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INNOVATION THEMES & STRATEGY

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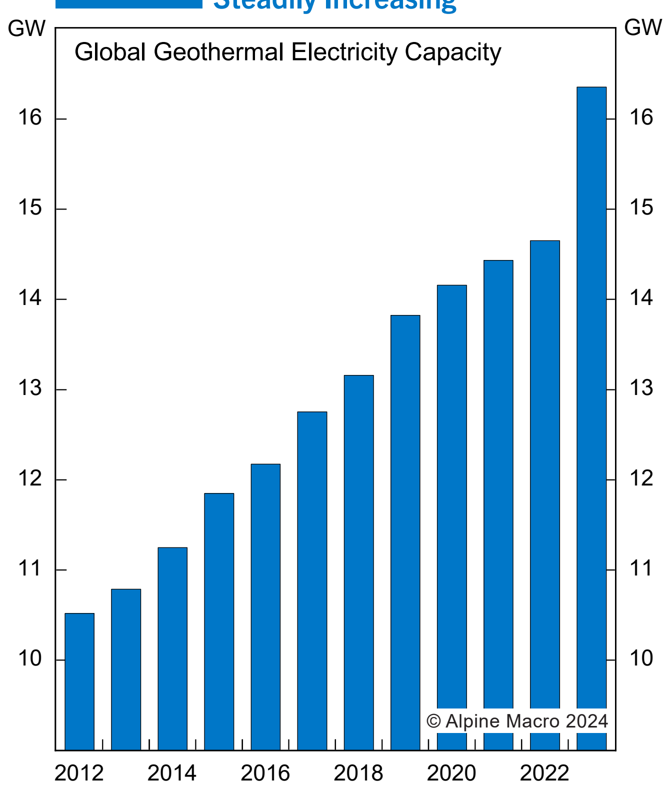
Unlocking Geothermal Energy's Potential

Geothermal is arguably the most underrated renewable energy source. Unlike weather dependent wind/solar and intermittent natural gas/coal generation, geothermal provides 24/7, baseload power, 365 days a year. Radioactive decay in the Earth's mantle and crust creates heat over 10,800°F, coined "the Sun beneath our feet" in the geothermal industry. This heat is continuously replenished at a flow rate of roughly 30 terawatts – nearly 2x all human energy consumption. This makes geothermal energy a self-sustaining, abundant, and accessible energy source virtually everywhere. Yet, both high upfront costs and geothermal well failure rates have historically made scaling geothermal economically unviable, leaving its potential largely untapped.

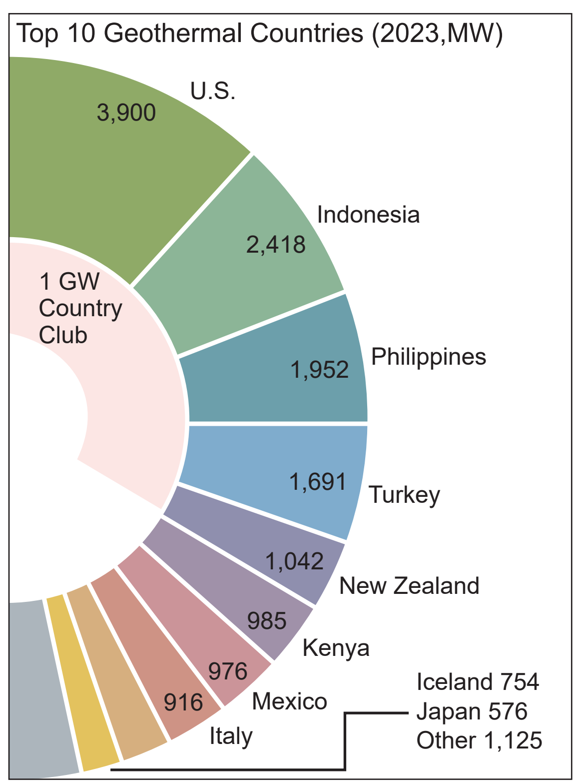
In This Report

Chart 1 Geothermal Capacity Steadily Increasing



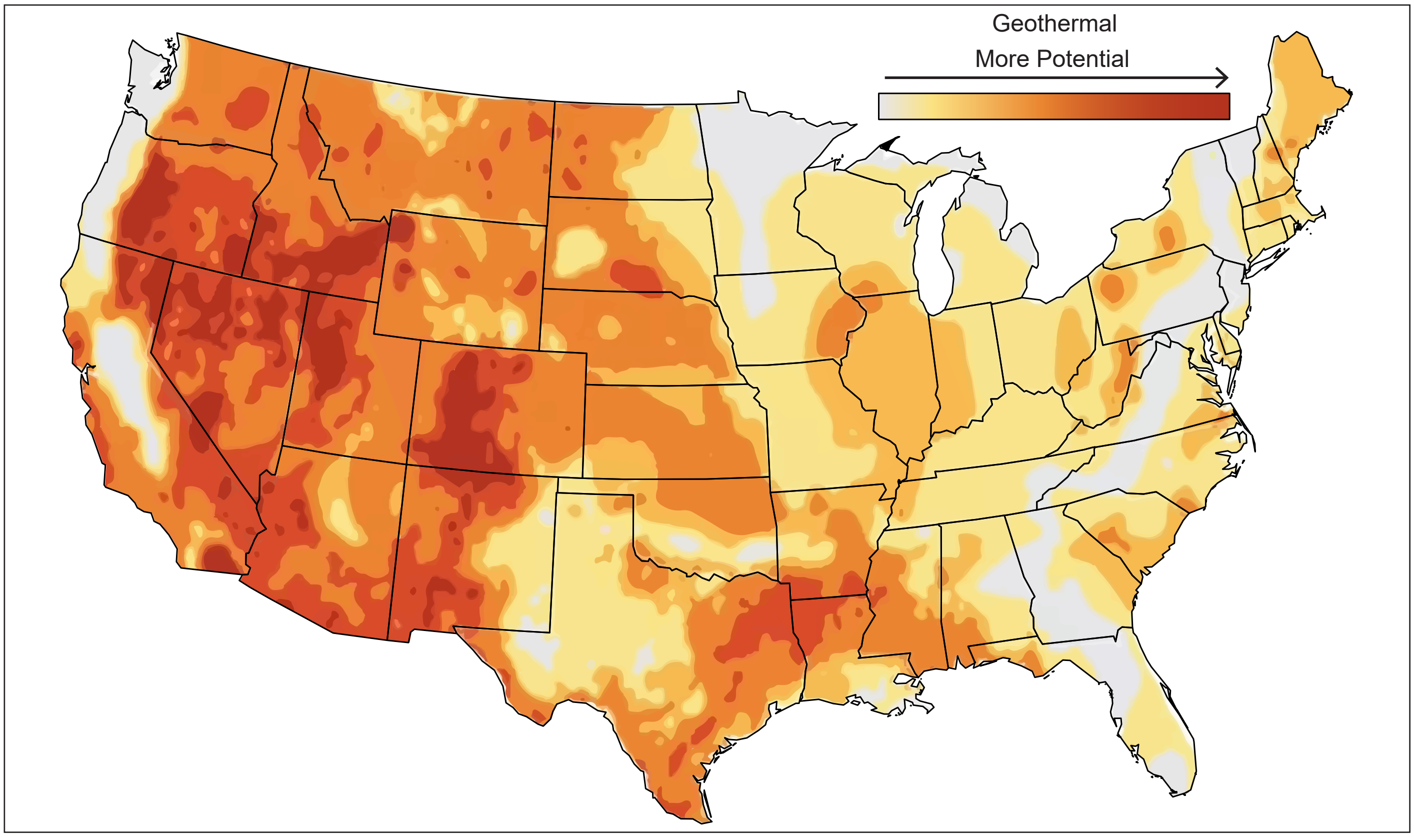
Source: International Renewable Energy Agency

Chart 2 Global Geothermal Generation



Source:ThinkGeoEnergy Research 2024

Chart 3 U.S. Geothermal Generation



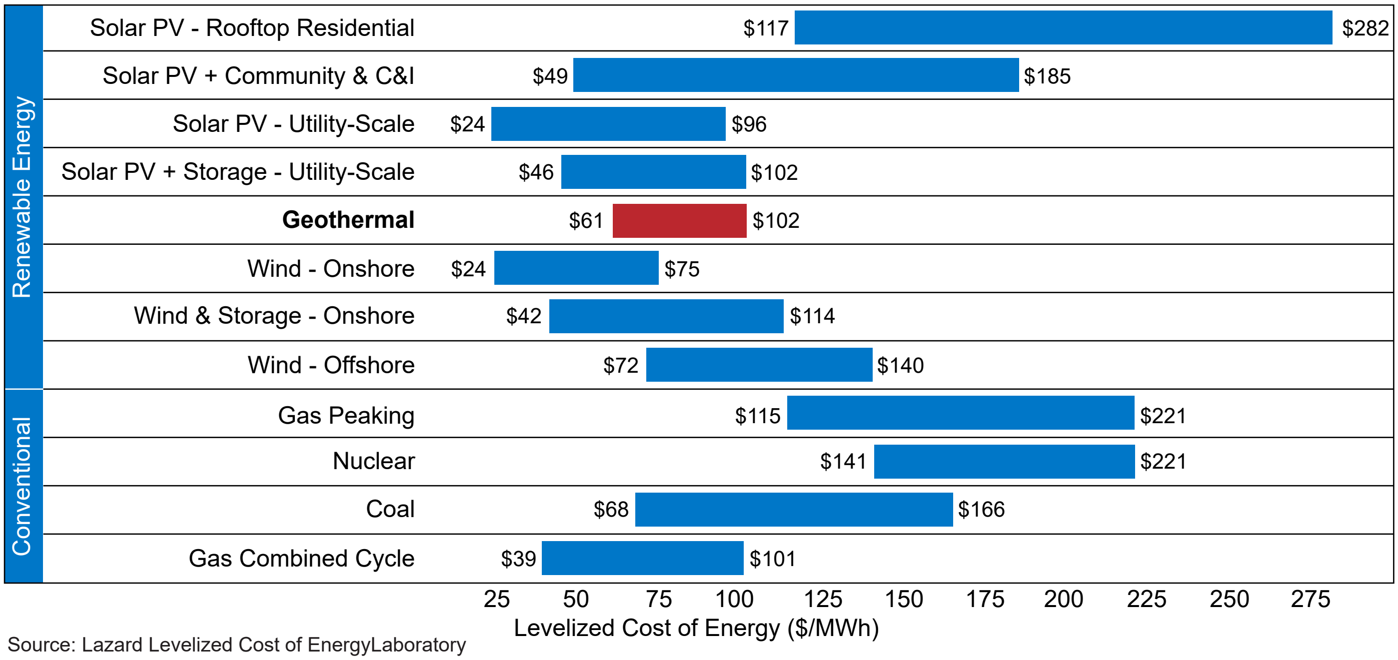
Source: National Renewable Energy Laboratory

Last year, global geothermal power generation capacity totaled 16,355 MW- roughly equal to the output of 16 nuclear reactors (Charts 1 & 2). Yet, its potential is significantly higher. For instance, a DOE analysis indicates that capturing just 2% of the thermal energy available, two to six miles beneath America's surface, would produce 2,000x the nation's total annual energy consumption. By 2050, the agency predicts that technological advancements will dramatically increase U.S. geothermal capacity by 20x to 90GW, enough to power 65 million American homes.

Today, the revitalized push to make geothermal energy a key power source has brought it back into the limelight. A disruptive start-up ecosystem developing next-generation drilling technologies, novel well designs, and modular geothermal plant configurations is ushering in a new geothermal era. While geothermal plants have historically been geographically confined to areas with natural geothermal reservoirs close to the surface of the earth, novel geothermal approaches are reducing the geographic limitations of geothermal energy while rapidly improving economics (Chart 3). Leading next-generation geothermal approaches are enhanced geothermal systems (EGS) and advanced geothermal systems (AGS).

Already, innovation in the sector has made geothermal's levelized cost of energy (LCOE) competitive with natural gas and coal. On a per MWh basis, geothermal's LCOE ranges from $61-$102,

Chart 4 Levelized Cost of Energy



Source: Lazard Levelized Cost of EnergyLaboratory

compared to $68-$166 for coal and $115-$221 for natural gas (**Chart 4**). Surging power demand from data centers, especially in baseload renewable forms, has emerged as another catalyst to the unfolding geothermal renaissance.

This report will argue that geothermal's time has come as it transitions into a scalable and economically viable energy source. We believe the undervalued energy form is undergoing a transition positioning it to play a growing role in the globe's energy mix. We will highlight the many advantages that set the energy form up for success, unpack novel geothermal approaches, and conclude with our investment considerations.

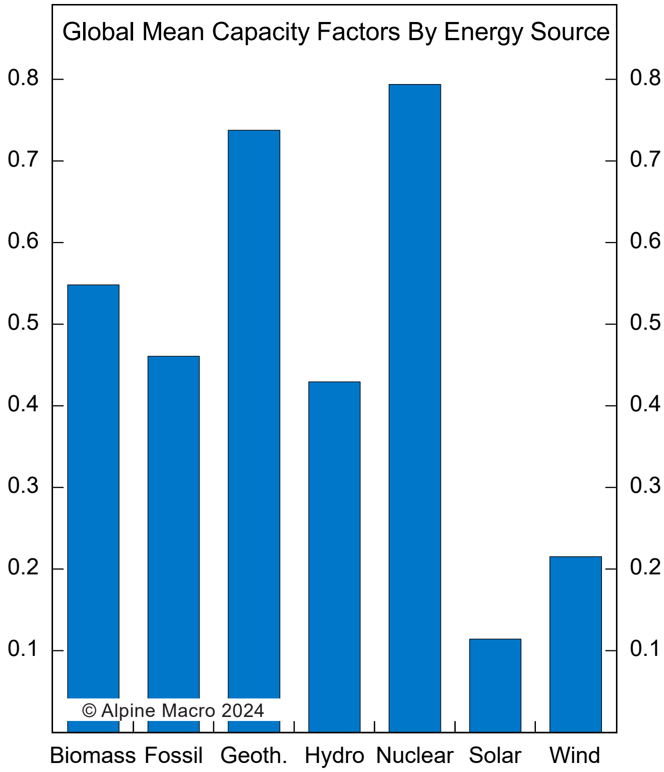
"The innovations – and the pace at which they are being realized – are increasing next-generation geothermal's visibility and viability in the future of energy nationwide, and key players are starting to take notice." **-** Department of Energy

Geothermal's Benefits

Although installed geothermal capacity greatly lags that of other renewable sources like wind and solar, emerging vulnerabilities from intermittent sources are becoming more pronounced as their penetration increases. Grid connection delays, supply chain issues, and lack of energy storage have cast a shadow on intermittent renewables. This has created a unique opportunity for geothermal despite being "late out of the gate". While geothermal's key attribute is its ability to provide baseload power, this is just one of many emerging benefits (**Chart 5**). Other noteworthy data points that facilitate geothermal adoption include:

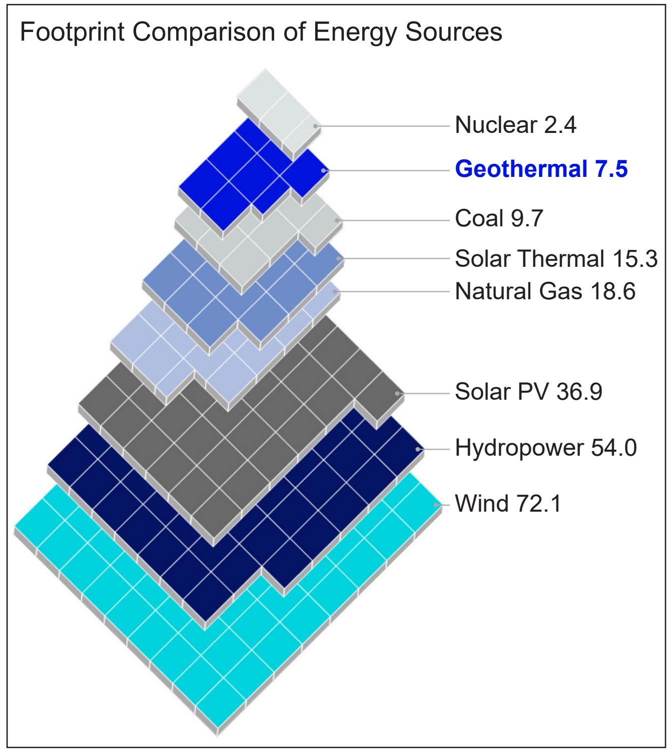
- **Proven energy form**: Geothermal is already a proven energy source. For example, nations situated on "geothermal hotspots", like Iceland and Kenya, use geothermal to fulfill 30% and 47% of total energy requirements, respectively.

Chart 5 Geothermal Leads Renewables In Generation



Note: Capacity factor is a measure of how often a power plant runs at full power; source: Bolson, Natanael, Pedro Prieto, and Tadeusz Patzek, 2022. "Capacity Factors for Electrical Power Generation from Renewable and Nonrenewable Sources" Proceedings of the National Academy of Sciences 119 (52).

Chart 6 Minimal Land Footprint



Note: Values are in square kilometers per terawatt hour per year (km^2.TW,h/yr); source: U.S. Global Change Research Program

It is important to note that "deep" geothermal extraction to reach sufficient heat is necessary in most parts of the world, which until recently has remained economically unavailable due to failure risk and the capital-intensity of deep drilling.

- **Carbon natural**: Geothermal plants emit virtually no emissions, operate quietly, and negate the need to store, transport, or combust fossil fuels.
- **Small operating footprint**: A geothermal plant's land footprint ranks second lowest among base-load energy sources. Specifically, an average geothermal plant requires 10% of the land of a wind farm and 20% of a solar farm (Chart 6).
- **Low operating cost**: Once built, geothermal plants are amongst the cheapest renewable energy forms. Operating costs range between $0.01-$0.03 per kWh.
- **Energy self-sufficiency**: Geothermal energy is produced without the need for imported raw materials including metals from foreign soils.
- **Ease of integration**: Energy produced via geothermal wells uses heated water or steam to spin a turbine, identical to conventional sources.

AI, "Big Data", And Utility Tailwinds

Computing's insatiable energy demand is driving newfound interest in geothermal. Already, tech-focused companies are leaders in renewable energy investment. For example, Amazon is the largest corporate backer of renewable energy, supporting over 500 projects that will total 77,000 GW/h once operational. Yet, the intermittency of wind and solar coupled with a lackluster battery storage rollout is proving insufficient. This has created a golden opportunity for geothermal.

By some estimates, data centers could consume 9% of U.S. electricity by the end of the decade, up from 4% today. A single ChatGPT query uses 10x the electricity of a normal Google search, notes Goldman Sachs. New developments indicate big tech is tapping geothermal to decarbonize data centers and stay on track to reach net zero goals.

For example, Fervo Energy, a pioneer in low-cost geothermal well drilling techniques backed by Devon Energy, has signed a 115 MW contract with Google to provide power to its data centers in Nevada. In another example, Meta recently announced a partnership with Sage Geosystems, another geothermal energy startup, to provide 150 MW for its data centers. We believe these deals represent the initial stages of scalable geothermal development backed by technology companies.

The U.S. defense industry is also beginning to explore geothermal possibilities. Recently, both the U.S. Airforce and U.S. Army selected Sage Geosystems to explore the feasibility of completely powering two bases in the U.S- Fort Bliss and Ellington Field Joint Reserve Base.

Utilities are also scaling their geothermal capacity. This year, utility Southern California Edison inked a 15-year, 320-MW geothermal deal with Fervo Energy. The deal represents the largest geothermal power purchase agreement (PPA) on record and could provide power to the equivalent of 350,000 homes across Southern California.

Novel geothermal generation approaches are driving a record interest. Over the past two years a record number of geothermal PPAs totaling 1GW have been signed by utilities, community choice aggregators, and commercial customers in the U.S. Last year, PPAs specifically for next-generation geothermal projects surpassed those for conventional geothermal projects in terms of capacity.

Next-Generation Geothermal

Advanced geothermal systems (AGS) and enhanced geothermal systems (EGS) are proving to be disruptive next-generation geothermal technologies, unlocking access to a wider range of geothermal resources. Unlike conventional geothermal that relies on natural fractures and fluid to bring geothermal heat to the surface, AGS and EGS use deeply drilled engineered reservoirs (**Charts 7** & **8**). This facilitates geothermal energy production from resources buried deeper underground once considered unrecoverable regardless of location, water, or rock type. In addition, these systems can act as long-lasting batteries, storing energy in the form of heat for hours or even days in the engineered reservoirs.

- **AGS**: leverage a "closed loop" system in which fluids circulate underground in sealed pipes and boreholes. These systems use the *thermosiphon* effect to circulate water naturally, as cold fluid on one side sinks while hot fluid on the other side rises. Since AGS does not require a pump, plant

Chart 7 EGS And AGS Well Designs

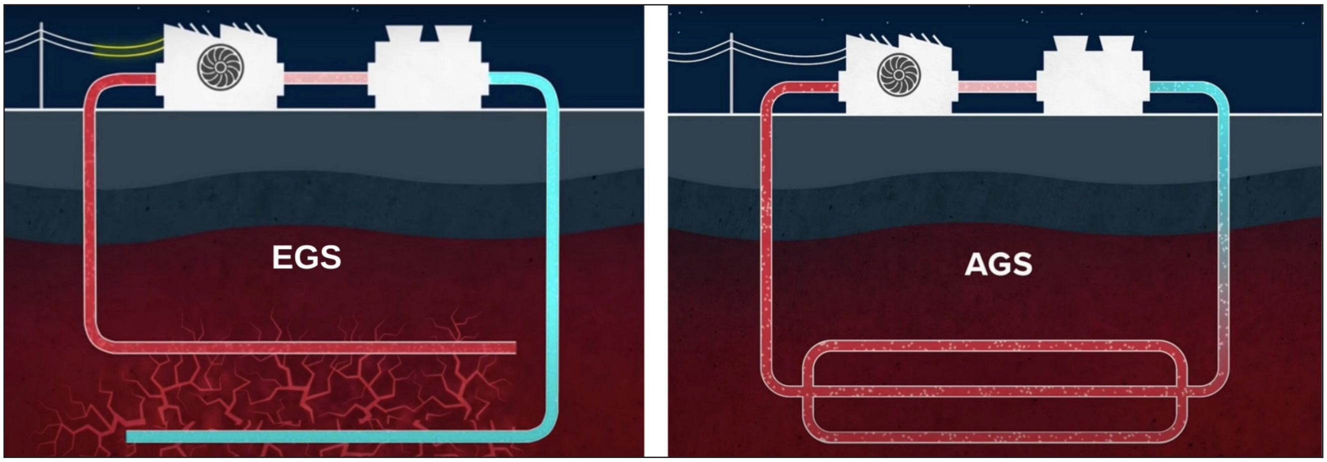
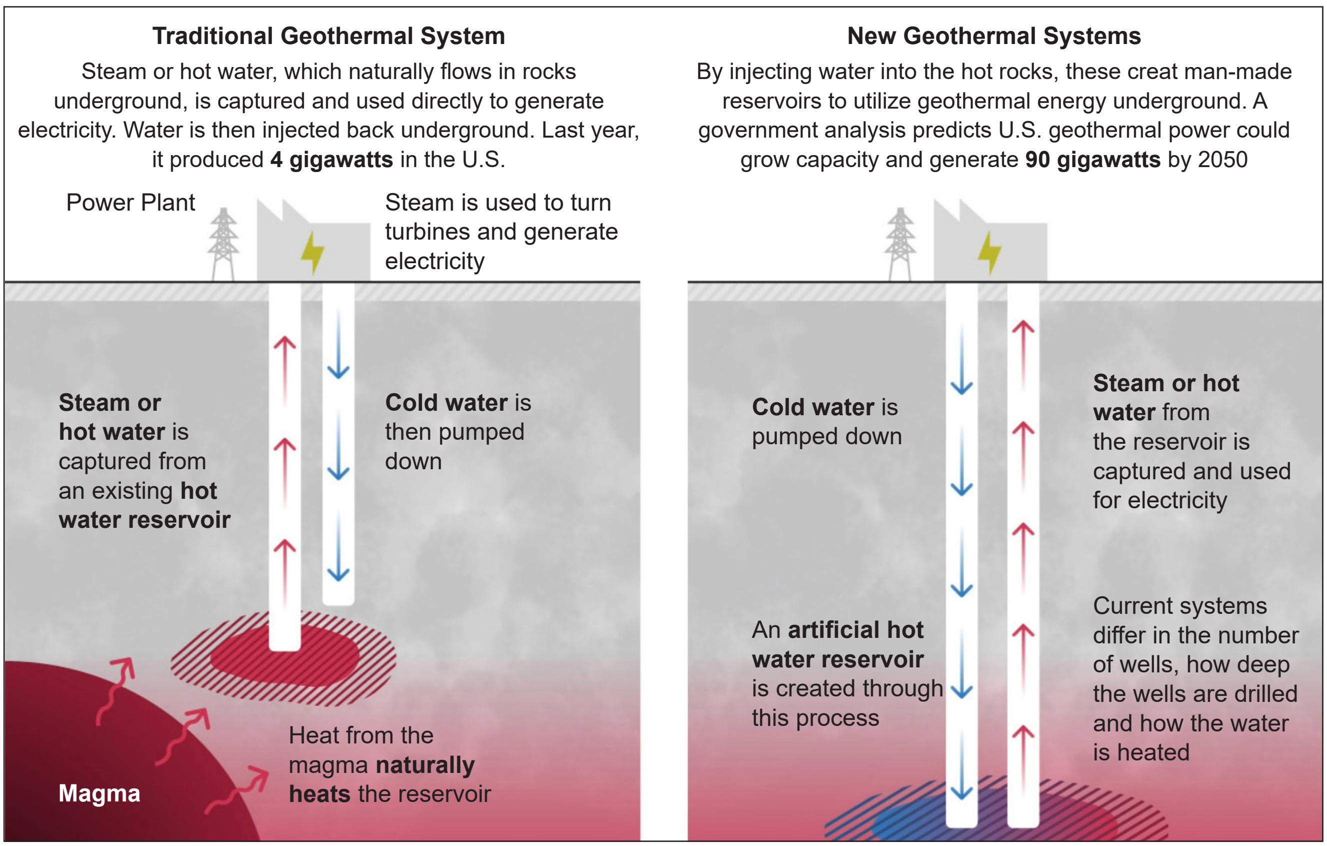


Chart 8 Conventional Versus Next-Generation Geothermal

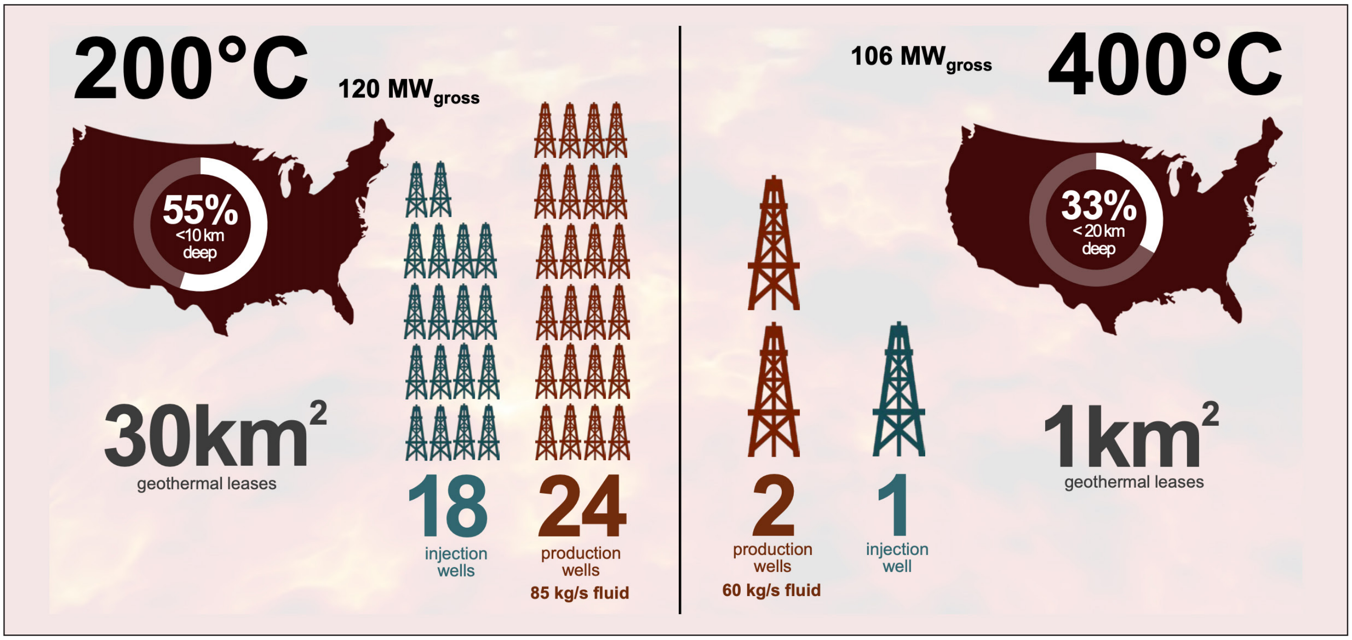


Sources: U.S. Department of Energy, U.S. Energy Information Administration, Sage Geosystems

operation costs are reduced. For example, start-up Eavor uses AGS to profitably tap relatively low heat, around 150°C, available almost anywhere roughly 1.5 miles down.

- **EGS**: is uniquely suited to extract geothermal heat in geographies where fluid volumes or rock permeability currently inhibits geothermal extraction using conventional methods. EGS is

Chart 9 Supercritical EGS Benefits



Source: Advanced Research Projects Agency–Energy

centered around increasing rock permeability to make an artificial reservoir. This is accomplished using horizontal drilling techniques and forcefully injecting fluid deep underground to create new fractures to improve permeability. Improved permeability allows more fluid to circulate throughout the more fractured hot rock. Operators then "pump" the heated fluid to the surface to produce electricity. Currently, EGS projects target subsurface temperatures of 200-275°C. Using EGS, leading geothermal firm Ormat (ORA), boosted the productivity of an existing geothermal field by 38% while also becoming the first EGS project to supply America's grid.

One exciting emerging area of EGS is "super-hot rock" geothermal. This form taps into extremely deep, hot rock where fluid becomes supercritical. This is accomplished when water exceeds 373°C and 220 bars of pressure, entering a new "form" that is neither liquid nor gas. Supercritical EGS energy extraction boasts unparalleled efficiency and energy density. For example, 400°C EGS system produces up to 10x more energy than a standard EGS system, consequently reducing the levelized cost of electricity to roughly $0.05/kWh compared to $0.10/kWh for an EGS project. As **Chart 9** shows, three wells on a 400°C supercritical project produce more than 42 EGS wells at 200°C.

Both AGS and EGS are benefitting greatly from engineering expertise passed down from the oil and gas industry. Specifically, fracking expertise has become highly valuable in accelerating horizontal drilling which compensates for conductive heat deficiency in shallower wells while also reducing failure rates by expanding the subsurface acreage of every well. For example, Fervo Energy is boring down 10,000 feet and then 5,000 feet to the side (horizontally) of each well.

I wonder how it affects the tectonics of the planet!?

Aside from the sectors having closely correlated engineering, there are millions of abandoned exploratory oil and gas wells that can be repurposed to extract geothermal energy. Importantly, all federal oil and gas leases can be converted into geothermal leases without having to go through any permitting review.

Innovation Expanding Possibilities And Reducing Cost

Technological developments are reducing the three largest hurdles for scalable geothermal viability: high upfront drilling costs, unsustainable well failure rates, and geographical limitations. For example, AI-powered models can now accurately simulate the earth's subsurface at a specific geographic location. This inherently reduces the risk of drilling a well that fails to reach adequate geothermal heat. Risk of failure has historically accounted for between 20%-30% of the cost of capital in early-stage geothermal projects. In addition, minimizing exploration risk shortens project development timelines from 6-8 years currently to 1-2 years.

Novel drilling technologies are also showing signs of promise to reduce cost and increase drilling accuracy. For deep drilling specifically, drill bits wear down quickly against hard, nonporous rock. Quaise Energy is using a millimeter-wave drilling technique from nuclear fusion (higher frequency microwaves like the ones used to heat food) to drill into 300—500°C rock. The laser vaporizes rock and allows drilling to exceed 20 kilometers below the Earth's surface. Importantly, such drilling techniques allow for subsurface "turning and steering", allowing drillers to reach specific target locations.

Another exciting area of innovation is co-extraction of rare-earth metals and geothermal energy. New approaches now facilitate the separation of minerals such as lithium from geothermal brine which flows in large volumes to the surface. For example, Occidental Petroleum has been testing commercial-scale direct lithium extraction using geothermal waste brine as a feedstock from a geothermal plant in California's Salton Sea. Some geothermal plants can produce over 2,000 gal/min of lithium brine.

Investment Considerations

While highly nascent, innovation in both AGS and EGS is making geothermal energy a viable renewable energy source. Although geothermal energy currently lags other renewables in capacity, we believe its adoption is reaching an inflection point as technological improvements drive down costs and the need for dependable baseload renewable power intensifies.

Legislative support is increasingly backing geothermal development. Geothermal is a part of the DOE's Earthshot initiative that seeks to cut the cost of next-generation geothermal power by 90% to $45/MWh by 2035. The project has allocated $44 million to help spur EGS innovation and $165 million to transfer practices from oil and gas to advance both EGS and conventional geothermal. The IRA has also allocated $84 million to advance EGS capabilities.

While the sector is moving in a positive trajectory, hurdles remain and investment levels will likely dictate geothermal's future. Yet, interest in geothermal from oil and gas companies and big tech alike positions the sector as a beneficiary of continued capitalization from cash-rich companies willing to invest with longer time horizons. In addition, geothermal is likely the "best protected" renewable source in the event of a Trump presidency, due to robust support and investment from the oil and gas industry. That said, a DOE report highlights that over $20 billion is needed in geothermal investment by 2030 to move toward widespread use.

Investors seeking portfolio exposure to geothermal can do so by investing in electric utility companies leading the charge in geothermal adoption, like Enel (ENEL), or by the only "pure play" publicly traded geothermal company, Ormat Technologies (ORA).

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