Powering the Future: What 50 Years of Enhanced Geothermal Teaches Us Today

Jason Lipton, Boulder Energy Advisory
Angela Seligman, Clean Air Task Force

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CATF CLEAN AIR TASK FORCE

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See the Superhot Rock Geothermal Glossary for more information on the definitions linked in this report.

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Section I

Executive Summary

Over 50 years have passed since the pioneering Fenton Hill Enhanced Geothermal System (EGS) project set out to create an artificial geothermal reservoir in hot 'dry' rock. Since then, **over 100 projects have been conducted worldwide**, collectively advancing EGS technology, techniques, and economics. This study sought to examine and analyze the progress that has been made, from the early research projects to today's commercially viable developments. Specifically, this research had two objectives: A) assembling a comprehensive and standardized database of all past and present EGS projects, and B) analyzing key trends and advancements to quantify where and how progress is enabling current and near-term developments. We are now seeing multiple projects at an unprecedented scale and speed of development, with hundreds of megawatts of capacity currently under construction.

Comprehensive EGS Project Database

To form the foundation for this analysis and to measure what metrics have improved, this study synthesized a comprehensive dataset of over 60 technical, operational, and financial characteristics from 103 historical and ongoing EGS projects. This roster of projects included 'traditional' EGS developments as well as enhanced hot sedimentary aquifers (HSA) and enhanced hydrothermal projects, as each of these has applied—and contributed to—EGS research and advancement. Over 400 research reports, technical papers, government publications, press releases, and company announcements were scrutinized to identify and incorporate reliable and representative data for each project.

Trend Analysis

Subsequently, an analysis of technical and economic characteristics from all projects was conducted. Comparative analysis **highlights dramatic improvements** that have been accomplished along a number of key technoeconomic metrics. Project data was analyzed along several key metrics and indicators commonly associated with technical advances and commercialization.

Key Findings

The current state of EGS—at the cusp of what appears to be a commercial naissance—has been attained through a combination of incremental advancements and recent transformative, step-change innovations. Notable findings include:

Faster drilling: Average total well rates of penetration (ROP) have reached up to 8.4 m/hr (28 ft/hr) in commercial wells, up to 31 m/hr (102 ft/hr) under test conditions at Utah FORGE (Akindipe & Witter, 2025), and an instantaneous ROP of over 300 ft/hr at Fervo's Sugarloaf appraisal well (Fervo Energy, 2025).

Increasing production temperatures: Over time, projects are getting hotter on average. As technology continues to improve, projects stand to leverage several times more energy from supercritical temperatures (Clean Air Task Force, 2022).

Improving flow rates: Production flow for 'traditional' EGS, enhanced hydrothermal (HYS) and enhanced hot sedimentary aquifer (HSA) projects is improving. Recent projects' production rates are approaching—and sometimes surpassing—markers and benchmark values for commercial viability. Fervo Energy's (Fervo's) Cape Station has reached 93-120 L/s in production testing, well above the often-cited commercial threshold of 80 L/s.

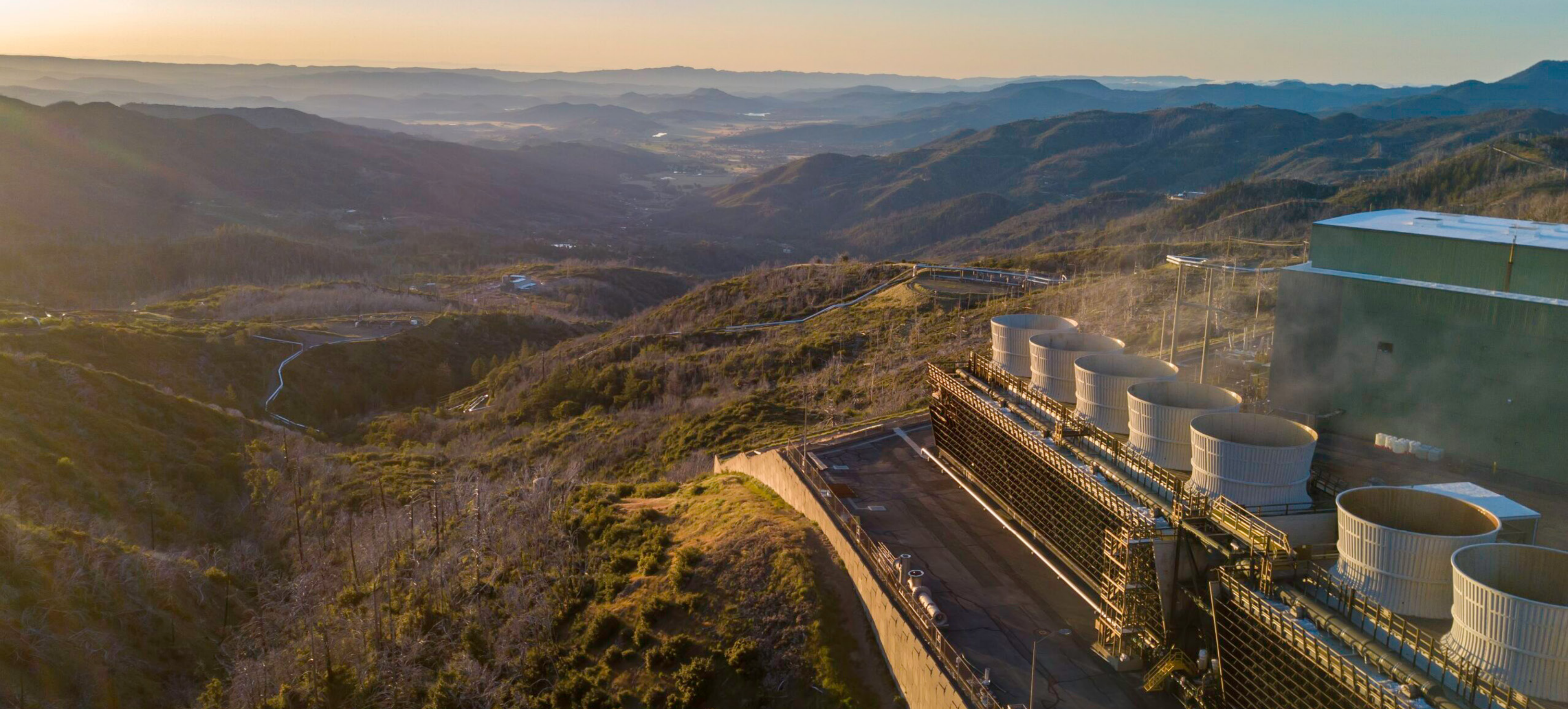
Deeper—and longer—wells: Average measured depth (MD) has increased to over 4 km for wells drilled in the past 5 years. Additionally, at least eight wells have been drilled by Fervo with up to mile-long (1.6 km) horizontal segments through crystalline basement rock. The drilling of horizontal wells has been a game changer for flow rates and recovery efficiency, allowing for greater surface area and enhanced heat transfer while resulting in substantially increased power per well.

Declining drilling costs: Fervo's Cape Station wells have so far been drilled at a rate of $4.6M/well, vs. the historical average of $17M/well for all prior EGS wells (Akindipe & Witter, 2025; and this study). With less than 10% of planned wells drilled, Cape Station costs are already approaching scenario thresholds for maturing technology. Costs are expected to further decline as they did when shale gas exploration first utilized these techniques. In addition to cost reductions due to the learning curve in the field, efficiencies of scale become more pronounced over hundreds of wells per site.

Additional revenue streams: From multidimensional output products, most frequently including direct heat or lithium extraction, and particularly prevalent in European EGS projects.

A massive upsurge in Power Purchase Agreements and installed capacity: Contracts executed within the past 5 years will rely on over 610 MW_e, over ten times more capacity than all prior EGS projects' installed capacity combined. This has been made possible by Fervo's current projects, developing up to 500 MW_e each via hundreds of wells per project—compared to the prior standard project size of one well pair with a capacity of 5 MW_e or less.

Each of these advancements reflects steady technological and economic progress. Collectively, incremental gains and recent step-change improvements are transforming the industry, enabling current EGS developments to achieve technical success and commercial viability at an unprecedented scale. This momentum is not only bringing first-of-a-kind large-scale EGS commercialization within reach but also building a pipeline for future projects' commercial success.



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Section II

EGS Overview

Geothermal energy projects require underground reservoirs with three key conditions: high subsurface heat, rock permeability, and fluid flow circulating through the system. In a hydrothermal development, these requirements exist naturally. Such 'conventional' geothermal projects have demonstrated themselves as clean and reliable sources of heat and power for over a century. As of 2024, geothermal plants accounted for a combined 16.9 GW_e of installed power generation capacity, predominantly in the western United States, Indonesia, Philippines, Türkiye, and New Zealand (Cariaga, 2025). Many geothermal plants have also provided direct heat for industrial, residential, or other uses. Hydrothermal plants can only be built in areas with the requisite underground reservoir conditions, constraining their development to less than 10% of the Earth's surface (Duffield & Sass, 2003), largely along tectonic boundaries.

Under most of the rest of the Earth's surface, there is abundant heat within reach, but inadequate permeability or fluid flow through the rock to transport thermal energy effectively. Enhanced Geothermal Systems (EGS) artificially create or enhance a geothermal reservoir to levels that could support commercial energy extraction.

Specifically, EGS is typically defined by the application of hydraulic fracturing or other artificial stimulation methods such as thermal fracturing or electrical stimulation to create or expand conductive fractures and sustained fluid circulation (see Figure II.1). Through EGS, the promise of commercial-scale geothermal power can be developed in many areas previously unsuitable for geothermal development, vastly expanding its global reach and potential.

In practice, the dividing lines between hydrothermal, HSA, and EGS systems is not always clear (see Figure II.2). EGS reservoirs may be developed below or adjacent to known hydrothermal systems. Similarly, EGS-style stimulation techniques have also been successfully applied to numerous hydrothermal and HSA projects, resulting in improved injectivity and production rates, and often extending the operating life of hydrothermal reservoirs. For the purposes of this report, any project that created an EGS reservoir or that has applied EGS stimulation and techniques is included in the database and analysis.

Figure II.1: Components of EGS
(U.S. Dept of Energy (DOE), 2023)

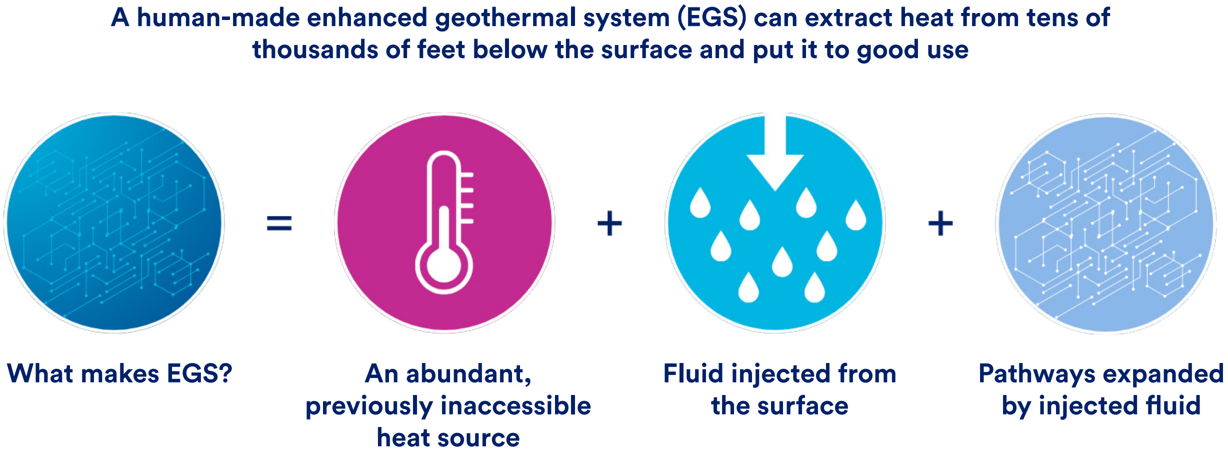
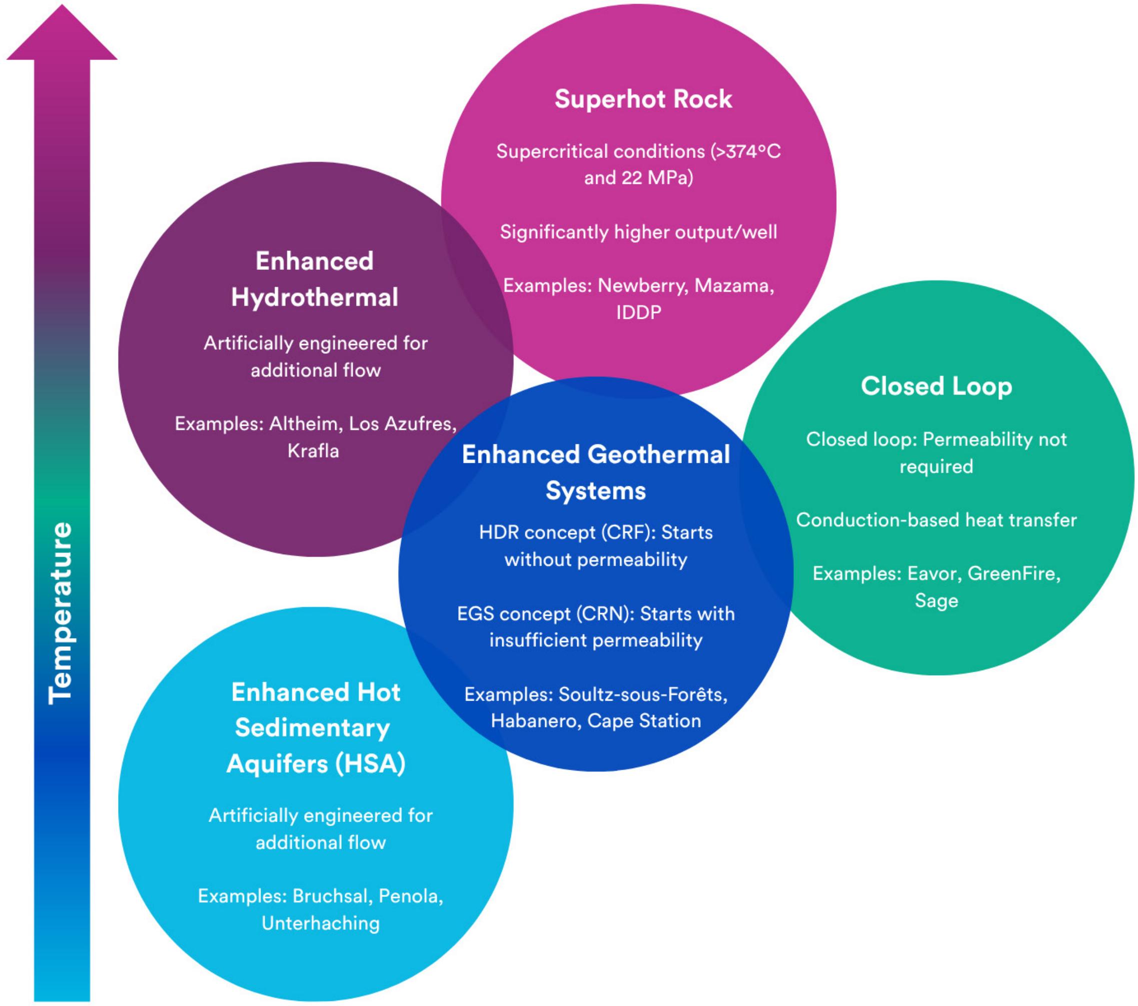


Figure II.2: Blurred Lines Between Geothermal Project Categories
EGS (enhanced geothermal system), CRF (crystalline rock with dominant artificial fractures), CRN (crystalline rock with dominant natural fractures or faults). Adapted from (Bloomberg NEF, 2023 and this research).



Key benefits of EGS and geothermal energy include:

- Providing continuous **baseload/firm power**. Geothermal plants produce reliable power with one of the highest capacity factors of any conventional or renewable technology, often above 90% (IRENA, 2023a).
- Promoting **energy security and price predictability.** Geothermal operations are relatively immune from fuel supply shocks, insulating operators and consumers from price volatility and geopolitical trade risk.
- Many **oil, gas, power, and mining skillsets are transferable** (IEA, 2021). This facilitates workforce mobility, promotes cross-sector investment, and can invite a broader set of entities to see geothermal as an opportunity for expansion.
- One of the **smallest land-use** footprints per energy output (renewable or conventional)—second only to nuclear (Betanabhatla, 2023; U.S. Dept of Energy (DOE), 2019) and growing smaller as industry pursues higher temperature ultimately reducing the number of wells necessary.
- Providing **clean, sustainable power**, with one of the lowest lifecycle carbon emissions of any generation technology (U.S. Dept of Energy (DOE), 2019). Additionally, EGS binary power systems have lower total lifecycle greenhouse gas (GHG) emissions than any conventional source (Eberle et al., 2017; Nicholson & Heath, 2021). These benefits become particularly valuable in regions and markets with carbon credits, taxes, or other schemes.
- Increasingly, geothermal plants offer at least partial dispatchability. Plants such as Puna, Hawaii have power purchase agreements (PPAs) based on **operational flexibility** and offtaker demand. This load-balancing becomes all the more essential as grids are under pressure to manage increasingly intermittent generation (U.S. Dept of Energy (DOE), 2019).
- While hydrothermal plants are geographically-limited, EGS can be installed in a **broader range** of settings, potentially closer to demand centers (Aljubran & Horne, 2024).
- Sustainability incentives: EGS projects can incorporate treated **wastewater** or potentially **CO_2** (Sowiżdżał et al., 2022) as a circulating fluid. This offers greater sustainability and could qualify those EGS projects for carbon capture and storage (CCS) credits and related financial incentives.

Photo credit: Ormat Technologies

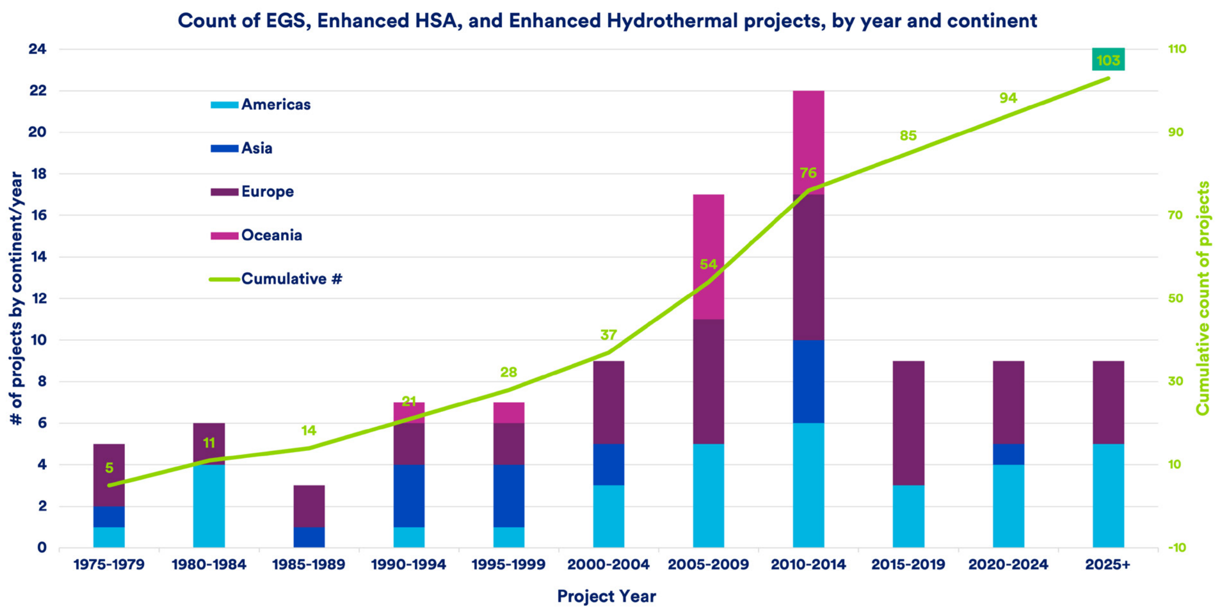
Section III

Results and Current Status

Since its origins in the 1970s, over 100 EGS projects have been launched worldwide (see Figure III.1). These range from early-stage research projects on stimulation methods to more recent commercial projects providing power and/or direct heat. They include projects deemed successes, failures, and many with mixed results.

Figure III.1: EGS Projects by Operational Year and Continent

For projects that didn't reach an operational phase (or didn't report an operational date), start of development year is used (this study from multiple sources)



Of the 103 projects examined in this study, over half are traditional EGS efforts with crystalline rock basement reservoirs, approximately one-quarter are enhanced hydrothermal efforts (HYS), and the remainder are enhanced hot sedimentary aquifers (HSA) (see Table III.1). The crystalline rock EGS systems are further subcategorized as either crystalline rock with dominant artificial fractures (CRF) or those with dominant natural fractures or faults (CRN). Through Q1 2025, EGS projects have taken place in 23 countries, with most located in Europe (>40%) or the Americas (32%).

Table III.1: EGS Projects by Dominant Reservoir Type and Region
Through Q1 2025 (this study from multiple sources)

	Dominant Reservoir Type				
	Traditional EGS		Enhanced Hydrothermal (HYS)	Enhanced Hot Sedimentary Aquifer (HSA)	Unspecified
Region	Crystalline Rock - Artificially Fractured (CRF)	Crystalline Rock - Natural Fracture/ Fault (CRN)			
Americas	9	6	8	1	9
Asia	3	5	6	1	
Europe	15	6	10	8	3
Oceania	4	3		4	2
Percent of projects	35%	22%	27%	16%	16%

Analysis of the amassed project- and well-level datasets highlight the results of both incremental and step-change improvements along with a number of key metrics commonly associated with commercial viability. The following subsections delve into each of the observed trends.

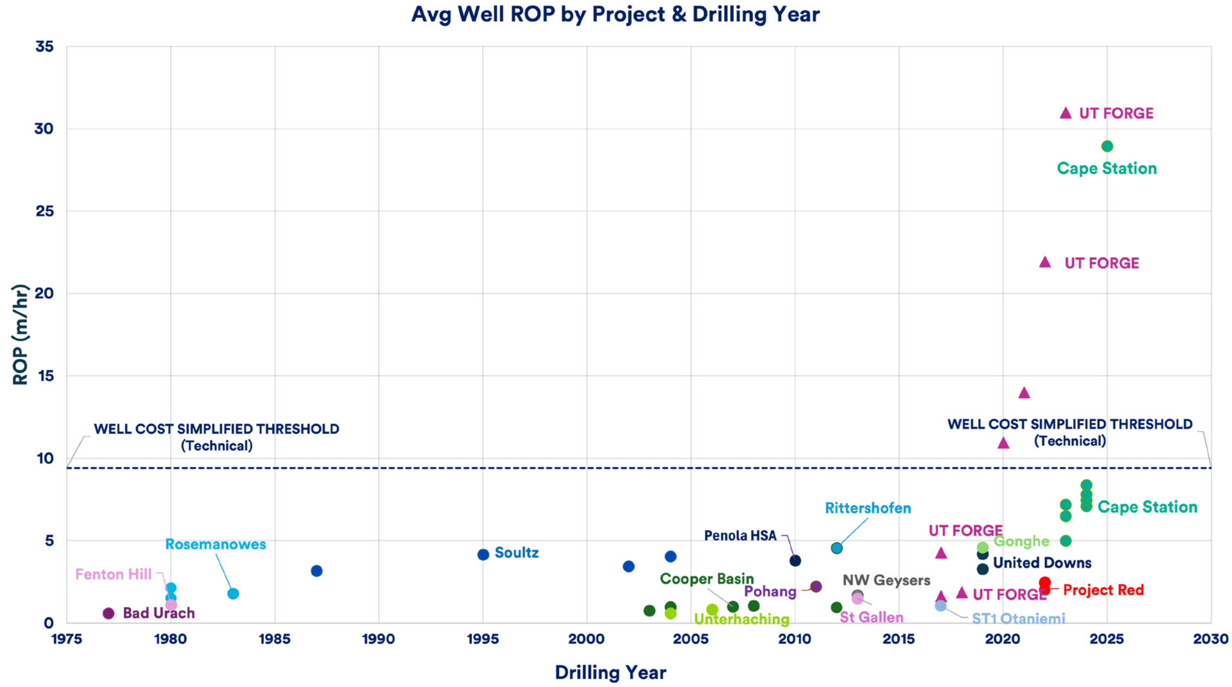
A. Faster drilling (ROP)

Recent EGS projects are achieving substantially faster drilling times than the average even five years ago. Fervo's Cape Station and Project Red commercial wells have reached an average ROP of up to 8.4 m/hr (27.6 ft/hr). In research wells, an impressive 31 m/hr (102 ft/hr) has been attained at Utah FORGE (Akindipe & Witter, 2025). These gains are particularly notable given the typical depth (≥4,000 m) and crystalline, granitic basement lithology of most EGS wells.

To evaluate this progress against established benchmarks, Sandia National Labs' Well Cost Simplified (WCS) model offers scenarios and assumptions for various levels of technical maturity (Lowry, Finger, et al., 2017). The model uses ROP assumptions of 7.62 m/hr (25 ft/hr) for Intermediate 1 Scenario, 15.24 m/hr (50 ft/hr) for Intermediate 2 Scenario, and 30.48 m/hr (100 ft/hr) for the Ideal Scenario. The Ideal Scenario—identified as the highest foreseeable potential—is also associated with the Technical Improvement Scenario in the DOE GeoVision report—where technical advancements have reached a level that permits geothermal (mostly EGS) to rapidly expand and supply over 8% of the U.S. electrical demand by 2050 (U.S. Dept of Energy (DOE), 2019).

Figure III.2: Average well ROP by Drilling Year

Benchmark (well cost simplified threshold) of 9.4 m/hr. from (Lowry, Finger, et al., 2017), only surpassed to date by Utah FORGE experimental wells and Fervo Energy's Sugarloaf appraisal well, which was a maximum average ROP (this study based on multiple sources)



To date, only Utah FORGE and Fervo Energy's Sugarloaf appraisal well have reached the Ideal Scenario ROP. However, Lowry et al. (2017) also flag an ideal average *daily* penetration rate of 226 m/day (9.4 m/hr) down to 4,000 m—a depth that current wells are regularly reaching and Fervo Energy recently achieved a *maximum* average ROP of 29 m/hr at their Sugarloaf appraisal well (Fervo Energy, 2025). Compared to these scenario assumptions, recent commercial projects have passed the Intermediate 1 drilling rate marker and are approaching the daily ideal technical marker, while several research wells' extraordinary ROP offers hope of further progress.

This study focuses on ROP because it is a widely-reported key component of drilling cost. ROP, however, is hardly the *only* component of drilling and rig time. Drilling rig costs –assumed between $28,500-$38,400/day in the WCS model (Lowry et al., 2017)—are also impacted by tripping (roundtrip non-drilling time to bring the drill bit to the surface and back to the bottom), bit rates (bit life in hours or days before replacement), mobilization, trouble time, casing and bottom hole assembly materials, and other cost factors. Time-dependent costs (particularly those associated with ROP) have the highest impact on drilling cost reduction (Lowry et al., 2017).

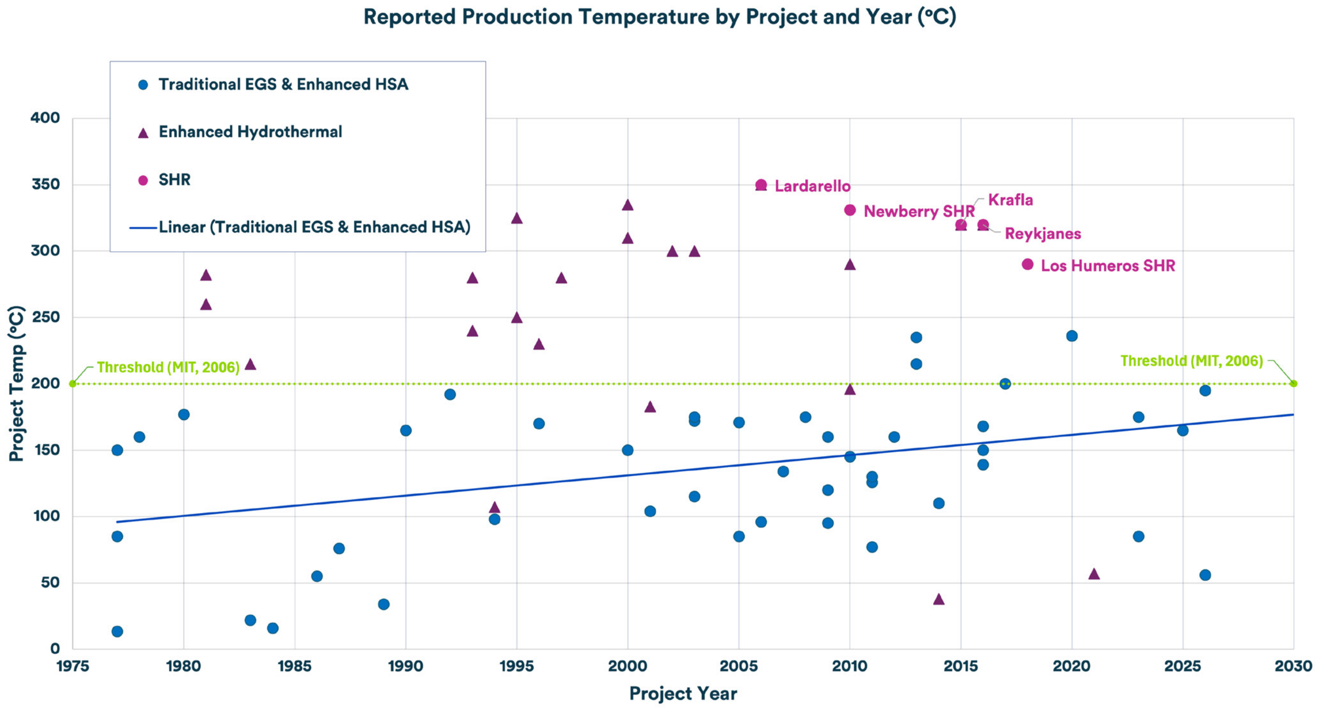
It's also worth highlighting that average ROP per well masks individual advances by rock type and bit types. Recent polycrystalline diamond compact (PDC)-drilled segments at Utah FORGE have reached up to an astonishing 276 ft/hr (84.12 m/hr)—more than 2 ½ faster than the Ideal Scenario assumptions (Akindipe & Witter, 2025).

B. Higher production temperatures

EGS production and bottom-hole temperatures have trended upwards over the past five decades. Projects started prior to 2000 averaged 101 °C, as compared to an average of 153 °C for projects after the turn of the century. The overall trajectory is approaching commercial benchmarks of 190-200°C[1] (see Figure III.3). These gains reflect advances in technology and materials that are more tolerant to heat and the associated complexities in fluid chemistry.

Figure III.3: Production Temperature by Project Year (multiple sources)

Notes: 1) When production temp not available, bottom hole temperature was included. 2) Threshold of 200 °C is a benchmark for commercial power production (The Future of Geothermal Energy, 2006). 3) For additional data on SHR projects, see CATF's SHR map and fact sheets.



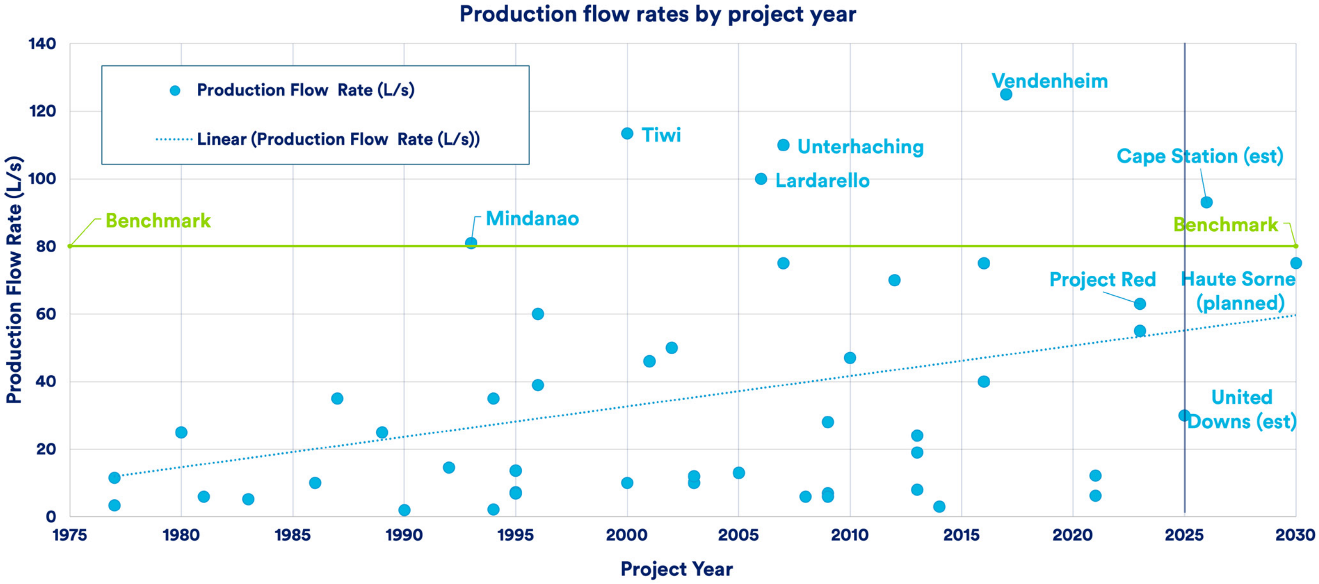
C. Higher flow rates

The trend of production flow rates over time for EGS projects continues to rise, although few operational projects have exceeded the widely-cited 80 L/s commercial benchmark.[2] Notably, Cape Station—currently under development—has reported promising flow rates ranging from 93-120 L/s during testing (J. H. Norbeck et al., 2024). This is particularly significant given its ambitious planned capacity of up to 500 MW_e (Businesswire, 2025; Fercho et al., 2025) (see Figure III.4). CATF's SHR Preliminary Techno-Economic Model further emphasizes that achieving and sustaining high flow rates is a critical determinant of project-level economics, with substantial implications for Levelized Cost of Electricity (LCOE).

1 190 °C: Economically Viable benchmark in (Lowry et al., 2017); 200°C: a benchmark for high-grade EGS (The Future of Geothermal Energy, 2006) and a benchmark from the GeoVision report (U.S. Dept of Energy (DOE), 2019).

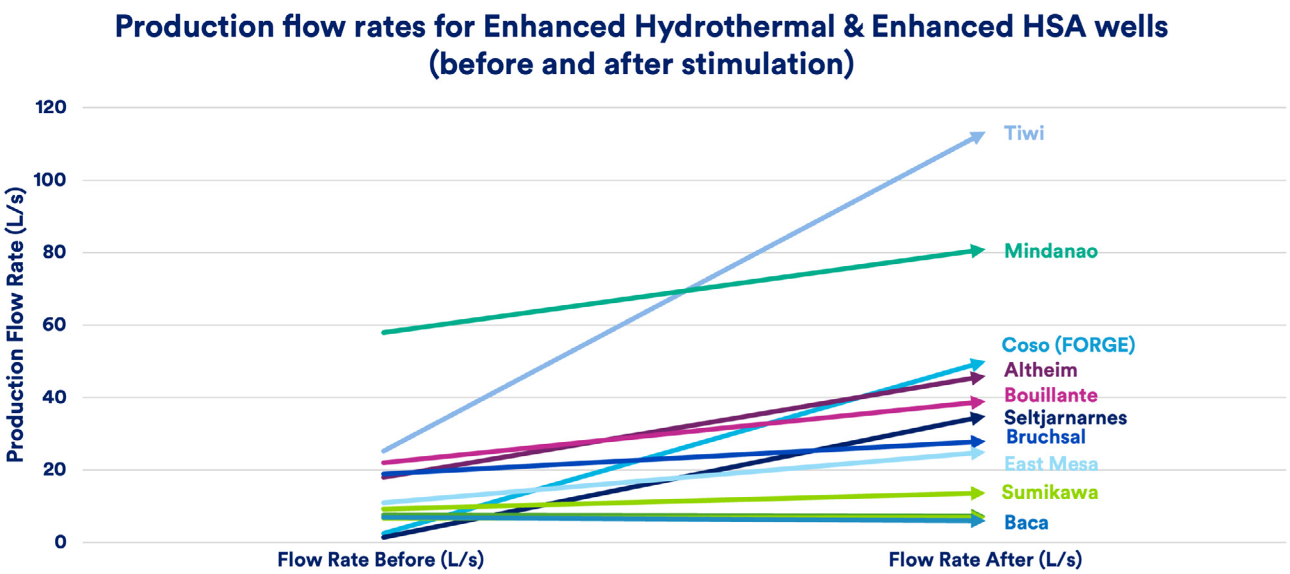
2 40 L/s for the Midterm Scenario, 80 L/s for the Commercially Mature Scenario (The Future of Geothermal Energy, 2006).

Figure III.4: Production Flow Rates by Project Operation Year (when available)
Notes: 1) Cape Station and Haute Sorne—both currently in development—based on test or expected rates. 2) Flow rate benchmark of 80 L/s from Commercially Mature Scenario in (The Future of Geothermal Energy, 2006) (this study from multiple sources).



Stimulation has also enhanced flow at many existing hydrothermal and HSA projects. Production flow rates measured before and after hydraulic or other EGS stimulation programs showed improvement in 11 of 12 cases analyzed in this study (see Figure III.5). Additionally, a 2023 study evaluating injectivity index changes from stimulation found at least 23 cases that led to enhanced injectivity index (Luo et al., 2023).

Figure III.5: Production Flow Rates for 12 Enhanced Hydrothermal and Enhanced HSA Wells (multiple sources)



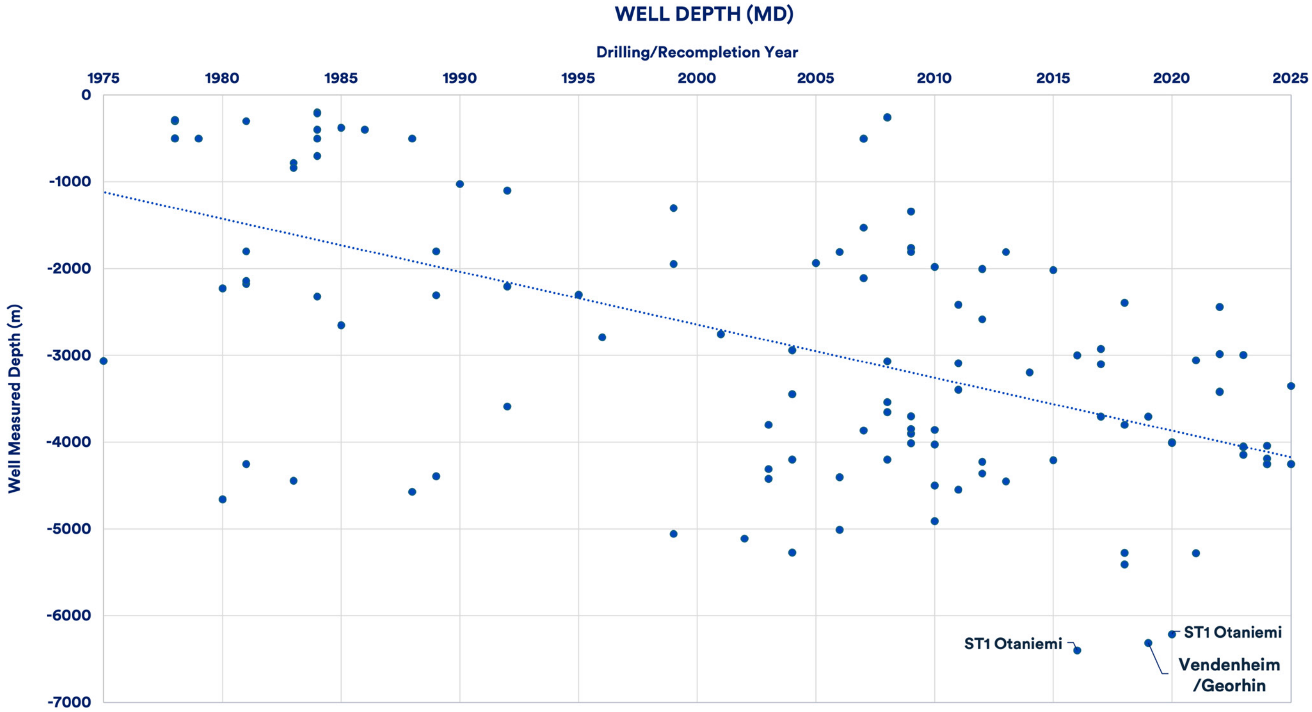
D. Deeper and longer wells

The average measured depth (MD) per EGS well has more than doubled since the early projects in the 1970s and early 1980s (see Figure III.6). Recent projects—including Fervo's Project Red and Cape Station—are drilling extensive ~mile-long horizontal segments through granitic basement rocks, enhancing heat transfer and surface area, and mirroring shale oil and gas drilling best practices. Fervo noted that it has attained higher power capacity density than expected (9.1 MW_e per km^3, at least partly due to their well drilling techniques and hotter than anticipated reservoir temperatures (J. H. Norbeck et al., 2024).

Geo-Energie Jura's Haute Sorne in Switzerland and E2E's Rainbow Lake in Canada are expected to mimic this technique (DESTRESS, 2017a; E2E Energy Solutions, 2023). Cheaper, faster drilling processes will allow for deeper, longer wells. This trend towards deeper drilling may ultimately split by output type: direct heat projects do not generally need to drill as hot (or deep) as power-generation projects.

Figure III.6: Measured Depth (MD) for EGS and Enhanced HSA wells by Drilling/Recompletion Year (multiple sources)

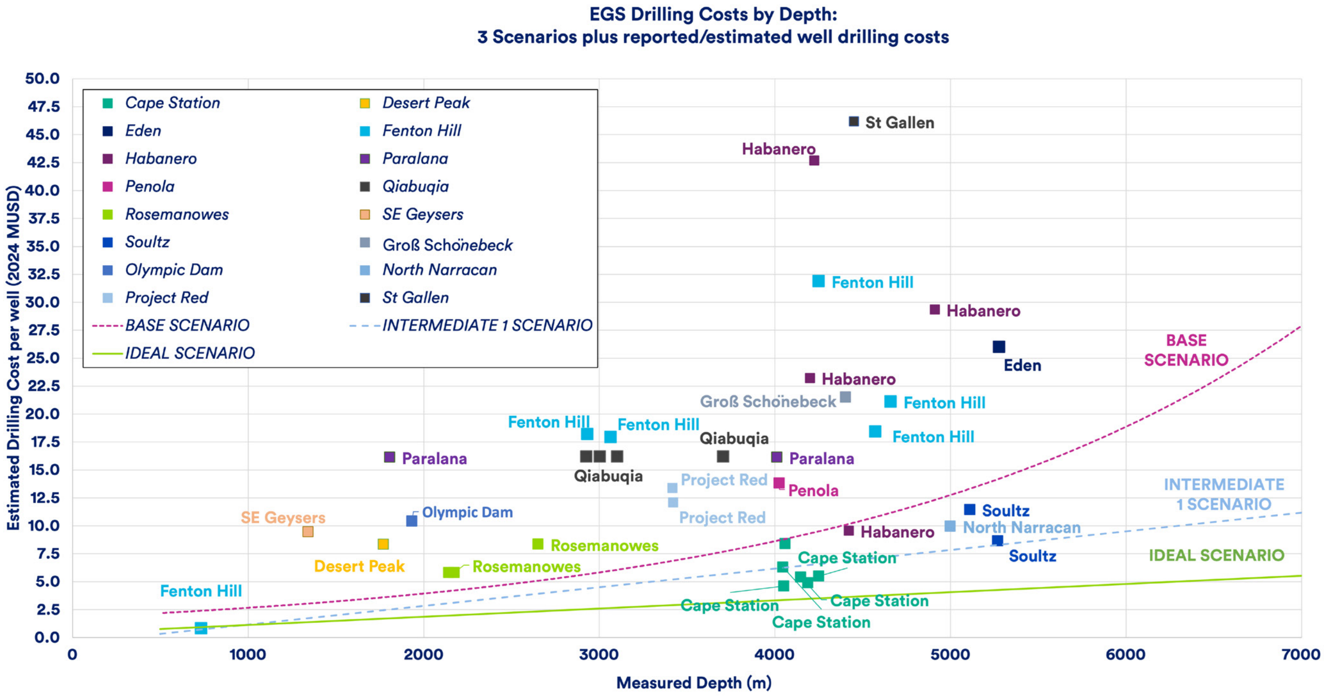
Note: Labels added for wells >6,000 m MD



E. Lower drilling costs

Ultimately, technical improvements are translating into lower drilling costs. Recent wells have been drilled to depths of 4,000 m or more for as little as $4.6M--approximately $1,065/m ($346.45/ft)—for drilling alone, excluding completion costs (Akindipe & Witter, 2025) (see Figure III.7). This is less than 20% of historical drilling costs from such projects as Habanero and Fenton Hill. Of note, Cape Station wells are beginning to approach the Ideal Scenario cost curves from (Lowry et al., 2017).

Figure III.7: Estimated and Reported Well Drilling Costs, against cost curves for 3 Scenarios, (adapted from Augustine et al., 2019; Lowry, Finger, et al., 2017)
Note: Prior drilling costs first standardized to 2024 in reported currency via CPI calculator, then converted to 2024USD via currency exchange calculators (this study from multiple sources)



There are caveats to these data. While efforts were made to standardize costs to 2024USD, a more meticulous approach with a drilling index and accounting for externalities, differences in rock types, and other myriad of dependencies would likely be more precise (Lukawski et al., 2014, 2016). It is apparent—even with the streamlined method applied here—that recent Utah wells are being drilled at lower cost and that subsequent, scaled wells in the same lithology are clustering around these step-change reductions.

Additionally, while drilling represents one of the largest components of capital expenses, it is hardly the only one. Several additional current advancements that are likely to reduce costs include:

1. **Multi-well pads**, with eight or more wellheads drilled per pad, are likely to offer more predictability in lithology (leading to faster drilling and longer bit runs), less rig mobilization between proximal wells (lower rig time and costs), and more consolidated above-ground infrastructure (less material and time cost) (Horne et al., 2025).

2. **More efficient stimulation and connectivity processes**, such as zipper and multi-stage fracturing, improved packers, and temperature-responsive 'smart' tracers (J. H. Norbeck et al., 2024; J. W. Tester et al., 2021).

F. Coproduction opportunities

In addition to electricity, EGS projects have been diversifying revenue streams through multidimensional coproduction. This aids EGS' path towards broad commercial viability, most commonly including sales of direct heat, lithium, and natural gas. Each mechanism—dependent on local conditions—may also broaden project appeal to investors and industry alike:

- Direct Use (Thermal)
  - Geothermal for heat (as a primary or secondary output) has been leveraged for over a century.
  - Geothermal parks, with multiple users at cascading temperatures have proven an effective way to monetize geothermal energy (such as Hellisheiði, Lardarello, and Soultz-sous-Forêts).
- Mineral Cogeneration
  - Lithium and other mined minerals from wells and brine (Wertich, Tiewsoh, & Tiess, 2018), (CHPM2030, 2019).
  - Several Upper Rhine Graben and Cornwall projects have significant lithium concentrations in their brine. Up to 80% of revenue has been estimated to come from lithium sales.
- Carbon Sequestration
  - CO_2 as a working fluid may help conductivity (Kumari & Ranjith, 2019) and can qualify a project for carbon capture and storage (CCS) incentives if geologic data show that the CO_2 will remain stored underground.
- Thermal Energy Storage
  - An increasing number of new ventures are proposing solutions that offer short- and longer-term thermal storage (E2E Energy Solutions, 2023; Sage Geosystems, 2025; GreenFire Energy, 2020; Fervo Energy, 2023b).
  - This could raise the value of next-generation projects, particularly with rapid load-following to handle peaking and grid stabilization (Ricks et al., 2022).

As the value of lithium rises, some EGS projects have focused on establishing coproduction partnerships. Entities including Vulcan and EnBW have acquired or taken operational control of EGS facilities, overseeing lithium extraction and signaling strong commercial interest in mineral development (Cariaga, 2024b). At least seven EGS projects in Europe and Canada have reported lithium concentrations ranging from 162-220 mg/L (see Table III.2), with current or planned lithium extraction underway (Abesser et al., 2023; E2E Energy Solutions, 2023; Genter et al., 2023).

Table III.2: Current and planned lithium coproduction at EGS projects
Note: URG = Upper Rhine Graben

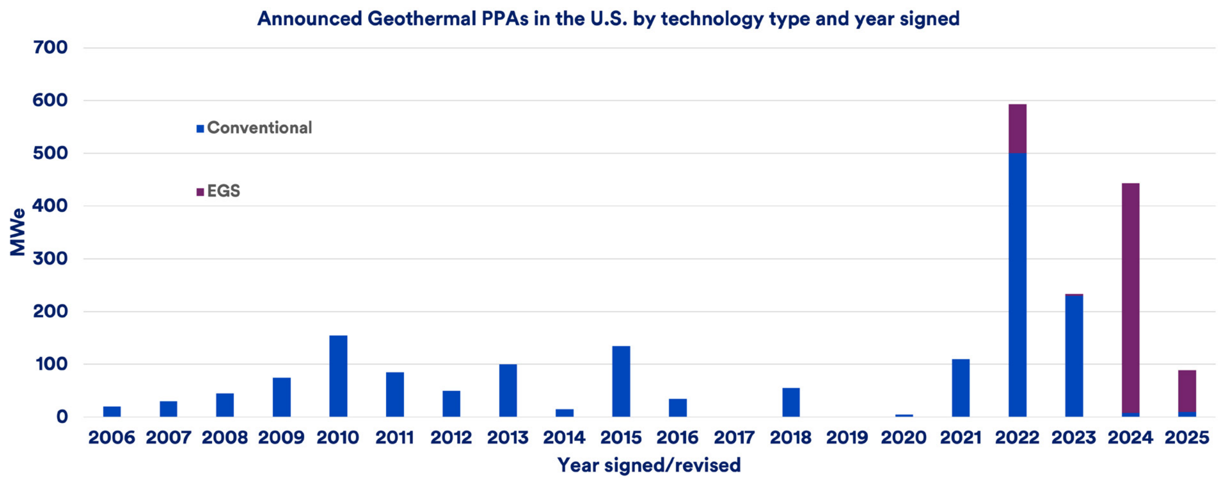
Project, Region	Coproduction	Status	Source
Bruchsal, URG	162 mg/L Lithium concentration in brine; producing battery-grade lithium carbonate	Current commercial coproduction	(Cariaga, 2024b; A. Genter, personal communication, April 14, 2024)
Insheim, URG	168 mg/L Lithium concentration in brine	Current commercial coproduction	(A. Genter, personal communication, April 14, 2024; Vulcan Energy, 2024)
Landau, URG	180 mg/L Lithium concentration in brine	Current commercial coproduction	(Cariaga, 2023; A. Genter, personal communication, April 14, 2024)
Rainbow Lake, Canada	Proposed project, lithium co-production expected	Planned	(E2E Energy Solutions, 2023)
Rittershoffen, URG	190 mg/L Lithium concentration in brine; 1800-2000 tonnes of Li production/year possible	Planned	(A. Genter, personal communication, April 14, 2024)
Soultz-sous-Forêts, URG	173 mg/L Lithium concentration in brine; Lithium carbonate extraction since 2021	Current commercial coproduction	(A. Genter, personal communication, April 14, 2024)
United Downs, UK	“Very high” lithium concentration; planned extraction of 220 mg/L	Planned	(Abesser et al., 2023)

G. Growth in Purchase Agreements (PPAs and HPAs)

One of the most significant measures of EGS commercial maturity is the growth in number and volume of power purchase agreements (PPAs) and heat purchase agreements (HPAs). Impressive growth has occurred in recent years as offtakers have contracted for hundreds of megawatts (over two orders of magnitude larger than prior agreements), reflecting increased offtaker confidence in EGS technologies and longevity (see Table III.3).

PPAs in the U.S. include Fervo’s Project Red (currently online, with 3.5 MW_e to Google), Cape Station (in development, at least 490 MW_e in PPAs), and Corsac Station (planned, with 115 MW_e in executed PPAs) (see Figure III.8). This total of 610.5 MW_e in EGS PPAs signed since 2022 represents over ten times the installed capacity of all prior EGS projects combined.

Figure III.8: Announced Geothermal PPAs by Type and Year Signed/Revised
Notes: Data through Q1 2025, 2) Limited data for Conventional PPAs for 2024 and 2025. Adapted from (Bloomberg NEF, 2023) and this study



In Europe, projects with commercial output include Soultz (online since 2016, delivering 1.7 MW_e to the grid), Rittershoffen (with 24 MW_t of heat to a nearby bio-refinery since 2016), Insheim (a Feed-in Tariff (FiT) of €250/MWh for 4.8 MW_e), and United Downs (expected online H2 2025, with 3 MW_e to Ecotricity).

Table III.3: Publicly-announced PPAs, HPAs, FITs, and Related Contractual Agreements for EGS projects, through Q1 2025 (this study from multiple sources)
Notes: URG = Upper Rhine Graben, FiT = Feed-in Tariff

Operator	Plant	Offtaker	Location	Power (MW_e)	Thermal (MW_t)	Signed	Start	Terms/ Details	Source
ES	Soultz	EDF	URG	1.7	–	–	2016	FiT: €246/ MWh for 15 years	Genter, 2021
ES	Rittershoffen	Roquette Frères biorefinery	URG	–	24	2016	2016	Heat Purchase Agreement (HPW)	Roquette, 2016
Vulcan Energy	Insheim	–	URG	4.8	–	–	–	FiT: €250/ MWh	Richter, 2019
GEL	United Downs	Ecotricity	UK	3	–	2021	2025	PPA	Richter, 2021
GEL	United Downs	Cornish Geothermal Distillery Company (CGDC)	UK	–	–	2021	2025	Heat Purchase Agreement (HPA)	Richter, 2021
Fervo	Cape Station	9 California community choice aggregators	U.S.	53	–	2022	Q2 2026	PPA, 15 years	Businesswire, 2022, Richter, 2025
Fervo	Corsac Station	AVA/ East Bay Community Energy (EBCE)	U.S.	40	–	2022	Q2 2030	PPA, 15 years	Ava Energy, 2024
EGL	Eden Geothermal	Eden Biome Project	UK	–	1.4-4	–	2023	–	Eden Project, 2023
Fervo	Project Red	Google – data center	U.S.	3.5	–	2023	2023	–	Businesswire, 2024
Fervo	Cape Station	SoCal Edison	U.S.	70	–	2024	2026	PPA, 15 years	Businesswire, 2024
Fervo	Cape Station	SoCal Edison	U.S.	250	–	2024	2028	PPA, 15 years	Businesswire, 2024
Fervo	Corsac Station	Sierra Pacific (NV Power)	U.S.	115	–	2024	2030	PPA, 15 years	NV Energy, 2024
Fervo	Cape Station	Clean Power Alliance	U.S.	48	–	2025	Q2 2028	PPA, 15 years	Clean Power Alliance, 2025
Fervo	Cape Station	Shell Energy	U.S.	31	–	2025	2026	PPA, 15 years	Richter, 2025

Photo credit: Fervo Energy

Section IV

Additional Keys to Unlock Full Potential

While recent progress has clearly been made along numerous technical and economic measures, additional support is needed in several key areas to speed the growth of EGS and unlock its full potential. These include:

Policy and Regulatory Support: Stable and supportive policy are essential to promoting geothermal as a secure, baseload, reliable, and long-term resource. Frameworks that recognize EGS' additional contributions to thermal energy, storage, lithium, and related coproduction stand to benefit even further from geothermal research and investment.

Commercial Investment: As EGS projects scale to commercially-competitive levels of production, developments will require billions of dollars in public and private investment (US Dept of Energy (DOE), 2024). The foundation of this will be a recognition of geothermal's unique investment profile: often higher upfront costs, and extended development and payback timeframes –but with lower operating costs and highly stable returns—compared to other baseload or conventional technologies.

Research Investment: Technology and techniques must be further tested and refined under experimental and demonstration conditions to leverage hotter temperatures and continue to optimize production levels and development costs. Additionally, the breakthrough potential from Superhot Rock (with supercritical reservoirs over 375 °C) offers exponentially more energy density, maximizing the output per well (see CATF's Superhot Rock Energy: A Vision for Firm, Global Zero-Carbon Energy report). Cracking this code would further transform the industry and is worthy of further research investment into suitable materials and advanced EGS engineering.

Longevity and Reservoir Decline Management: Early results from current projects are indeed promising (J. H. Norbeck et al., 2024), however, sustained operational performance remains untested under these breakthrough conditions. Long-term strategies for managing thermal drawdown, pressure losses, and geofluid chemistry risks remain to be proven at scale over the 15-30+ year lifetime of a typical project.

Full recognition of EGS' unique value: As noted, EGS offers premium value as a price-inelastic, firm, sustainable source of power. As such, it can command a higher price, compared to lowest cost—intermittent—providers. Recent PPAs appear to show that some current EGS projects have committed to 15-year contracts below $110/MWh (NV Energy, 2024). This price is enough to be competitive in some markets, but is still above the average commercial maturity benchmark of $80/MWh (The Future of Geothermal Energy, 2006). The convergence of continued cost reductions from the top, with the recognition of EGS' added value from the bottom—beyond simplified LCOE metrics—are likely to make future EGS investments increasingly attractive.

Managing Seismicity: More recent seismicity monitoring and "traffic light" procedures have mitigated induced seismicity for most projects. Managing induced seismicity must remain a key priority, including both technoeconomic and social acceptance strategies.

Geographic Expansion: To demonstrate EGS' ability to scale globally, larger projects at scale should be developed in a broader range of geographies, lithologies, and market conditions.

Improving Data Transparency and Standardization: Limited and non-standardized data reporting complicates cross-project analysis, slows innovation, and hinders public and private investment. Publicly-available data is particularly limited for financial metrics, water usage (C.E. Clark et al., 2013; Soltani et al., 2021), well injectivity indexes (Riffault et al., 2018), and operational performance. In terms of standardization, several notable reports have called for nomenclatures that better address differentiations and improve comparative analysis including Breede et al. (2015) and Pollack et al. (2021). It is hoped that this study will contribute to this effort.

Photo credit: Geodynamics

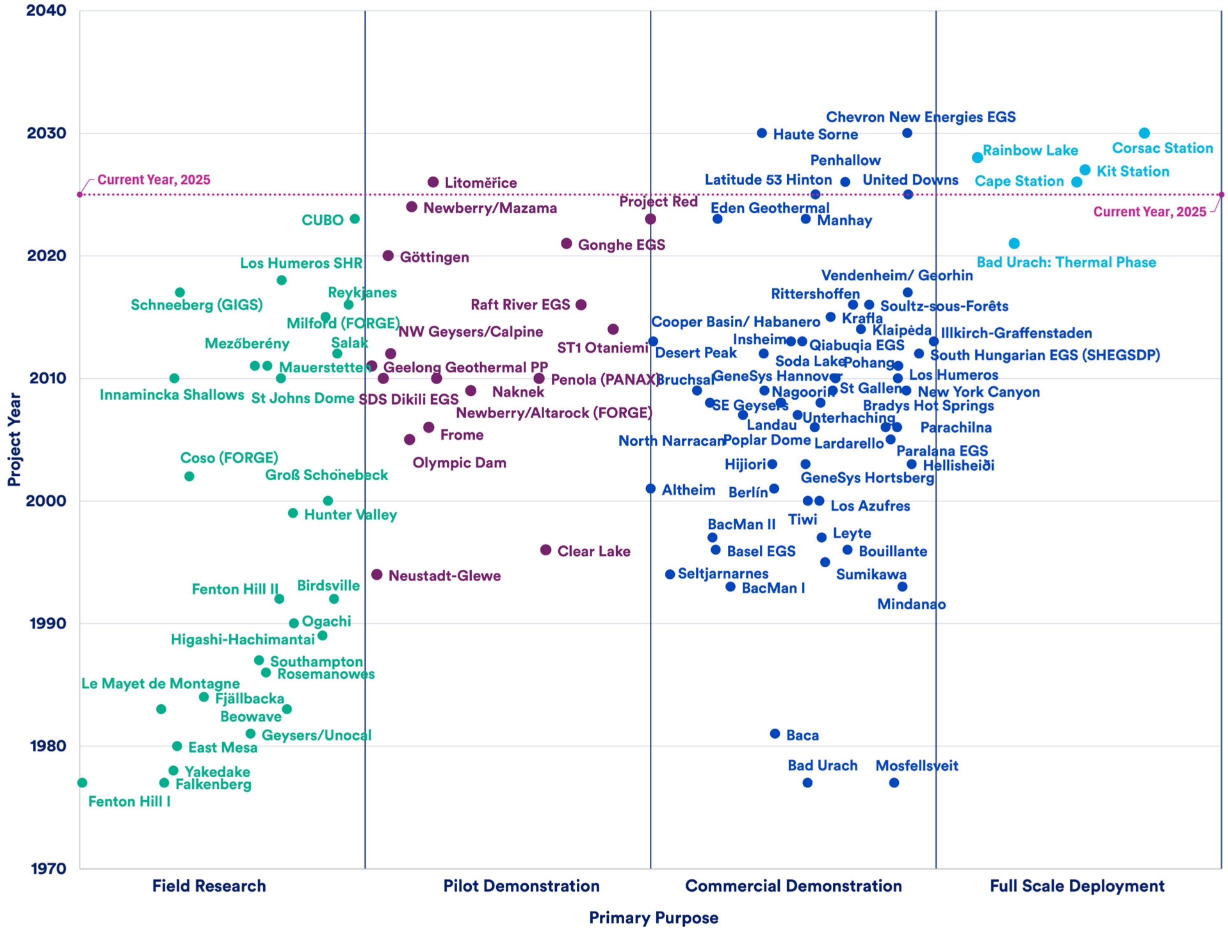
Section V

Conclusion

Enhanced Geothermal Systems (EGS) appear to be at a pivotal point towards scalability and broader commercialization. Analysis of public project data from the past 50+ years confirms that significant advances—both gradual and step-change—can be seen along all technical and economic metrics examined in this study. These advancements have enabled an increasing number of projects to deliver commercial power and direct heat (see Figure V.1). Additionally, recent commercial project development—based on breakthroughs in drilling, stimulation, and development at an unprecedented scale are showing signs of wider commercialization in competitive markets and regions. A remaining breakthrough will be the exponential growth in energy density made possible by future Superhot Rock EGS projects, which can harness supercritical reservoirs exceeding 375°C. These systems have the potential to generate 20-50 MW_e per well (Cladouhos & Callahan, 2024; Clean Air Task Force, 2022).

Figure V.1: EGS Projects by Year, Stated Purpose, and Commercial Achievement

All tracked projects categorized by primary purpose, regardless of level of completion as of Q1 2025. Notes: Field Research – Early-stage exploration and validation in natural settings; Pilot Demo – Small-scale system to test technical feasibility; Commercial Demo – Larger system operating in real-world conditions, often with risk-mitigating support; Full Scale Deployment – Market-competitive and fully integrated into the commercial landscape (Lipton, 2024 and this study from multiple sources).



Notable improvements that have contributed to substantially improved metrics include many best practices from oil and gas drilling that are being applied to EGS including:

- Advanced polycrystalline diamond compact (PDC) drill bits, with higher thermal tolerance and longer bit runs in certain hard rock formations, reducing bit replacement trips and increasing performance (Su et al., 2024).
- Physics-based and limiter redesign drilling techniques, leading to longer bit runs, shorter on-bottom drilling hours, and faster ROP (Su et al., 2024).
- Factory or batch drilling methods, centralizing up to eight wells per pad, enabling reductions in cost through repeatability, shorter rig mobilizations, and drilling and infrastructure efficiencies (Horne et al., 2025).
- More efficient stimulation and completion practices, plug-and-perf and multistage stimulation for improved connectivity and flow rates (J. H. Norbeck et al., 2024).

Demand for firm, clean baseload power from EGS projects is surging, as evidenced by the explosion of power purchase agreements, which have grown from the single digits to commitments approaching 500 MW_e. These contracts are enabling modern projects to achieve commercial viability at a price that recognizes the added value of EGS over conventional or intermittent renewable power. As these projects demonstrate sustained, long-term operational success, they will establish the foundation for expanded investment, research, and fuel further deployments.

Projects that have achieved contractually-delivered commercial output to date have several commonalities. Based on advancements and recent project successes and strategies, the following near-term commercial pathways are apparent:

A. **Enabling future industry and markets dependent upon abundant, baseload affordable power** such as coupling data centers with next generation geothermal. Google, for example, has committed to at least 115 MW_e long-term contracts from two or more Fervo EGS projects for their data centers (GeoEnergy & Cariaga, 2024a).
B. **Developing large-scale projects (tens to hundreds of megawatts)** to unlock economies of scale and attract major power purchase agreements. Scaling up projects significantly reduces costs and makes geothermal more attractive to large offtakers. Currently, Fervo is the only developer operating at this scale.
C. **Supplying entities that have mandates for sourcing clean power**, such as community aggregators in California and offtakers in the European Union.
D. **Producing or co-producing district or industrial heating**, particularly in Europe where pre-existing infrastructure and supportive policy is often already in place.
E. **When lithium or similar coproduction is in place**, allowing for more diversified investment and expanded revenue streams.

Updating this comparative analysis over the coming decade will offer valuable insights into the rate and reach of continuous refinements, as EGS scales up and expands globally. The outlook for EGS is promising—advancing from yesterday's demonstration technology to a keystone contributor of commercial, sustainable, and secure firm power, efficient heat, and critical mineral coproduction.

Section VI

Key References Per Project

Project	References
Altheim	(Breede et al., 2013, 2015; Christi et al., 2025; Evans et al., 2012; Jiang et al., 2023; Kamila et al., 2021; J. Lund & Chiasson, 2007; MND, 2014; Pemecker, 1999; Pollack et al., 2021)
Baca	(Entingh, 2000; Morris & Bunyak, 1981; Pollack et al., 2021; Republic Geothermal, 1983, 1984)
BacMan I	(Alcalá, 2012; Buñing et al., 1995; Kamila et al., 2021; Pollack et al., 2021; Relativo-Fajardo et al., 1999; Rivera Diaz et al., 2016; Rosell & Ramos, 1998; TURBODEN, 2024)
BacMan II	(Alcalá, 2012; Flores-Armenta & Alcalá, 2012; Kamila et al., 2021; Luo et al., 2023; Malate et al., 1998; Pollack et al., 2021; Relativo-Fajardo et al., 1999; Rivera Diaz et al., 2016; Rosell & Ramos, 1998; TURBODEN, 2025)
Bad Urach	(Breede et al., 2013, 2015; Carlo Cariaga, 2022; Pollack et al., 2021; Rathnaweera et al., 2020; Schanz et al., 2003; Sigfússon & Uihlein, 2015a, 2015b; Tenzer, 2003, 2003; The Future of Geothermal Energy, 2006)
Bad Urach: Phase 2	(Carlo Cariaga, 2022, 2022; GEOTIS, 2022b; Richter, 2021, 2021; Sigfússon & Uihlein, 2015b)
Basel EGS	(Alt-Epping et al., 2013; Baujard, Hehn, et al., 2017; Boyet et al., 2023; Breede et al., 2013, 2015; Evans et al., 2012; Grünthal, 2014; Häring et al., 2008; Kang et al., 2022; Liu et al., 2024; Sowiżdżał et al., 2022; The Future of Geothermal Energy, 2006)
Beowave	(ARENA, 2014a; C.E. Clark et al., 2013; Christi et al., 2025; Entingh, 2000; Kamila et al., 2021; Luo et al., 2023; Morris et al., 1984; Pollack et al., 2021; Portier et al., 2009; Republic Geothermal, 1984; Rivera Diaz et al., 2016)
Berlín	(Breede et al., 2013, 2015; Jiang et al., 2023; Kamila et al., 2021; Kang et al., 2022; Kumari & Ranjith, 2019; Luo et al., 2023; Majer et al., 2007; Pollack et al., 2021; Rivera Diaz et al., 2016)
Birdsville	(Richter, 2009b; Rivera Diaz et al., 2016)
Bouillante	(Boissavy et al., 2021; Breede et al., 2013; Jiang et al., 2023; Kamila et al., 2021; Pollack et al., 2021; Sanjuan, B et al., 2000)
Bradys Hot Springs	(Akerley et al., 2021; BLM, 2013; Breede et al., 2013; DOE, 2023; Drakos & Akerley, 2017; Kamila et al., 2021; J. H. Norbeck & Latimer, 2023; Pollack et al., 2021; Rivera Diaz et al., 2016; Wertich, Tiewsoh, & Tiess, 2018; Ziagos et al., 2013)
Bruchsal	(ARENA, 2014a; Breede et al., 2013, 2015; EnBW, 2025; Evans et al., 2012; A. Genter, personal communication, April 14, 2024; GEOTIS, 2022b; Jiang et al., 2023; Kang et al., 2022; Sigfússon & Uihlein, 2015b, 2015a)
Cape Station	(Akindipe & Witter, 2025; Bureau of Land Management (BLM), 2024; Businesswire, 2022, 2025, 2025; Capestation.com, 2024; Clean Power Alliance, 2025; El-Sadi et al., 2024; Fercho et al., 2025; Fervo Energy, 2023a, 2024; Hao, 2024; McConville, 2023; J. H. Norbeck et al., 2024)
Chevron New Energies EGS	(Energy.gov, 2024; Hao, 2024; Sonoma Clean Power, 2024)
Clear Lake	(Capuano et al., 2008; Jager, 1996; Rivera Diaz et al., 2016; The Future of Geothermal Energy, 2006)
Cooper Basin/ Habanero Geothermal Project (HGP) II	(ARENA, 2016; Breede et al., 2013; GEODYNAMICS, 2016; GeoEnergy & Richter, 2015; B. A. Goldstein et al., 2009; Hogarth & Holl, 2017; Lowry, Foris, et al., 2017; Mattson & Blankenship, 2018)

Project	References
Cooper Basin/ Habanero Pilot Plant (HPP) I	(ARENA, 2014a, 2016; Augustine et al., 2006; Bendall et al., 2014; Breede et al., 2013, 2015; Budd, 2013; GeoEnergy & Richter, 2010, 2015; B. A. Goldstein et al., 2009; B. Goldstein & Bendall, 2010; Hogarth & Holl, 2017; Kong et al., 2021; Liu et al., 2024; Pollack et al., 2021; Richter, 2013b; Sowiżdżał et al., 2022; The Future of Geothermal Energy, 2006; Wertich, Tiewsoh, & Tiess, 2018; Zang et al., 2014; Ziagos et al., 2013)
Corsac Station	(Ava Community Energy, 2024; Hall et al., 2022; NV Energy, 2024; Penrod, 2024)
Coso (FORGE)	(Akindipe et al., 2023; Breede et al., 2013, 2015; EERE, 2002; GTO, 2020; Horne et al., 2025; Kamila et al., 2021; Kang et al., 2022; Pollack et al., 2021; Portier et al., 2009; Rose et al., 2006; The Future of Geothermal Energy, 2006)
CUBO	(Beckers et al., 2024; Cornell University, 2021, 2022; Fulton et al., 2024; J. Tester et al., 2023; K. M. Zhang et al., 2015)
Desert Peak	(Akerley et al., 2021; Benato et al., 2016; Breede et al., 2013; Chabora & Zemach, 2013; DOE, 2023; EGS Energy Ltd., 2016; Horne et al., 2025; Kamila et al., 2021; Kang et al., 2022; Richter, 2013a; Sanyal, 2009; The Future of Geothermal Energy, 2006; Wertich, Tiewsoh, & Tiess, 2018; Ziagos et al., 2013)
East Mesa	(Entingh, 2000; Pollack et al., 2021; Republic Geothermal, 1984; Republic Geothermal et al., 1981)
Eden Geothermal	(Abesser et al., 2023; Breede et al., 2015; Cossins-Smith, 2023; Eden Geothermal, 2019, 2021, 2025; Pollack et al., 2021; Wertich, Tiewsoh, & Tiess, 2018)
Falkenberg	(Breede et al., 2013, 2015; Kang et al., 2022; Kappelmeyer & Jung, R, 1987; Pollack et al., 2021; Rummel & Kappelmeyer, 1983; Stafford, 2010; Tenzer, 2003; The Future of Geothermal Energy, 2006)
Fenton Hill I	(Breede et al., 2013, 2015; Jung, 2013; Kumari & Ranjith, 2019; Laughlin et al., 1983; Mattson & Blankenship, 2018; Murphy et al., 1982; J. H. Norbeck et al., 2018; Pollack et al., 2021; Sowiżdżał et al., 2022; Stafford, 2010; The Future of Geothermal Energy, 2006; Ziagos et al., 2013)
Fenton Hill II	(Breede et al., 2013; Jung, 2013; Kelkar et al., 2016; Laughlin et al., 1983; Murphy et al., 1982; J. H. Norbeck et al., 2018; Pollack et al., 2021; Sowiżdżał et al., 2022, 2022; The Future of Geothermal Energy, 2006; Ziagos et al., 2013)
Fjällbacka	(Breede et al., 2013, 2015; Eliasson et al., 1987; Jiang et al., 2023; Kang et al., 2022; Pollack et al., 2021; Rummel & Kappelmeyer, 1983; Stafford, 2010; The Future of Geothermal Energy, 2006; Wallroth et al., 1999)
Frome	(Breede et al., 2015; Energy News Bulletin, 2007; Geothermal Resources Limited, 2009; B. A. Goldstein et al., 2009; Huddlestone-Holmes, 2014; Long et al., 2010; Richter, 2009a)
Geelong Geothermal PP	(GeoEnergy & Richter, 2009b, 2011, 2013; Giles Parkinson, 2017; B. A. Goldstein et al., 2009; B. Goldstein & Bendall, 2010; Huddlestone-Holmes, 2014)
GeneSys Hannover	(Breede et al., 2013, 2015; Genesys Hannover, n.d.; GEOTIS, 2022b; Kang et al., 2022; Kong et al., 2021; Liu et al., 2024; Pollack et al., 2021; Sigfússon & Uihlein, 2015b)
GeneSys Hortsberg	(Breede et al., 2013, 2015; Evans et al., 2012; GEOTIS, 2022b; Jung et al., 2005; Sigfússon & Uihlein, 2015b; The Future of Geothermal Energy, 2006)
Geysers/Unocal	(Entingh, 2000; Mumma, 1982, 1982; Pollack et al., 2021; Rivera Diaz et al., 2016)
Gonghe EGS	(Jiang et al., 2023; Kong et al., 2021; Liu et al., 2024; Wei et al., 2023; Yin et al., 2024; E. Zhang et al., 2022, 2024)
Göttingen	(Hérisson, 2021; MEET-H2020, 2019; Romanov & Leiss, 2021)
Groß Schönebeck	(Blöcher et al., 2016; Breede et al., 2013, 2015; Christi et al., 2025; Ernst Huenges, personal communication, June 19, 2024; Evans et al., 2012; Henninges et al., 2015; Interreg, 2024; Kang et al., 2022; Luo et al., 2023; Mattson & Blankenship, 2018; Patel, 2023; Sowiżdżał et al., 2022)
Haute Sorne	(Cariaga, 2024a; Castilla et al., 2024; DESTRESS, 2017a; Geo-Energie Jura, n.d., 2024; Geo-Energie Suisse, 2023; GeoEnergy & Cariaga, 2024b; Khodayar & Björnsson, 2024; Renewable Energy Magazine, 2022)

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Hellisheiði	(Bjornsson, 2004; Kamila et al., 2021; Luo et al., 2023; Pollack et al., 2021; Rivera Diaz et al., 2016)
Higashi-Hachimantai	(International Workshop on Hot Dry Rock. Creation and Evaluation of Geothermal Reservoirs, 1988, pp. 91–107; Niitsuma, 1989; Stafford, 2010)
Hijiori	(Breede et al., 2013, 2015; Kaieda, 2021; Pollack et al., 2021; Sasaki, 1998; Sowiżdżał et al., 2022; Stafford, 2010; The Future of Geothermal Energy, 2006; Ziagos et al., 2013)
Hunter Valley	(Breede et al., 2015; Huddlestone-Holmes, 2014; Kang et al., 2022; Kitsou et al., 2000; Richter, 2013b; Sigfússon & Uihlein, 2015b; Sowiżdżał et al., 2022; Stafford, 2010; The Future of Geothermal Energy, 2006)
Illkirch-Graffenstaden	(Boissavy et al., 2021; Glaas et al., 2021; Maurer et al., 2021)
Innamincka Shallows	(ARENA, 2016; B. Goldstein & Bendall, 2010; McLaughlin, 2011; Richter, 2011, 2013c)
Insheim	(ARENA, 2014a; Baujard, Hehn, et al., 2017; BESTEC GmbH, 2018a; Breede et al., 2013, 2015; Cariaga, 2024b; Jiang et al., 2023; Kang et al., 2022; Liu et al., 2024; Maurer et al., 2021; Pollack et al., 2021)
Kit Station	(Hall et al., 2022)
Klaipėda	(DESTRESS, 2017b; Guinot & Marnat, 2021; Petrauskas et al., 2018; Pollack et al., 2021)
Krafla	(Axelsson et al., 2006; Eggertsson et al., 2020; Kamila et al., 2021; Pollack et al., 2021)
Landau	(ARENA, 2014b; Baumgärtner et al., 2013; BESTEC GmbH, 2018b; Breede et al., 2013, 2015; EGS Energy Ltd., 2016; A. Genter, personal communication, April 14, 2024; Kamila et al., 2021; Kang et al., 2022; Liu et al., 2024; Maurer et al., 2021; Pollack et al., 2021; Rivera Diaz et al., 2016; Schindler et al., 2010; Sigfússon & Uihlein, 2015b; Vidal & Genter, 2018)
Lardarello	(Breede et al., 2013, 2015; Kamila et al., 2021; Pollack et al., 2021)
Latitude 53 Hinton	(E2E Energy Solutions, 2025; GeoEnergy & Cariaga, 2022a; Novus Earth, 2022)
Le Mayet de Montagne	(Breede et al., 2013, 2015; F. Cornet, 1987; F. H. Cornet, 2021; Sigfússon & Uihlein, 2015b; Stafford, 2010; The Future of Geothermal Energy, 2006)
Leyte	(Alcalá, 2012; Apuada et al., 2005; Kamila et al., 2021; Malate et al., 1997; Pollack et al., 2021; Yglopaz et al., 1998)
Litoměřice	(Breede et al., 2013, 2015; Fischer et al., 2023; Pollack et al., 2021; Šafanda et al., 2020; Tym, 2019)
Los Azufres	(Flores-Armenta & Alcalá, 2012; Kamila et al., 2021; Luo et al., 2023; Pollack et al., 2021; Tello-López et al., 2010; Torres-Rodríguez et al., 2005)
Los Humeros	(Alcalá, 2012; Flores-Armenta & Alcalá, 2012; Jolie et al., 2021; Peter-Borie et al., 2019; Rivera Diaz et al., 2016)
Los Humeros SHR	(Flores-Armenta & Alcalá, 2012; Jolie et al., 2021; Kamila et al., 2021; Kumari & Ranjith, 2019)
Manhay	(GeoEnergy & Cariaga, 2023a; Olver & Law, 2025)
Mauerstetten	(Breede et al., 2013, 2015; GeoEnergy & Richter, 2016a; GEOTIS, 2022b; Mattson & Blankenship, 2018; Mraz et al., 2018; Pollack et al., 2021; Sigfússon & Uihlein, 2015b; Wolfgramm et al., 2015)
Mezőberény	(Brehme et al., 2024; DESTRESS, n.d.)
Milford (FORGE)	(Brehme et al., 2024; GTO, 2020; Jiang et al., 2023)
Mindanao	(Malate et al., 2000; Pollack et al., 2021; Trazona et al., 2002)
Mosfellsveit	(Pollack et al., 2021)
Nagoorin	(Granite Power, 2009; Stafford, 2010)
Naknek	(C.E. Clark et al., 2013; Jennejohn, 2010; Loy, 2016; Stafford, 2010)

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Neustadt-Glewe	(ARENA, 2014a, 2014b; Breede et al., 2013, 2015; Erdwärme Neustadt-Glewe, 2025; Evans et al., 2012; GEOTIS, 2022b; Jia et al., 2022; Jiang et al., 2023; Kang et al., 2022; J. Lund & Chiasson, 2007; Rivera Diaz et al., 2016; Seibt et al., 2005)
New York Canyon	(Jennejohn, 2010; Pollack et al., 2021; Raemy, 2012; US Dept of Energy (DOE), 2010)
Newberry/Altarock (FORGE)	(AltaRock Energy, Inc, n.d.; Breede et al., 2015; Cladouhos et al., 2016, 2018; Data.gov, 2012; Pollack et al., 2021; Sonnenthal et al., 2012; Stafford, 2010; Wertich, Tiewsoh, & Tiess, 2018; Ziagos et al., 2013)
Newberry/Mazama	(Energy.gov, 2024; Mazama Energy, 2025)
North Narracan	(Beardsmore et al., 2016; Granite Power, 2009; Stafford, 2010)
NW Geysers/Calpine	(Breede et al., 2013, 2015; DOE, 2023; Garcia et al., 2012; Hartline et al., 2019; IRENA, 2023; John Farison, 2019; Kang et al., 2022; Liu et al., 2024; J. H. Norbeck & Latimer, 2023; Sigfússon & Uihlein, 2015b; Stafford, 2010; Wertich, Tiewsoh, & Tiess, 2018; Ziagos et al., 2013)
Ogachi	(Breede et al., 2013, 2015; Kaieda, 2021; Kang et al., 2022; Pollack et al., 2021; Sigfússon & Uihlein, 2015b; Sowiżdżał et al., 2022; Stafford, 2010; The Future of Geothermal Energy, 2006; Ziagos et al., 2013)
Olympic Dam	(Bendall et al., 2014; Breede et al., 2015; Earths Energy, 2025a; B. A. Goldstein et al., 2009; Green Rock Energy Ltd., 2008; Larking et al., 2010; Pesa News, 2007; Pollack et al., 2021; The Future of Geothermal Energy, 2006)
Parachilna	(Breede et al., 2015; Long et al., 2010; Stafford, 2010)
Paralana EGS	(Bendall et al., 2014; Breede et al., 2013, 2015; Earths Energy, 2025b; B. A. Goldstein et al., 2009; B. Goldstein & Bendall, 2010; Kang et al., 2022; Kong et al., 2021; Louise McAllister, 2010; Lowry, Foris, et al., 2017; Lu, 2017; McLaughlin, 2011; J. H. Norbeck & Latimer, 2023; Pollack et al., 2021; P. Reid & Messeiller, 2013; P. W. Reid et al., 2010; Riffault et al., 2018; Rojas, 2014; Wertich, Tiewsoh, & Tiess, 2018; Zang et al., 2014)5/19/25 1:13:00 PM
Penhallow	(alex.lomax, 2022; GeoEnergy & Cariaga, 2022b, 2022c; Olver & Law, 2025)
Penola (PANAX)	(Breede et al., 2015; de Graaf et al., 2009; B. A. Goldstein et al., 2009; B. Goldstein & Bendall, 2010; Huddlestone-Holmes, 2014; McLaughlin, 2011)
Pohang EGS	(Breede et al., 2015; Deliverable D7.8: Final Report on DESTRESS Site Access Program, 2020; Diaz et al., 2018; Ellsworth et al., 2019; Grigoli et al., 2018; Jiang et al., 2023; Kang et al., 2022; Luo et al., 2023; Pollack et al., 2021; Sowiżdżał et al., 2022; Wertich, Tiewsoh, & Tiess, 2018; Yu, 2022)
Poplar Dome	(Petty, 2006; The Future of Geothermal Energy, 2006)
Project Red	(Akindipe et al., 2023; Akindipe & Witter, 2025; El-Sadi et al., 2024; Fervo Energy, 2023b; Mark McClure, 2023; J. Norbeck et al., 2023; J. H. Norbeck et al., 2024; J. H. Norbeck & Latimer, 2023; Ormat, 2008)
Qiabuqia EGS	(Lei et al., 2019; Pollack et al., 2021; Yu, 2022; Zhai et al., 2023; E. Zhang et al., 2022; Zhang L. et al., 2025; Zhong et al., 2022)
Raft River EGS	(Bradford et al., 2015; CHPM2030, 2019; EERE Success Story—Geothermal Technology Breakthrough in Idaho, 2016; GeoEnergy & Richter, 2016b; IRENA, 2023; Jones et al., 2011; Kamila et al., 2021; Pollack et al., 2021; POWER Magazine, 2007; Republic Geothermal, 1984; Xing et al., 2024; Ziagos et al., 2013)
Rainbow Lake	(E2E Energy Solutions, 2023, 2025; GeoEnergy & Cariaga, 2022a, 2024c; Huang et al., 2020; Wertich, Tiewsoh, & Tiess, 2018)
Reykjanes	(Friðleifsson et al., 2020; Gunnarsson et al., 2024; Hofmann et al., 2021; Kamila et al., 2021; Pollack et al., 2021; Sigurdsson, 2021)
Rittershoffen	(Baujard, Genter, et al., 2017; Boissavy et al., 2021; A. Genter, personal communication, April 14, 2024; Genter et al., 2023; IRENA, 2023; Lacirignola, 2015; Maurer et al., 2021; Mouchot et al., 2019; Pollack et al., 2021; Ravier, 2020; Trullenque et al., 2018; Wertich, Tiewsoh, Tiess, et al., 2018)

Project	References
Rosemanowes	(Augustine et al., 2006; Breede et al., 2013, 2015; EGS Energy Ltd., 2016; Evans et al., 2012; Mattson & Blankenship, 2018; Olver & Law, 2025; Parker, 1999; Reinecker et al., 2021; Sowiżdżał et al., 2022; Stafford, 2010; The Future of Geothermal Energy, 2006; Zang et al., 2014; Ziagos et al., 2013)
Salak	(GeoEnergy & Richter, 2020; Golla et al., 2020; Luo et al., 2023; Pasikki et al., 2010; Pollack et al., 2021; Rivera Diaz et al., 2016; Yoshioka et al., 2019)
Schneeberg (GIGS)	(GeoEnergy & Cariaga, 2023b; GeoEnergy & Richter, 2019; Pollack et al., 2021; Think GeoEnergy & Richter, 2019; Tiefe Geothermie, 2010; Wagner et al., 2015)
SDS Dikili EGS	(Hou et al., 2015; Mertoglu et al., 2021; Turan et al., 2021)
SE Geysers	(AltaRock Energy, Inc, 2013; Breede et al., 2013; Petty, 2014; Pollack et al., 2021; Rathnaweera et al., 2020; Rivera Diaz et al., 2016; Sigfússon & Uihlein, 2015b)
Seltjarnarnes	(Axelsson et al., 2006; Luo et al., 2023; Pollack et al., 2021; Tulinius et al., 1996)
Soda Lake	(Bakar & Zarrouk, 2018; Cyrq Energy, 2025; Echols et al., 2011; Kamila et al., 2021; Ohren et al., 2011; Pollack et al., 2021)
Soultz-sous-Forêts	(Baria et al., 2006; Baujard et al., 2021; BESTEC GmbH, 2018a; Boissavy et al., 2016, 2021; Breede et al., 2013; F. H. Cornet, 2021; ÉS Géothermie, 2025; A. Genter, personal communication, April 14, 2024; Genter, 2021; Genter et al., 2023; GeoEnergy & Richter, 2016c; Grünthal, 2014; Heidinger, 2010; IRENA, 2023; Jung, 2013; Kang et al., 2022; Luo et al., 2023; Maurer et al., 2021; Mouchot et al., 2019; Riffault et al., 2018; Schindler et al., 2010; Schmittbuhl et al., 2021; Sowiżdżał et al., 2022; The Future of Geothermal Energy, 2006; Trullenque et al., 2018; Wertich, Tiewsoh, Tiess, et al., 2018; Zang et al., 2014; Ziagos et al., 2013)
South Hungarian EGS (SHEGSDP)	(Ádám & Cladouhos, 2016; Breede et al., 2015; GeoEnergy & Richter, 2012; Interreg EU, 2018; Nádor et al., 2019; Pollack et al., 2021; Rojas, 2014; Toth & Nádor, 2023)
Southampton	(Abesser et al., 2023; Breede et al., 2015; J. W. Lund & Toth, 2021)
St Gallen	(Breede et al., 2015; Hirschberg et al., 2014; Kang et al., 2022; Kumari & Ranjith, 2019; Liu et al., 2024; Mateeva, 2013; Pollack et al., 2021; Saar, 2019; Sigfússon & Uihlein, 2015b; Wolfgramm et al., 2015)
St Johns Dome	(Eastman & Muir, 2012)
ST1 Otaniemi	(Cardoe et al., 2021; Kang et al., 2022; I. Kukkonen & Pentti, 2021; I. T. Kukkonen et al., 2023; Pollack et al., 2021; ST1, 2020)
Sumikawa	(Christi et al., 2025; Kamila et al., 2021; Kitao et al., 1990; Kumari & Ranjith, 2019; Luo et al., 2023; Pollack et al., 2021)
Tiwi	(Christi et al., 2025; GeoEnergy & Richter, 2009a; Ontoy et al., 2003; Pollack et al., 2021)
United Downs	(Abesser et al., 2023; Breede et al., 2015; Engineering, 2023; Farndale & Law, 2022; GEL Energy, 2024; Ledingham et al., 2019; Ledingham & Cotton, 2020; Olver & Law, 2025; Reinecker et al., 2021; Thrive Renewables, n.d.; Triple Point Heat Networks, n.d.)
Unterhaching	(ARENA, 2014b; Breede et al., 2013, 2015; Evans et al., 2012; GeoEnergy, 2018, 2018; GEOTIS, 2022a; Kamila et al., 2021; Liu et al., 2024; Wolfgramm et al., 2007)
Vendenheim/ Georhin	(Boissavy et al., 2021; DEEPEGS, 2020; Fiori et al., 2023; GEODEEP, 2020; Peter-Borie et al., 2019; Wertich, Tiewsoh, Tiess, et al., 2018)
Yakedake	(Kobayashi et al., 1982; Kuriyagawa, 1987; Tomita et al., 1988; Yamaguchi et al., 1984)

Section VII

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Section VIII

Appendix: Methodology

The following section outlines the methodology used to research and create a database of EGS projects for analysis.

To develop a comprehensive database of current and historical EGS projects and wells, over 400 academic, media, and commercial sources were reviewed. Data was collected on a range of technical and economic characteristics across traditional EGS, enhanced hydrothermal, and enhanced hot sedimentary aquifer (HAS) projects from the 1970s through Q1 2025.

All reported values were standardized by unit of measurement, currency, and other categories to facilitate comparative analysis. Specifically for drilling costs, the following simplified method was applied:

1. Currency inflation adjustment using annual consumer price index (CPI) or producer price index (PPI) calculators to estimate 2024 values in the reported currency (Bank of England, 2025; Euro Inflation Calculator, 2025; Federal Reserve Bank of Minneapolis, 2024; Reserve Bank of Australia, 2025; Switzerland Inflation Calculator, 2025).
2. Subsequently, currency conversion from reported 2024 currency to 2024 USD, to enable comparison across currencies and countries, using an annual foreign exchange converter (IRS.gov, 2025). It is recognized that the application of drilling cost and regional producer indexes (such as the Cornell Energy Institute (CEI) index) would likely result in a more precise cost comparison (Lukawski et al., 2014). Nonetheless, the streamlined approach followed in this report is meant to provide at least indicative trend analyses of drilling costs over time. The original 'as reported' figures are also provided for further standardization by alternate means.

Many projects had differing or contradictory values from conflicting sources—and sometimes multiple values for a single attribute were found within a single report. In some cases, these differences were likely attributable to different phases of a project's development. In others, no clear explanation was apparent. In all cases, preference was given to primary sources—including contemporaneous academic publications by firsthand project researchers and government filings—over secondary or derivative reporting.

Standardized data was then analyzed along key technical and economic metrics commonly associated with technical maturity and commercial viability. For example the selected indicators are amongst those highlighted in the 2024 Pathways to Commercial Liftoff report (US Dept of Energy (DOE), 2024). Other sources for metrics and indicative commercial benchmarks were applied from (Lowry et al., 2017; Raos et al., 2022; The Future of Geothermal Energy, 2006; US Dept of Energy (DOE), 2019). Further explanation of the metric selection (including applied benchmarks and thresholds) may be found in (Lipton, 2024).