, and consolidation of public datasets along with data quality statements could create a more robust knowledge base.
- Proactive community engagement and transparent reporting are vital for building trust around water use and induced seismicity. Improved seismic monitoring, expanded predictive and adaptive management systems (building upon reactive traffic light protocols), and long-term, high-fidelity studies on faults and regional stress regimes may reduce the risk of earthquakes, but it is impossible to predict every seismic event.
- Effective water management, including tracking subsurface water volumes, minimizing loss to fractures, and monitoring for and limiting potential contamination, is critical for sustainable NGG operations.
- The economic viability of NGG projects depends on defining and agreeing on what is a favorable target for an NGG development (beyond heat), improved resource

[1] This workshop considered Next-Generation Geothermal technologies including Enhanced Geothermal Systems and Pressure Geothermal Systems. Advanced Geothermal Systems were not included as their power generation efficiency and operational challenges and risks differ. In this report "NGG" refers to EGS and PGS.

characterization, technological and operational innovation, comprehensive techno-economic analyses, and clear communication with investors.
- Demonstrating NGG in a variety of geologic settings through additional FORGE- type demonstration sites or less expensive test wells elsewhere in the U.S. could derisk investment

Background & Workshop Structure

Geothermal energy has the potential to play a key role in addressing the United States' energy demand and decarbonization challenges. NGG makes use of derisked oil and gas drilling techniques, such as directional drilling and hydraulic stimulation, to create geothermal reservoirs in otherwise non-viable hot, dry rock. According to the U.S. Department of Energy, fully realized resources could provide up to 90 GW of power by 2050.[2] Current NGG pilot facilities exist in rock with favorable and relatively predictable composition and structural features; however, subsurface geology differs in the high demand and high-growth potential electrical markets east of the Rocky Mountains, such as the Rio Grande Rift region, the Gulf Coast, and Eastern U.S. where new clean firm power could be most valuable. Bringing NGG to these markets will not only involve making advancements in subsurface characterization but also addressing potential concerns with deploying the technology near population centers.

The workshop combined group discussion and breakout sessions around four sets of questions on key development bottlenecks, with the understanding that other important gaps and unknowns may be raised. The participants were first asked to identify data and models that could derisk potential bottlenecks, then develop an outline for actionable policy and research.

Challenges to Scaling

Despite its promise as a decarbonized energy source, NGG faces significant challenges in scaling to meet U.S. electricity needs. Workshop participants identified five key challenges:

- Subsurface Uncertainty
- Induced Seismicity Risk
- Water Use, Losses & Potential Contamination
- Project Economics & Investment Risk
- Policy & Regulatory Environment

1. Challenge: Subsurface Uncertainty

Successful NGG energy extraction requires accurately characterizing the subsurface environment. A recurring theme of the workshop was the importance of data – its collection,

[2] Pathway to Commercial Liftoff Report, 2025. U.S. Department of Energy.

accessibility, and integration. The varied tectonic settings, stress regime, and compositions of basement rock across North America, as well as the potential for deep sedimentary operations, require more thorough investigation. High quality exploration data are needed to understand where faults are located (in three-dimensions) and minimize water loss, short-circuiting, and induced seismicity, to control fracture creation and maximize heat recovery, and to know the composition and chemical behavior of the rock and rock-fluid interactions over time. However these data are scarce due to the expense of drilling and completing wells, the amount of three-dimensional space to cover, and the proprietary nature of the existing data. At present, only two full-scale field NGG demonstration projects exist in the world: Department of Energy-funded Utah FORGE, and Mazama Energy at Newberry Volcano in Oregon. Other U.S. pilot sites are also in Western states, most often collocated with known conventional hydrothermal resources. Commercial NGG operators have purchased land surrounding FORGE in a bid to leverage existing subsurface data and models. However, expanding to the Rio Grande Rift region, Gulf Coast, and Eastern U.S., where the need and projections for clean firm power is greatest and geothermal resource potential is still very high, will require working in geologies where rock-water interactions, fracture propagation, and thermal longevity are not well understood. Because of this, additional effort is needed to produce an accepted definition of what constitutes a favorable NGG target across diverse geological settings.

Proposed Solution: Mapping & Characterization

Participants emphasized the need for higher resolution geomechanical and thermal property maps, shifting from the continental scale to the state or even county scale. In the exploration phase, an operator could work with a scale of tens of km^2. In the development phase, meanwhile, they want to go down to the km^2 scale. A "map of maps" that consolidated subsurface data from public resources was also proposed, acknowledging that Project InnerSpace has begun publishing reports on the future of geothermal at the state level (e.g. Texas, New Mexico, and Pennsylvania), and has produced GeoMap to provide an interactive map platform for finding data. NREL has also developed a Geothermal Energy Atlas (GEA), an interactive map designed to advance geothermal deployment by making complex geothermal geospatial data discoverable, understandable, and actionable. There are also opportunities to collect thermal data from non-producing oil and gas wells, and passive seismic (e.g. TexNet) and other kinds of geoscientific data that could be used for improved subsurface characterization and derisking.

Further discussion centered on how to access critical datasets that oil and gas majors have likely already developed. Options include establishing data sharing agreements and industry consortiums, or ownership agreements. Improved metadata schemas for high-value datasets and pilot data sharing agreements were recommended to facilitate broader access and utility. Groups including but not limited to the Geothermal Data Repository, Project InnerSpace (GeoMap), and the International Heat Flow Committee have made some progress around developing metadata schemas and increasing access to existing high-quality datasets, but additional effort is needed to acquire knowledge from the wealth of proprietary data contained in larger subsurface industries like oil and gas. Participants were divided on whether another large-scale FORGE-type site was critical to understanding deep sedimentary basins beyond the western U.S., or if a sufficient regional knowledge base could be created with more economical forms of testing multiple wells across the geography, with a clear need of power and existing geothermal resource potential. These new test wells could serve as a springboard for commercial deployment.

2. Challenge: Induced Seismicity Risk

Induced seismicity is one of the biggest risks associated with NGG. While some form of stimulation is necessary to create and maintain fluid pathways for hot brine production, excessive stress (i.e., fluid injection-enhanced pore pressure) can lead to earthquakes on known critically stressed faults and reactivation of so-called "blind," or unmapped faults due to stress induced by fluid injection. Beyond avoiding damaging earthquakes, NGG operators also aim to keep reservoir stimulation within a defined radius, typically a few hundred meters around the injection well, to maximize heat extraction from a controlled volume of rock. Effective seismic monitoring must therefore balance two key objectives: mitigating the risk of large events and optimizing reservoir performance. Where significant earthquakes (as large as magnitude 5.4) have occurred due to NGG, the projects have had to shut down (e.g., Pohang in South Korea). Current sites in the US tend to be in sparsely populated regions, but large-scale deployment would have to manage this risk better.

Proposed Solution: Improved tools

Improved seismic monitoring tools and protocols are needed to track fracture propagation and water movement and detect subsurface faults that are not mapped at the surface. Existing traffic light systems (TLS) are generally reactive, i.e. rely on observed seismicity which itself can be a problem, and over a given threshold can effectively stop a project. Participants explored the concept of predictive and adaptive TLS. These systems, which adjust operational parameters in response to real-time seismic data, are seen as vital for anticipating and mitigating risks as NGG projects scale up. High-temperature (above 200°C) tools and remote sensing to visualize previously unmapped faults and large fracture zones could also be a part of the solution. The group recognized the value of long-term studies to understand the evolution of seismicity over time and for the calibration of models using data from diverse geological settings.

Regulatory frameworks for seismicity reporting and management were also discussed, with an emphasis on the need for standardized forms and clear terminology for wells, injection monitoring, and water types. The workshop highlighted the importance of community engagement, including regular meetings with local stakeholders and public access to seismic data, to build trust and transparency around NGG operations. An example from the FORGE project demonstrated the value of early and deep community engagement.

3. Challenge: Water Use, Losses & Potential Contamination

Water management is a multifaceted challenge for NGG, encompassing issues of use, loss, and contamination. Participants underscored that the impact of water use depends on both technology and the quality and availability of water resources. As deployment scales up, proactive planning is needed to optimize solutions and avoid conflicts over water use.

Proposed Solution: Quantitative Records

Participants identified the need for high-resolution volume tracking of subsurface water, supported by long-term studies (ranging from four months to a year) to understand water loss rates and recycling potential. The goal is to reduce water loss to less than 1%, a significant

improvement over current benchmarks such as the FORGE 30-day test, which reported a 10% loss. Fluid-rock interactions are more likely in hotter rocks, and can lead to mineral scaling and degradation of reservoir quality. Produced water monitoring, transparency, and careful surface management are essential.

The use of saline produced water, with appropriate treatment, was proposed as a solution to water scarcity challenges. Monitoring for contaminants such as hydrogen sulfide (H_2S) in sedimentary rocks is critical for environmental safety. The workshop also discussed the importance of regulatory frameworks for reporting water volumes and composition, and the need for streamlined permitting processes through standardized forms for state regulators and the U.S. Bureau of Land Management.

Proactive community engagement emerged as a key strategy for addressing water concerns, in particular communication of procurement, use, and treatment practices and data. Reporting working fluid additives in an existing online database, FracFocus, for non- oil and gas wells would be an excellent step towards transparency and building social license. Regular meetings with county commissioners, city councils, and other local stakeholders, as well as public viewing of water management data, were recommended to foster transparency and build public trust.

4. Challenge: Project Economics & Investment Risk

The economic viability of any energy resource projects, including NGG projects is shaped by technical performance, resource potential, and market dynamics. The workshop emphasized that risk centers around whether a given well produces, and is often short-term, while profit is realized over the long term. Utility-like models, which require demonstration of long-term data and reliability, could attract investment and scaling deployment. Communicating risk and value to investors in concrete terms was identified as a significant barrier.

Proposed Solution: Comprehensive Techno-economic Analyses

Participants posited that a clear, comprehensive techno-economic analysis (TEA) using current technology and achieved values, including thermal longevity and decline curve understanding that demonstrated economic viability would motivate investors. This would depend on collecting thermal longevity data that does not yet exist but is planned at FORGE. A key path to impact for such an analysis, if it were successful, would be high profile media exposure such as *The Economist*.

Standardized checklists for startup metrics and improving resource tier categorization were proposed to improve communication with investors and regulators. Such approaches are commonly used in the oil and gas industry to map Tier 1, 2, and 3 resources, project economic outlook, and identify opportunities for further in-fill drilling as needed. The development of economic models that properly reward clean firm power, and the quantification of its value to grid stability in systems with variable renewables, were identified as priorities.

Industry consortiums for data sharing and matchmaking entities to connect oil and gas with geothermal startups were discussed as mechanisms to foster collaboration and accelerate innovation (e.g., HotRock consortium at Bureau of Economic Geology at the University of Texas). The workshop also highlighted the importance of investor outreach and education,

particularly around alternative metrics to Levelized Cost of Energy (LCOE) and the composition and resolution of resource footprint capacity maps. The sole reliance on LCOE as a metric does not account for intermittency and capacity factor. Geothermal energy has high reliability and capacity factor.

Importantly, the group identified that geothermal heat resource for MW-scale power generation is expected to be deeper in the Gulf Coast and Eastern U.S. (except for some areas within these regions). Demonstrating the ability to hydraulically stimulate successfully and effectively with standard 15,000 psi pumps at depths larger than 5km would expand the area in which NGG could be viable, at least with respect to depth. DOE could be an appropriate actor on this point for facilitating further field tests and regional partnerships as well as for developing high temperature downhole tools.

Ultimately, the economic success of NGG projects will depend on the ability to derisk investment through better data, mapping, and policy frameworks, and to demonstrate the value of clean firm power at a systems level.

5. Challenge: Policy & Regulatory Environment

Policy and regulatory frameworks play a pivotal role in shaping the trajectory of NGG deployment. Participants stressed the need for model regulations that address the unique challenges of geothermal energy, including definitions of technologies, resource ownership clarity, and streamlined forms for operators to submit to state regulators and the Bureau of Land Management.

Solution: Standardization & Community Engagement

A regulatory landscaping exercise was proposed to build on forthcoming reports and to inform the development of protocols for seismic activity, water volume reporting, and community engagement. The importance of joining industry consortiums and informing regulatory work through data sharing efforts was emphasized.

Community engagement models, informed by experience at FORGE and other pilot projects, were recommended to ensure that water and seismicity reporting are transparent and accessible. The workshop also discussed the need for regionally specific approaches and challenges, and for the integration of geothermal resource data into broader energy system models to support policy development.

Participants noted the value of a process to disseminate best practices and guardrails for NGG technology. Along with standardized resource categorization and comprehensive TEAs, this could enable more investment in NGG technologies. The ultimate goal is to enable data-informed decisions on deployment, including risk tradeoffs and economic opportunities.

Pathways to Impact

The workshop concluded with a discussion of the strategic paths to impact for NGG. Strategic investments in data collection, research, and demonstration projects are needed to reduce uncertainties and inform expectations, best practices, and policy recommendations.

Participants outlined a theory of change: by demonstrating the need and value of clean firm power at a systems level, collecting data on geothermal resources and environmental safety, and derisking investment through data sharing and mapping, the industry can move safely and effectively. The development of adaptive and predictive seismic protocols, long-term studies on water loss and thermal longevity, and the validation of advanced technologies in real-world settings were identified as critical steps.

Cross-cutting programs that address proppant, high-temperature logging tools, stimulation technologies and designs, computer and electronic components, coolant, insulated pipes, particle drilling, and fiber optic cable deployment were recommended to support innovation. These could be pursued in the setting of national labs, private industry research, or may exist already. The integration of geothermal, geologic hydrogen, minerals, and geologic storage into broader energy system models and roadmaps will enhance the visibility and impact of NGG technology.

Finally, the workshop emphasized the importance of ongoing dialogue with communities, investors, regulators, and other stakeholders to align technical progress with societal values. By weaving together data, technology, economics, policy, and engagement, the geothermal industry can overcome barriers and realize its potential as a cornerstone of the clean energy transition.

Conclusions

NGG has the potential to play a critical role in the global energy transition by providing a reliable and dispatchable source of clean baseload power, but scaling will require addressing several technical, financial, and regulatory challenges. This workshop highlighted the importance of improving subsurface characterization, reducing seismic risks, optimizing water use and loss, and creative regulatory frameworks that support economic development.

Participants

EDF is grateful for the participation and contributions of the following experts to our workshops. Their participation in the discussion does not equate to full endorsement, by them as individuals or as representatives of their institutions or organizations, of this summary of the workshop.

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