ISSUE BRIEF 1



Bridging the Valley of Death:

How Test Centers Can Unlock the Geothermal Opportunity

By Laura Katharina Mueller

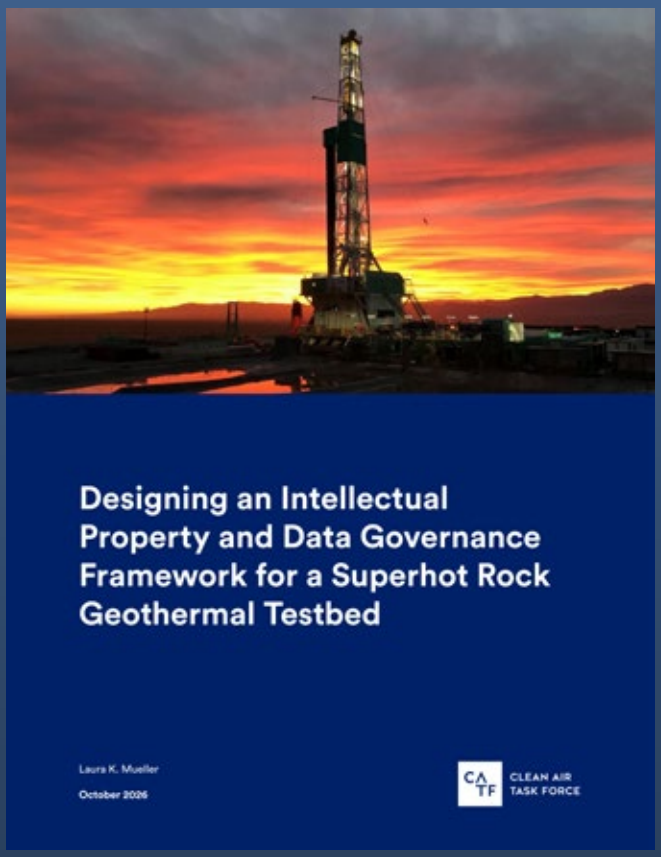
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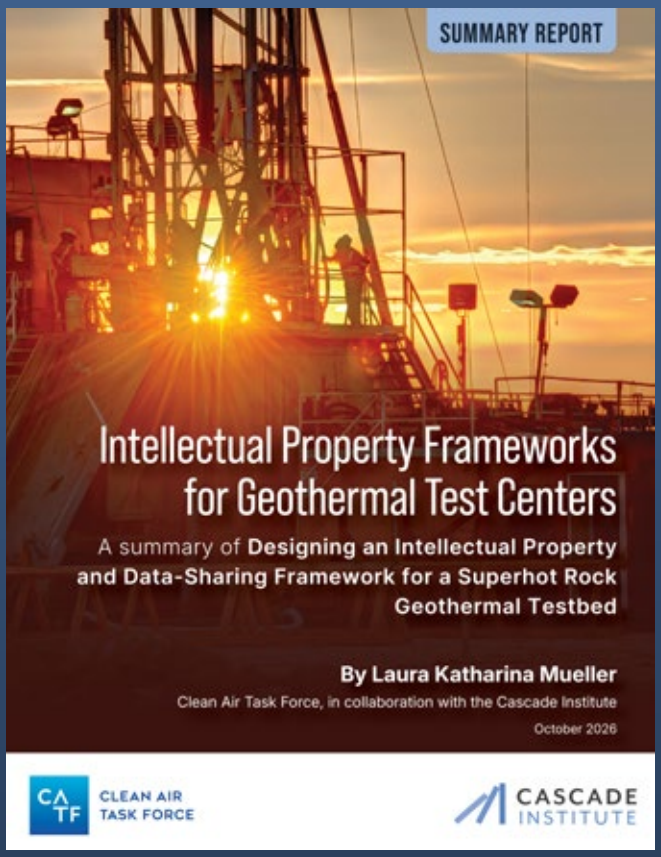
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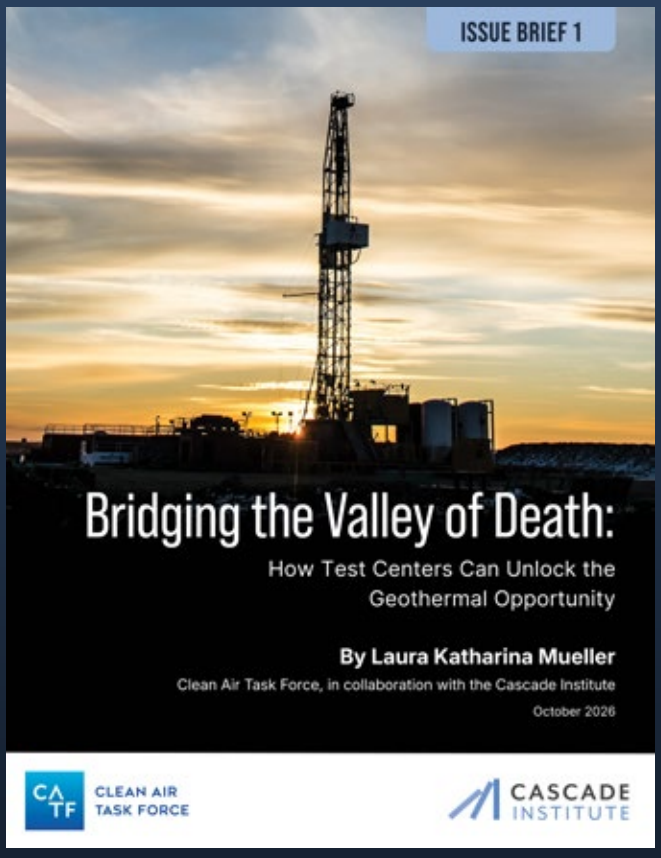
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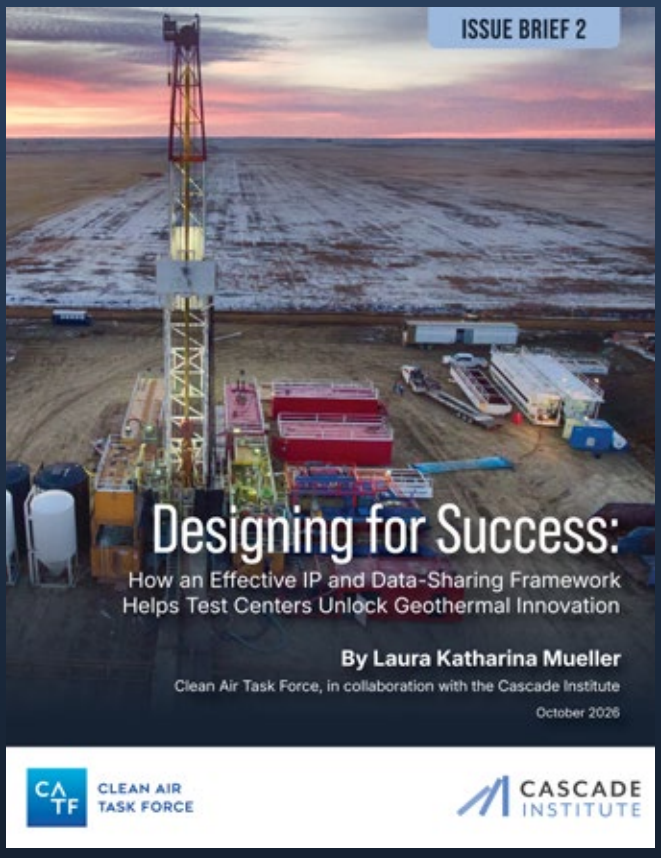
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This brief explains:

- why test centers have become an increasingly important policy tool for accelerating energy innovation,
- what lessons can be drawn from existing programs, and
- why IP and data-sharing frameworks are central to attracting industry participation.

The clean energy transformation has largely been an above-ground story. Over the past two decades, solar, wind, and battery storage have transformed electricity systems and become increasingly cost-competitive. As growing electricity demand, energy security concerns, and decarbonization goals drive the search for clean, reliable, and complementary energy sources, attention is increasingly turning to next-generation geothermal technologies such as superhot rock, enhanced geothermal systems, and advanced geothermal systems.

Achieving commercial viability for such technologies requires field-scale testing using infrastructure that is costly, technically complex, and often beyond the reach of individual companies, particularly early-stage developers. Test centers provide shared infrastructure that can address these high initial costs and facilitate rapid innovation. By enabling companies, researchers, and public institutions to test and validate technologies under real-world conditions, test centers reduce technical uncertainty, lower the cost and risk of commercialization, and accelerate technology development. In doing so, they have helped catalyze technological breakthroughs, crowd in private investment, and accelerate deployment across multiple energy sectors. This brief explains why test centers have become an increasingly important policy tool for accelerating energy innovation, what lessons can be drawn from existing programs, and why intellectual property (IP) and data-sharing frameworks are central to attracting industry participation.

Geothermal's moment

Accelerating clean energy technology innovation is more important than ever. Rising electricity demand from electrification, artificial intelligence, data centers, and advanced manufacturing, together with growing concerns about energy security and decarbonization, are rapidly increasing demand for reliable, low-carbon sources of power. This demand will continue to grow regardless of net-zero policy. With many above-ground renewable energy technologies, such as solar, wind, and battery storage, having reached commercial maturity, growing attention is shifting toward the next generation of complementary energy technologies needed to deliver secure, reliable, and industrial-scale clean energy.

> *Next-generation geothermal could unlock a global investment opportunity approaching US$1 trillion cumulatively by 2035, and US$2.5 trillion by 2050.*

Geothermal energy exemplifies this growing opportunity. Advances in drilling technology, increases in public investment, and the rapid expansion of private-sector interest have transformed expectations for what next-generation geothermal can achieve. Next-generation geothermal has the potential to provide zero-carbon, always-on power and industrial heat almost anywhere in the world. Although geothermal today accounts for just 0.3% of global electricity generation, the International Energy Agency (IEA) estimates that continued technological improvements could enable it to provide up to 15% of global electricity demand growth by 2050 through the deployment of approximately 800 gigawatts of capacity. This deployment would produce nearly 6,000 TWh of electricity annually, equivalent to the current electricity demand of the United States and India combined.[1] The Earth's geothermal resource is immense, yet geothermal today supplies only a small share of global electricity because the cost and technical risk of discovering, drilling, and developing deep geothermal resources have historically constrained investment. The IEA estimates that next-generation geothermal could unlock a global investment opportunity approaching US$1 trillion cumulatively by 2035, and US$2.5 trillion by 2050, while providing a significant source of firm electricity and industrial heat.[2] Realizing this potential, however, requires drilling deep, high-temperature wells, developing new drilling and reservoir technologies, and validating their performance under subsurface conditions that, unlike many above-ground energy technologies, are expensive to access, difficult to replicate, and beyond the economic reach of most individual developers, making shared testing infrastructure particularly valuable.

1 International Energy Agency, The Future of Geothermal Energy (2025), Executive Summary, p. 7.
2 International Energy Agency, The Future of Geothermal Energy (2025), Executive Summary, p. 8.

Several developments are driving accelerated momentum in geothermal:

1. **Technological advances are improving the feasibility of next-generation geothermal systems.** In the U.S., for example, horizontal drilling and hydraulic fracturing techniques adapted from the oil and gas sector are expanding the technical and economic viability of enhanced geothermal systems.
2. **Governments are rapidly increasing public investment to support research and demonstration.** In February 2026, the U.S. Department of Energy (DOE) announced up to US$171.5 million for next-generation geothermal field tests and confirmation drilling. Canada has launched work on a national geothermal roadmap, Germany has introduced a €600 million geothermal drilling guarantee framework, and Iceland continues to expand public investment in geothermal innovation.[3]
3. **Increasing patent activity and strong private investment reflect growing confidence in the commercial potential of next-generation geothermal technologies.** Together, successful demonstrations and sustained public investment have helped de-risk the sector, catalyzing a new wave of private capital. Fervo Energy's May 2026 Nasdaq initial public offering raised approximately US$2.2 billion, at a valuation of around US$10 billion, representing the largest financing event in the sector to date. Fervo's IPO success is part of a broader wave of private geothermal investment that includes Quaise Energy's US$134 million Series B financing, Hephae Energy Technology's US$17.8 million Series A financing, and continued investment in companies such as Rodatherm Energy.

These developments reflect a broader shift. As demand for reliable, low-carbon power continues to grow, next-generation geothermal is uniquely positioned to become a foundational component of the future energy system. Realizing that opportunity now depends on accelerating the demonstration and commercialization of the technologies that will bring next-generation geothermal to scale.

How test centers can bridge "the valley of death"

Developing next-generation subsurface technologies requires high upfront capital investment, sequential field testing, and long development timelines before commercial revenue can be generated. Unlike above-ground renewable technologies, where prototypes can often be tested and refined at relatively low cost, subsurface technologies depend on access to deep geological formations that are expensive to reach and inherently uncertain until drilled. Individual wells often cost tens of millions of dollars, and each stage of exploration depends on the results of the previous one. A failed drilling campaign or unsuccessful technology demonstration can therefore impose costs that few early-stage companies can absorb. These characteristics make shared test infrastructure particularly valuable for subsurface technologies.

3 U.S. Department of Energy, Office of Geothermal, Notice of Funding Opportunity DE-FOA-0003472 (Feb. 25, 2026) (up to $171.5 million for next-generation geothermal field tests, characterization, and confirmation drilling), https://simpler.grants.gov/opportunity/3c361922-30e8-4d25-a270-bf2fa7b92c66; Natural Resources Canada, Canada Invests in Its First National Geothermal Energy Roadmap (June 11, 2026) ; KfW, KfW-Förderkredit Geothermie (Dec. 18, 2025), https://www.kfw.de/About-KfW/Newsroom/Latest-News/Pressemitteilungen-Details_875520.html; https://www.thinkgeoenergy.com/germany-launches-kfw-geothermal-loan-and-drilling-risk-cover/; Government of Iceland, Climate and Energy Fund (2026), https://www.thinkgeoenergy.com/iceland-announces-recipient-geothermal-projects-for-isk-600-million-in-grants/.

These challenges create the so-called “valley of death” between successful laboratory or pilot-scale research and commercial deployment, where promising technologies often struggle to secure the capital and field validation needed to reach the market. The challenge is particularly pronounced for next-generation geothermal technologies. Much of the sector is being driven by venture-backed companies developing proprietary drilling technologies, high-temperature tools, stimulation methods, software, and other technical innovations. Yet these companies operate in a sector that depends on costly field infrastructure and repeated demonstrations before technologies can be commercialized. This situation differs fundamentally from the asset-light, rapidly scalable business models on which traditional venture capital is typically based. As a result, many promising technologies struggle to progress beyond the demonstration stage, despite substantial commercial potential.

This struggle to scale reflects a fundamental tension in innovation policy. Private firms invest to generate private returns from innovation, while governments invest because innovation creates broader economic, environmental, and societal benefits. Test centers provide a mechanism for aligning these interests by using public investment to reduce risks and costs that would otherwise impede commercially driven technology development.

> *Test centers have helped reduce technical risk, distribute early-stage costs, accelerate technology development, and support commercialization.*

Across multiple energy sectors, test centers have helped reduce technical risk, distribute early-stage costs, accelerate technology development, and support commercialization. Their value is particularly pronounced for subsurface energy technologies, where the cost and uncertainty of accessing the resource create barriers that do not exist for other renewable technologies.

For next-generation subsurface technologies, test centers are an effective tool to overcome scale-up failures and commercialization barriers by providing shared, instrumented infrastructure where multiple developers can validate technologies under operational conditions. By providing shared, instrumented field infrastructure, technical expertise, and access to deep subsurface conditions, test centers enable multiple developers to validate technologies under operational conditions, without each bearing the full cost and risk of developing dedicated field sites. They reduce both technical and financial risk while generating independent, credible performance data that strengthens investor confidence. Because testing takes place in a shared research environment, unsuccessful experiments generate knowledge that benefits the wider sector, rather than remaining solely private commercial losses. Recent engagement with investors also suggests growing interest in shared test centers, both as infrastructure investments and as places where portfolio companies can validate technologies under field conditions.

The value of test centers extends beyond reducing technical and financial risk. The potential market for next-generation geothermal and other subsurface technologies is sufficiently large that no single developer is likely to meet future demand alone. At this stage of development, reducing technical uncertainty and demonstrating reliable performance at depth are shared challenges across the sector. Test centers therefore enable companies to collaborate on these pre-competitive challenges while continuing to compete through their proprietary technologies, engineering approaches, and commercial execution. In doing so, they generate both new technical knowledge and commercially valuable innovations while protecting proprietary technologies and other IP. Successful test centers support this balance by safeguarding commercially sensitive innovations while enabling the exchange of operational and scientific knowledge that accelerates progress across the industry.

A comparative analysis of three successful test centers

Test centers have accelerated technology development across a range of subsurface energy sectors and operating under different governance structures, ownership models, funding arrangements, and IP frameworks. The following case studies illustrate three successful approaches.

AOSTRA (Canada)

The Alberta Oil Sands Technology and Research Authority (AOSTRA), established in 1974 as a provincial Crown corporation, was created to address one of Canada's most significant energy challenges. Although Alberta possesses vast oil sands resources, only about 20 percent of its heavy oil deposits could be recovered using conventional surface mining methods. Recovering the remaining resource was theoretically possible but technically uncertain and commercially uneconomic, and industry was reluctant to invest in the high costs and technical risks of field-scale experimentation.[4]

Initially capitalized with C$100 million (approximately C$625 million in today's dollars) and eventually investing more than C$620 million (approximately C$1.7 billion in today's dollars),[5] AOSTRA supported university research, operator-led field trials, and technology demonstration through a 50/50 cost-sharing model with industry. Its small, independent board, comprising retired industry and academic experts with no active commercial interests, was able to pursue high-risk technologies that private companies were unwilling to finance.[6]

The most significant outcome was the development of steam-assisted gravity drainage, which enabled in situ (subsurface) oil sands production. At a time when steam-assisted gravity drainage was widely regarded as too costly and technically uncertain for commercial deployment, AOSTRA established the Underground Test Facility, a fully government-funded field laboratory where the technology could be tested at scale. The Underground Test Facility successfully demonstrated horizontal drilling and steam-assisted recovery under operational conditions, providing the technical confidence needed for commercial adoption.[7] Within little more than a decade, steam-assisted gravity drainage had become the dominant recovery technology for Alberta's oil sands, and by 2007 heavy oil production had surpassed conventional oil production in the province. This demonstrates how strategically targeted public investment in shared testing infrastructure can rapidly accelerate the commercialization of technologies that industry is initially unwilling to pursue on its own.

4 Emily Smejkal, Peter Massie, and Leighton Gall, AOSTRA: A Model for Funding Geothermal Innovation (Cascade Institute, May 2025), pp. 1-2.
5 Emily Smejkal, Peter Massie, and Leighton Gall, AOSTRA: A Model for Funding Geothermal Innovation (Cascade Institute, May 2025), p. 2.
6 Emily Smejkal, Peter Massie, and Leighton Gall, AOSTRA: A Model for Funding Geothermal Innovation (Cascade Institute, May 2025), p. 4.
7 Emily Smejkal, Peter Massie, and Leighton Gall, AOSTRA: A Model for Funding Geothermal Innovation (Cascade Institute, May 2025), pp. 2-9.

The Hydraulic Fracturing Test Sites (United States)

The Hydraulic Fracturing Test Sites I and II, established in 2014 and 2018 respectively in the Permian Basin of West Texas, were created through U.S. Department of Energy-supported public-private partnerships to improve scientific understanding of hydraulic fracturing under real operating conditions. Unlike conventional demonstration projects, the Hydraulic Fracturing Test Sites brought together operators, service companies, researchers, and government in a shared field laboratory to generate high-quality subsurface data on fracture propagation, completion design, and well performance. GTI Energy served as the neutral program manager, while participating operators carried out the drilling and stimulation activities through a substantial industry cost-share.[8]

The projects produced some of the most comprehensive publicly available datasets on hydraulic fracturing ever assembled. High-resolution measurements of fracture growth, reservoir behavior, and stimulation performance provided new insights into how unconventional reservoirs respond under field conditions, improving reservoir characterization, completion strategies, and predictive modeling. By generating independently validated field data that no single company would likely have produced on its own, the Hydraulic Fracturing Test Sites accelerated technical learning across the unconventional oil and gas sector.[9]

The success of the Hydraulic Fracturing Test Sites also demonstrates that collaboration on pre-competitive research depends on carefully designed participation incentives. Companies retained ownership of their proprietary tools, workflows, and interpretation methods, while the consortium generated shared operational data. Project data remained within the consortium for approximately three years before non-proprietary datasets were released publicly, giving participating companies a meaningful head start on the data they helped generate. Participants have described this confidentiality period as an important reason the cost-sharing model was commercially attractive: it protected competitive advantages while ultimately expanding the industry's collective knowledge base.[10]

FORGE (United States)

The Frontier Observatory for Research in Geothermal Energy (FORGE) is the Department of Energy's dedicated field laboratory for enhanced geothermal systems, located near Milford, Utah, and operated by the University of Utah.[11] Since its establishment in 2018, FORGE has received approximately US$300 million in Department of Energy funding.[12] Its purpose is to provide a controlled, deeply instrumented site comprising seven dedicated research wells that provide shared infrastructure for testing innovative drilling technologies and engineered geothermal reservoirs at depth and temperature. By overcoming the high fixed costs of field-

8 U.S. Department of Energy, National Energy Technology Laboratory, Hydraulic Fracturing Test Site (HFTS), https://netl.doe.gov/node/1989; Hydraulic Fracturing Test Site II (HFTS2) Delaware Basin, https://netl.doe.gov/node/6840.

9 Jordan Ciezobka & Debotyam Maity, HFTS-1 (Final Report), U.S. Department of Energy (2023), https://www.osti.gov/biblio/2006840; Jordan Ciezobka & Debotyam Maity, HFTS-2 (Final Report), U.S. Department of Energy (2022), https://www.osti.gov/biblio/1907894.

10 GTI Energy, personal communication, January 6 and 13, 2026.

11 *See* more information under: https://www.energy.gov/hgeo/geothermal/forge.

12 The Department of Energy selected the University of Utah as the FORGE site in 2018 with up to US$140 million over five years. The project subsequently grew to roughly US$218 million in DOE support before receiving an additional US$80 million extension in 2024, bringing cumulative federal funding to approximately US$300 million. See https://www.energy.gov/articles/department-energy-selects-university-utah-site-140-million-geothermal-research-and, https://www.price.utah.edu/2024/10/01/forge-receives-80-million-funding-extension-from-the-u-s-department-of-energy.

scale testing, the facility thereby lowers barriers to entry for innovative companies while generating large quantities of non-proprietary, publicly available data.

In 2024, FORGE achieved one of the sector's most significant technical milestones by successfully circulating water through a stimulated geothermal reservoir and recovering heat at the surface, demonstrating the technical feasibility of enhanced geothermal system field conditions. Consistent with its research mandate, the facility is designed to validate drilling, reservoir, and stimulation technologies rather than operate as a commercial power project. Separating technology demonstration from electricity generation allows experiments to be conducted without the operational and contractual constraints associated with supplying power to the grid, preserving FORGE's role as a dedicated field laboratory. The achievement followed years of coordinated public investment in drilling, reservoir characterization, and stimulation technologies and is widely regarded as a turning point for the commercial development of next-generation geothermal, illustrating how publicly funded test centers can de-risk technologies before their transition to commercial deployment.

> *The FORGE experience demonstrates how strategically targeted public investment in shared testing infrastructure can reduce risks that private capital is initially unwilling to bear, creating the conditions for subsequent commercial deployment.*

FORGE's impact extended well beyond the test site. By reducing technical uncertainty, improving subsurface characterization, and generating and publicly releasing high-quality, non-proprietary operational data, FORGE helped create the conditions for commercial investment in the surrounding region. Adjacent to the site, Fervo Energy's Cape Station project has attracted well over US$1 billion in private investment and reached a multi-billion-dollar valuation following its 2026 public offering.[13] More broadly, the FORGE experience demonstrates how strategically targeted public investment in shared testing infrastructure can reduce risks that private capital is initially unwilling to bear, creating the conditions for subsequent commercial deployment.

The scale of the potential economic impact is illustrated by Cape Station. Using a representative commercial scenario of a 500-megawatt project operating at 98% availability and selling electricity at US$100/MWh, the project could generate more than US$429 million in annual gross revenue and more than US$8.5 billion over a 20-year power purchase agreement. Although these figures are based on a simplified scenario rather than Fervo's contractual terms, they illustrate the catalytic effect that public investment in demonstration infrastructure can have. A federal investment of approximately US$300 million in FORGE helped create the conditions for commercial activity, whose projected gross revenue from a single adjacent project is nearly 28 times greater than the original public investment.

Lastly, the FORGE experience also highlights an emerging policy consideration for future geothermal test centers. As publicly funded drilling and reservoir characterization reduce geological uncertainty, well-characterized geothermal leaseholds may themselves become valuable commercial assets. Decisions about how access to these sites is allocated, and how the value created through public investment is shared, are therefore likely to become increasingly

13 Fervo Energy, whose Cape Station development sits in the same Utah basin as FORGE, has raised on the order of US$1.5 billion since 2017, including a US$462 million Series E (Dec. 2025) and US$421 million in non-recourse project financing (March 2026), and completed a 2026 initial public offering at a multi-billion-dollar valuation. Devon Energy, an oil and gas company active in earlier subsurface test work, was among its investors.

important as the sector matures. Although these issues fall beyond the scope of this brief, they illustrate that successful test centers require not only technical and financial design, but also careful consideration of the commercialization pathways created by publicly supported innovation. They also represent an important area for future policy development and analysis as additional geothermal test centers are established.

Future geothermal test centers would complement FORGE by addressing questions that cannot all be answered at a single site. FORGE remains an exceptionally valuable asset for the industry and is particularly well positioned to continue advancing areas such as induced seismicity protocols, reservoir performance monitoring, and models that improve the prediction of reservoir decline over time. At the same time, every test site is constrained by its geology, temperature range, infrastructure, and operating model, which limits the types of technologies and stimulation approaches that can be evaluated there.

Looking ahead, one of FORGE's greatest impacts may be the model it created for the design and governance of future test centers. Building on the foundation established by FORGE, future test centers could be structured to accommodate a wider range of participants, support multiple experimental campaigns over time, and enable testing under conditions that do not exist at current facilities. Test centers that are intentionally designed to maximize shared learning, preserve flexibility for future experiments, and provide access to untested environments could generate insights that would be difficult to obtain through either a single test site or commercial projects alone.

Shared lessons

Although AOSTRA, FORGE, and the Hydraulic Fracturing Test Sites addressed different technologies under different governance arrangements, they responded to a common challenge: technologies with significant economic potential that were too costly, technically uncertain, and slow to deploy for individual companies to develop independently. Each was established with a focused, long-term mission supported by continuous public funding to address capital-intensive subsurface challenges that individual firms were unable or unwilling to solve alone. Their economic promise provided a strong rationale for sustained public investment and industry participation despite the substantial technical and financial risks involved. Public investment created shared, place-based testing infrastructure that lowered barriers to entry, while industry contributed technical expertise, operational experience, and commercialization pathways. Together, public and private participation reduced technical uncertainty, accelerated technology development, and unlocked follow-on commercial investment.

Equally important, each program consistently paired cost-sharing arrangements with commercially credible governance, IP, and data-sharing frameworks that encouraged companies to contribute technologies while protecting proprietary innovations. Companies were willing to contribute technologies, expertise, and data because the frameworks protected proprietary information while creating opportunities for shared technical learning. The specific mechanisms differed—from portfolio-wide access at AOSTRA to structured confidentiality periods at the Hydraulic Fracturing Test Sites—but all were designed to ensure that participants received sufficient commercial value to justify participation.

The principal lesson for next-generation geothermal is that test centers have a track record of reducing technological risk, crowding-in private investment, and accelerating commercialization.

Implications for energy innovation

The case studies demonstrate that test centers are a proven mechanism for accelerating the development of technologies that are too costly, technically complex, or commercially uncertain for individual companies to advance alone. By providing shared infrastructure for field-scale testing, they reduce the high cost of subsurface innovation while enabling public-private collaboration that lowers technical and financial risk and creates the conditions for commercialization.

These lessons extend well beyond geothermal and other subsurface technologies. Wherever innovation depends on shared infrastructure, public funding, and commercially sensitive technologies, similar design challenges emerge. Questions about governance, ownership, IP, data sharing, and participant incentives are not unique to geothermal—they recur across energy technologies whenever multiple organizations collaborate to develop and validate new technologies. While the specific arrangements vary, the underlying principles identified through comparative analysis are broadly transferable. The complete technical report examines how successful energy innovation test centers addressed these challenges, and identifies the governance, ownership, IP, and data-sharing principles that underpin the recommendations presented in Issue Brief 2.

The model also has clear international relevance, as interest in next-generation geothermal and other subsurface technologies is growing rapidly across multiple jurisdictions. Although legal frameworks, funding mechanisms, and institutional structures differ across countries, the core architecture of a successful test center can be adapted to different national contexts with targeted modifications. This adaptability is particularly important for subsurface technologies, because their performance must be demonstrated and optimized under diverse geological conditions before they can be deployed at scale.

A strong IP framework is the foundation of an effective test center

The value of a test center ultimately depends on the participation it attracts, and participation depends on confidence that IP and data will be managed appropriately. A robust, overarching IP and data strategy, implemented through an effective governance framework, is therefore a fundamental design feature of every successful test center. Without clear rules governing IP creation, IP ownership, IP protection, licensing, confidentiality, publication, and data sharing, the very features that make test centers valuable (such as shared infrastructure, independent validation, and collaboration) can become deterrents to participation by creating risks of premature disclosure or loss of competitive advantage. Companies that are uncertain how proprietary technologies or commercially sensitive information will be handled are unlikely to contribute them to a shared testing environment.

This challenge is particularly acute for next-generation geothermal, where many developers are venture-backed companies whose competitive advantage lies in proprietary technologies and technical know-how. These companies, and the investors supporting them, require confidence that commercially valuable technologies—in particular, proprietary information and sensitive data—will remain protected, while allowing sufficient sharing of operational knowledge to make participation worthwhile.

Successful test centers demonstrate that these objectives are compatible. By combining collaboration with commercially credible safeguards, they have enabled participants to contribute technologies while generating knowledge that benefits the wider sector. How those safeguards can be designed is the subject of Issue Brief 2.

The path forward

Test centers are critical infrastructure for the next phase of the clean energy transformation. They provide the shared environment needed to accelerate the development, demonstration, and commercialization of next-generation energy technologies that are unlikely to reach scale through private investment alone. As experience across geothermal, oil sands, and unconventional gas demonstrates, strategically targeted public investment in shared testing infrastructure can catalyze technological innovation, crowd-in private capital, and generate benefits that extend well beyond individual projects.

Realizing these benefits depends on creating commercially credible conditions for participation. IP and data-sharing frameworks are therefore an integral design feature, determining whether industry, investors, research institutions, and public funders are willing to participate in a test center.

Issue Brief 2 builds on the lessons presented here by examining IP and data-sharing arrangements that can help enable and structure participation in collaborative energy test centers. The complete technical report provides the detailed comparative analysis and recommendations that inform the proposed framework for geothermal testbeds. The framework does not purport to provide a comprehensive IP strategy or address every consideration that may arise—such considerations will vary depending on the applicable legal framework, technologies involved, participants, and commercial objectives and should be addressed with appropriate IP expertise.

This brief is intended to inform discussions on the design of future geothermal test centers. Together with the summary report and Issue Brief 2, this brief provides a common foundation for governments, industry, investors, and host institutions to design commercially credible test centers and to support policy convenings and stakeholder discussions on the governance, intellectual property, and data-sharing frameworks needed for future geothermal test centers.