OCEAN WALL

Geothermal Energy: Unlocking Earth's Limitless Potential

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Executive Summary

Understanding the world's future power requirements is becoming an increasingly complex task in light of various unforeseen market drivers that will necessitate power grids to potentially double capacity by 2050. The emergence of trends such as artificial intelligence and the 'electrification of everything' are forcing us to reevaluate the amount of energy our world will need in the future.

While quantifying our power requirements presents its own issues, the much larger and potentially derailing issue is where this power is going to come from. While renewables have made impressive progress in supplementing fossil fuel-based energy systems, they still only accounted for around 30% of global electricity in 2023. However, the 510 GW of global annual renewable capacity achieved in 2023 marked a 50% year-on-year increase, the fastest growth rate in the past two decades.[1]

What is abundantly clear is that we cannot rely solely on the likes of wind and solar to achieve our net-zero ambitions, given their intermittent and geographically sensitive properties. Decarbonising our world is going to require a basket of carbon-free solutions, and will be driven by continued innovation, requiring hundreds of billions of dollars of investment capital.

Scalable, baseload, carbon-free energy solutions such as nuclear power have and will continue to provide a solid foundation for the energy transition. Energy solutions with these characteristics are in short supply, in fact, nuclear power is only accompanied by only one other baseload, carbon-free energy source.

Geothermal energy harnesses the almost unlimited supply of heat beneath the Earth's surface, combining energy from the formation of the planet, and radioactive decay. While geothermal has had applications for thousands of years, its integration into our power grids remain, broadly, in its infancy.

Today, geothermal is limited to certain geographies with abundant near-surface heat, such as Iceland, New Zealand, and Indonesia. These regions sit on highly active tectonic plates, and deliver heat to the surface, making extraction both timely and cost-effective. As such, discovering sites ripe for geothermal expansion outside of these regions comes with significant exploration risk, and high upfront costs.

Advanced exploration and drilling techniques can change this by derisking these projects at both the exploration and production level. In turn, we estimate that current global geothermal capacity grow >10x by 2050 from 16 GW today, a 9.6% CAGR.

A particularly compelling use case for geothermal is the data centre industry. We have already seen investment in this type of energy from the likes of Google and Microsoft to help solve their burgeoning power problem. Data centre demand is growing at an unprecedented pace as the world succumbs to the reality that artificial intelligence will be increasingly integrated into our everyday lives. By 2034, global energy consumption by data centres is expected to top 1,580 TWh, about as much as is currently used by all of India.[2] Geothermal is one of the prime candidates to power these data centres, given its baseload, carbon-free, and potentially geographically agnostic attributes.

The promise of next-generation geothermal suggests that unlimited carbon-free power can be accessed anywhere, any time. It is indiscriminate of a nations natural resource, meaning the impact, particularly for emerging markets, is profound. The volatile and uncertain geopolitical backdrop that the world is presented with today has placed energy security at the forefront of global economic policy. Former US Vice President Al Gore, for instance, wrote about geothermal energy in 2009 as "*potentially the largest and most misunderstood – source of energy in the US and the world today*". Importantly, geothermal does not rely on a complex supply chain, or require any fuel.

We believe geothermal is at an inflection point that will unlock its true potential. This inflection point will be driven by technological advancements such as enhanced geothermal systems (EGS), closed-loop systems, and advanced drilling technologies, which are poised to harness geothermal resources universally, overcoming geographical limitations.

This report aims to provide a comprehensive overview of the geothermal industry of today, but more importantly provide context as to the role it might play in our future.

Introduction

History

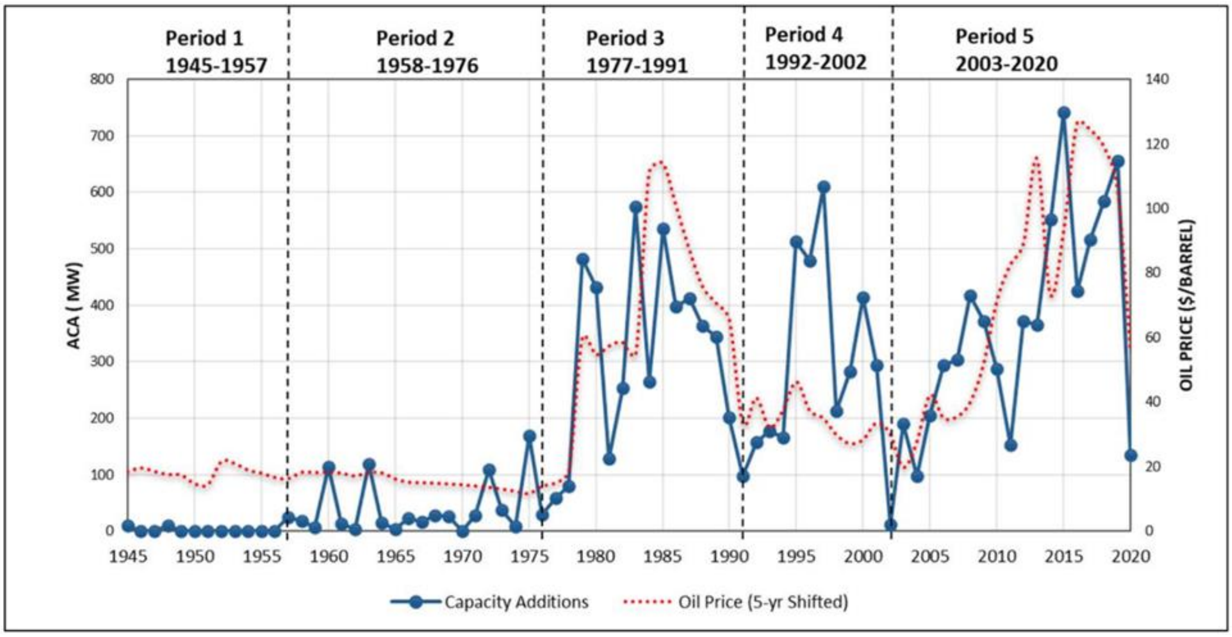
Uses of geothermal can be dated back thousands of years. Ancient civilisations used geothermal energy to preserve food and bathe before the resource was later harnessed and leveraged to heat buildings and generate electricity. In 1904, Piero Ginori Conti, Prince of Trevignano, invented the first geothermal generator at the Larderello dry steam field in Italy. Initially the technology only generated enough energy to power five lightbulbs. A year later, however, the generator could produce 20kW, enough to power over 300 lightbulbs. By 1944 the plant distributed 136MW of electricity and was capable of powering cities in the region.[3]

Fast-forward 14 years, and the first geothermal plant in the US began operation at The Geysers in California, producing 11 megawatts (MW) of net power.

	1950	1960	1970	1980	1990	2000	2010	2020
1	Italy	N. Zealand	N. Zealand	US	US	US	US	US
2		Italy	Italy	Philippines	Philippines	Philippines	Philippines	Indonesia
3		US	US	N. Zealand	Mexico	Mexico	Indonesia	Philippines
4			Japan	Japan	Italy	Italy	Mexico	Türkiye
5			Russia	Italy	N. Zealand	Indonesia	Italy	N. Zealand
6			Iceland	Mexico	Japan	Japan	N. Zealand	Mexico
7			China	El Salvador	Indonesia	N. Zealand	Iceland	Italy
8				Iceland	El Salvador	Iceland	Japan	Kenya
9				Indonesia	Nicaragua	Costa Rica	El Salvador	Iceland
10				Russia	Kenya	El Salvador	Kenya	Japan
11				Portugal	Iceland	Nicaragua	Costa Rica	Costa Rica
12				China	China	Kenya	Russia	El Salvador
13					Türkiye	Russia	Türkiye	Nicaragua
14					Russia	Guatemala	Nicaragua	Russia
15					Portugal	China	N.Guinea	N. Guinea
16						Türkiye	Guatemala	Guatemala
17						Portugal	China	Germany
18						Ethiopia	Portugal	Chile
19							Germany	Honduras
20							Ethiopia	Portugal
21								China
22								France
23								Croatia
24								Ethiopia

Countries ranked by Geothermal Capacity 1950-2020 [4]

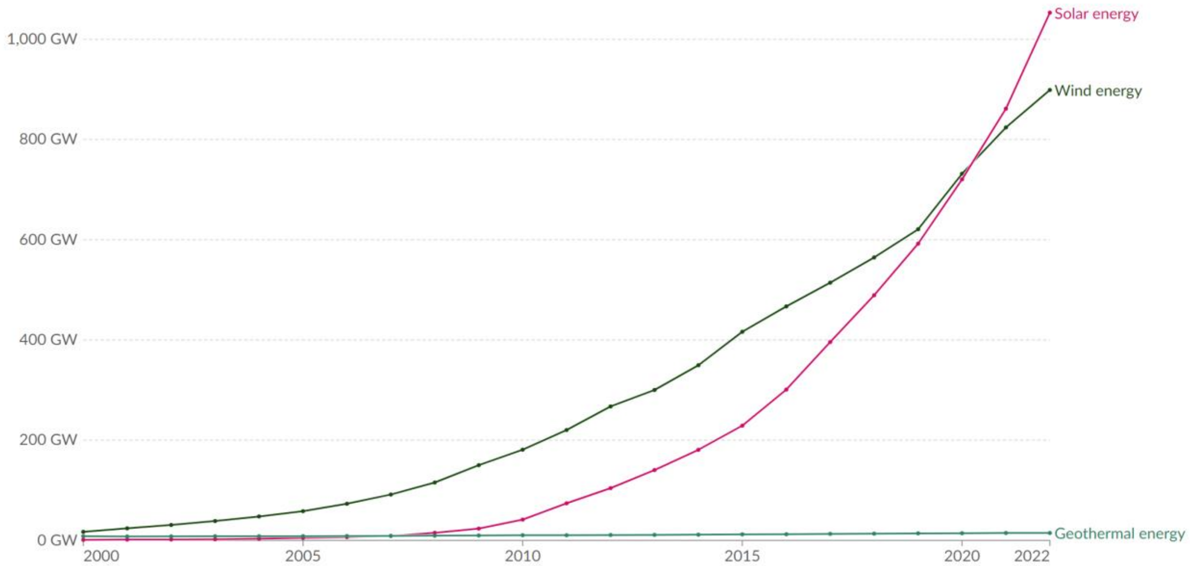
Throughout the 1970s deep well drilling technology improvements led to deeper reservoir drilling and access to more resources. The Fenton Hill hot dry rock (HDR) test site in New Mexico pioneered techniques for efficiently extracting geothermal energy. In 1978, an HDR power facility was tested at the site and two years later it started to generate electricity.[5] Increased public and private sector investment into geothermal coincided with the 1973-74 oil embargo. Both governments and utilities looked to diversify away from OPEC, investing into nuclear, wind, solar, and geothermal energy sources. Countries which had relied more heavily on oil for electric generation such as France and Japan invested significant capital into nuclear. France would construct 25 nuclear power plants over the next 15 years.[6] Industry led investment and research into alternative energy sources would continue to fluctuate according to oil prices. The graph below maps geothermal capacity additions against oil prices, illustrating the relationship.



Correlation of global annual capacity addition (ACA) curve with 5-year shifted oil-price curve [7]

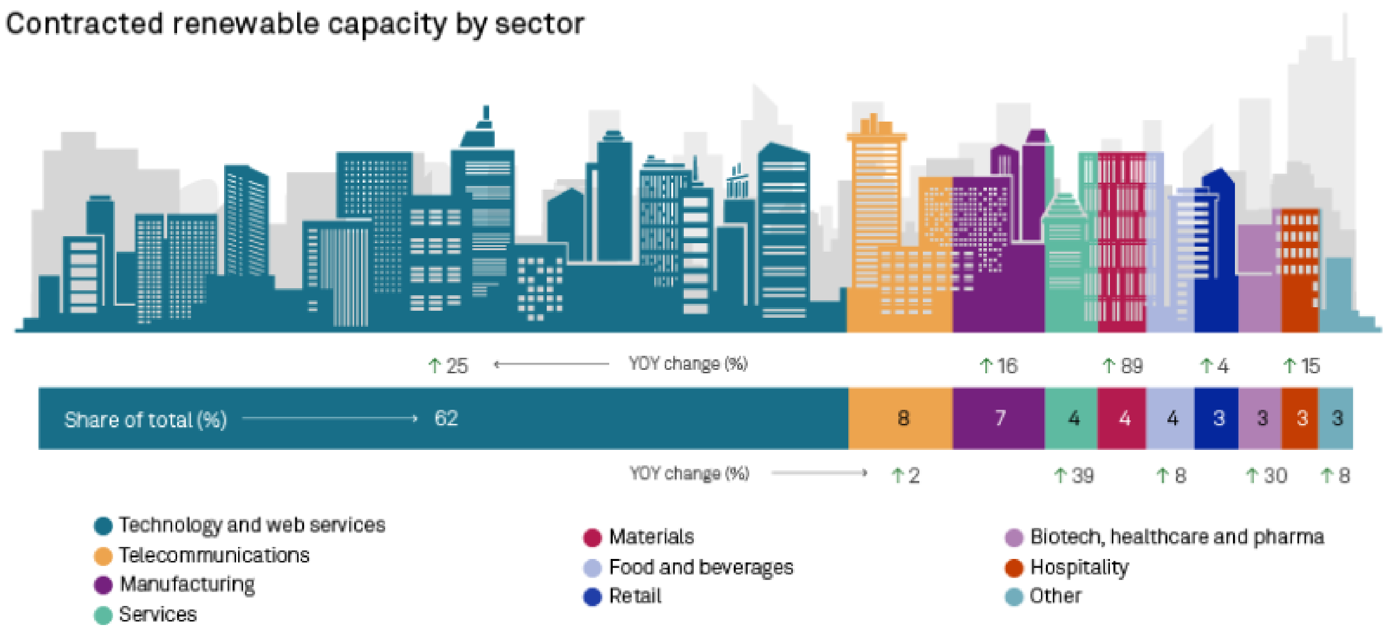
The high peaks in the graphic above between 1976–1991 and 2002–2020 are caused by the 1974, 1980, 2008 and 2011 oil crises, respectively. The only period where the curves do not correlate is 1991–2002. In this period, while oil prices are stable the curve has a significant peak and does not follow a similar pattern. This anomaly may be related to the global increase in international awareness of climate change and sustainable development as a result of several international events after 1987 such as the signing of the Kyoto Protocol in Japan. [8]

Despite this, geothermal capacity has lagged significantly behind its alternatives. Historically it has not been able to attract the same level of private investment as solar or wind. In 2020, for example, 83% of commitments in solar PV came from private finance. Meanwhile, geothermal has relied mostly on public finance for support with only 32% of investments in geothermal technologies coming from private investors at the time.[9] In the US, solar and wind have also dominated allocation of total renewables subsidies. [10]



Global installed renewable energy capacity by technology [11]

The IEA report that global spending on clean energy technologies and infrastructure is set to hit $2 trillion in 2024 due, in part, to higher financing costs for projects.[12] A significant portion of this investment is derived from data centre operators and technology companies managing their surging energy demand and ESG commitments. In the past year the technology sector accounted for more than 68% of contracted capacity. [13]



Contracted renewable capacity by sector[14]

"To date, S&P Global Commodity Insights has tracked 57.7 GW of renewable energy capacity contracted by US tech corporations. Amazon.com Inc. alone has amassed about 28 GW of renewable energy generation capacity, of which more than 63% is based in the US. Facebook, Instagram, and WhatsApp parent company Meta Platforms Inc. is a distant second, with a tracked 10.5 GW. Google parent Alphabet Inc. is not too far behind Meta, with an identified 9.5 GW." – S&P Global [15]

Geothermal is positioned to profit from major macroeconomic and microeconomic trends as public and private sectors balance their demand for baseload power with a transition to cleaner, carbon free energy. The US Department for Energy (DOE) have mapped out a potential 20-fold increase in geothermal capacity by 2050, generating 10% of the US's electricity.[16] Expanding the geothermal footprint will take time, as well as significant investment. Growth is conditional on the success of related technological innovations and their deployment – the DOE estimates as much as $250bn will be needed for projects to become widespread across the US.[17] Geothermal is now at an inflection point; many new technologies have advanced well past their seed stage and are now being field tested. These innovations have triggered an inflow of investment and support.

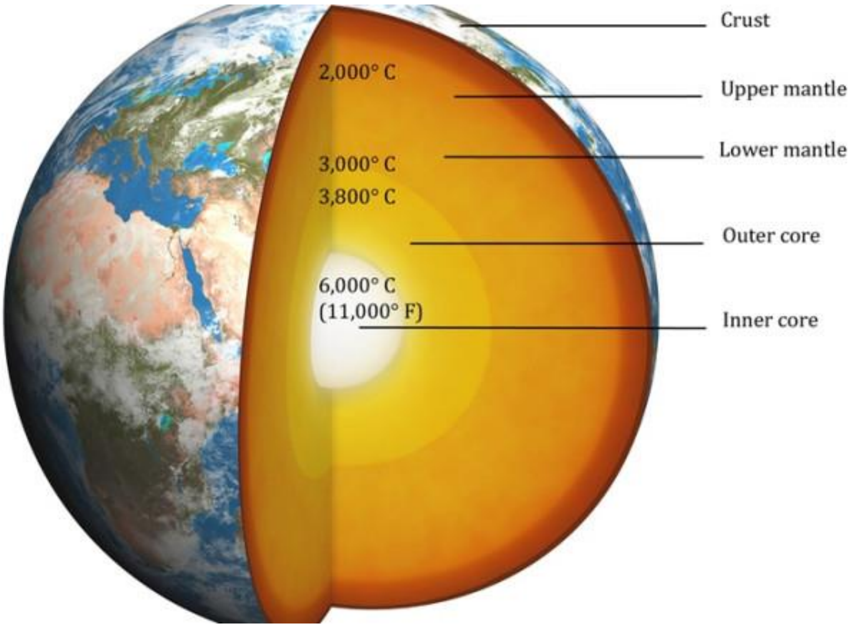
What is Geothermal Energy

Geothermal energy is heat stored in the Earth's crust. Heat flows from the Earth's inner core toward the surface and the rate at which the temperature increases with depth is referred to as the "geothermal gradient". This energy is extracted mainly by drilling into the ground and then transported to the surface using water. At the surface, the energy is extracted and converted to electricity or used directly as heat.[18]

In summary, conventional geothermal extraction requires the following:

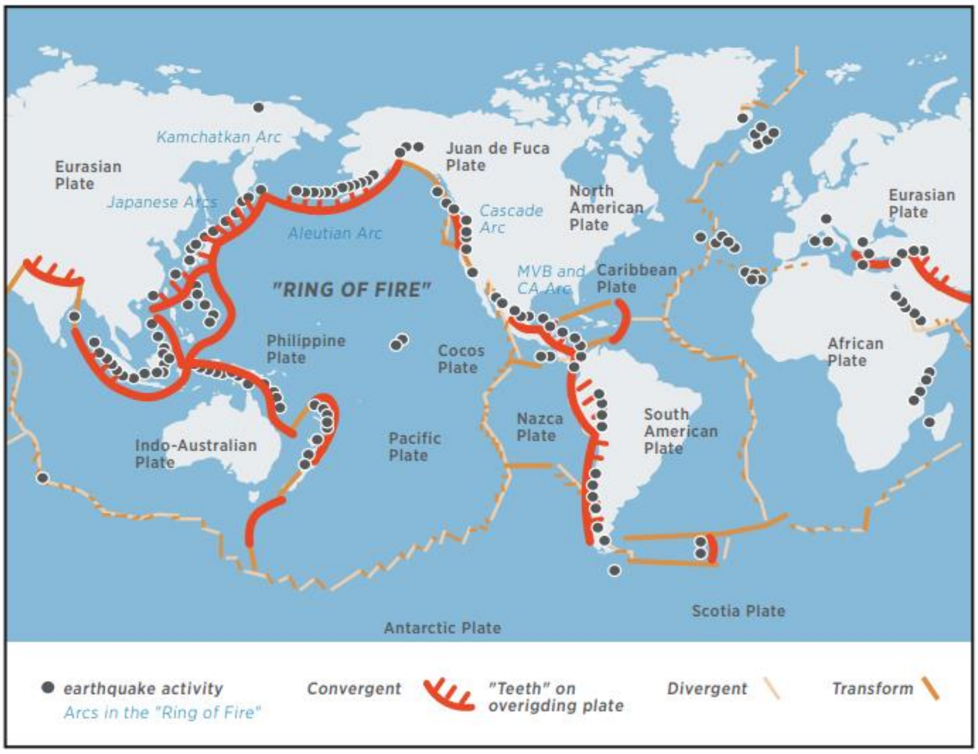
i. Heat: High temperatures are necessary to vaporise or heat the water/fluid into either a gaseous form which can turn a turbine or to provide heating. Currently the geothermal gradient determines the end use of the geothermal well.
ii. Permeability: Permeability is a measure of how easy it is for a fluid to move between the fractures in the earth. For a good geothermal resource, the reservoir needs to be as permeable as possible to allow movement of hot water or steam to flow between injection and abstraction wells. [19]

iii. Water: Geothermal heat is captured via water or an alternative working fluid.



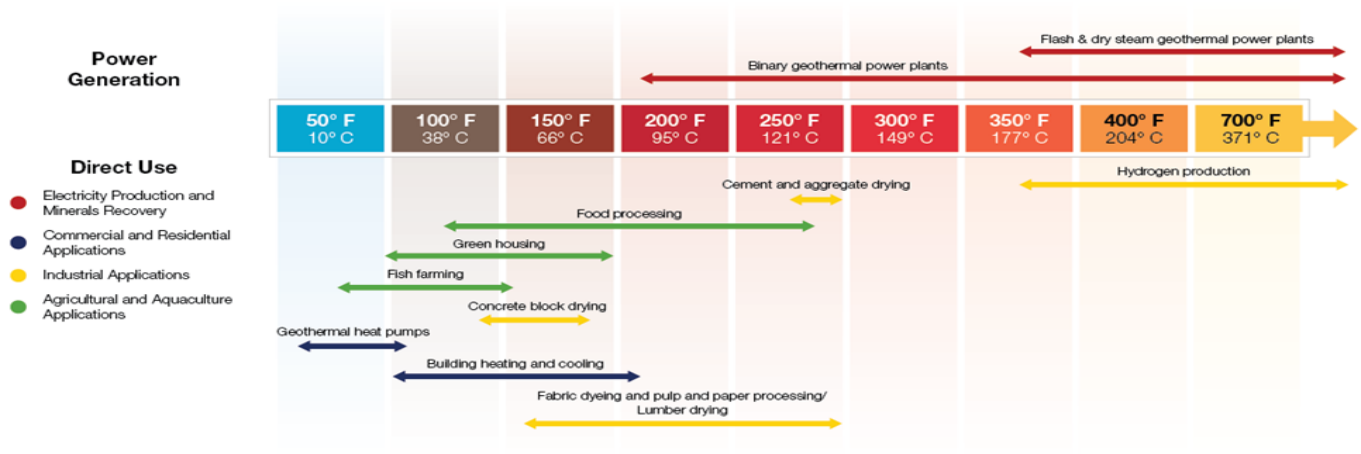
Varying temperatures of the Earth [20]

Regions where the heat flow or gradient is greater provide the most viable locations for geothermal energy.[21] Tectonic borders are an example of where the heat of the earth can be found closer to the surface, often manifested in hot springs, geysers and volcanic activity.[22] Iceland divides the North American and Eurasian plates and hosts Earth's most active geysers. Consequently, geothermal energy in Iceland can be harvested less than 1km below the surface. In regions further away from tectonic borders, like Germany, 4-5km of drilling is required to access the same temperatures.



Tectonic plates and global geological activity [23]

Temperatures are divided into three groups: high (greater than 150°C), medium (90-150°C), and low (less than 90°C). Medium to high temperatures are preferable for electricity production however one can produce electricity from temperatures as low as 70°C using adapted technology. For commercial-scale electricity generation, a minimum resource temperature of about 150-180°C is necessary.[24]

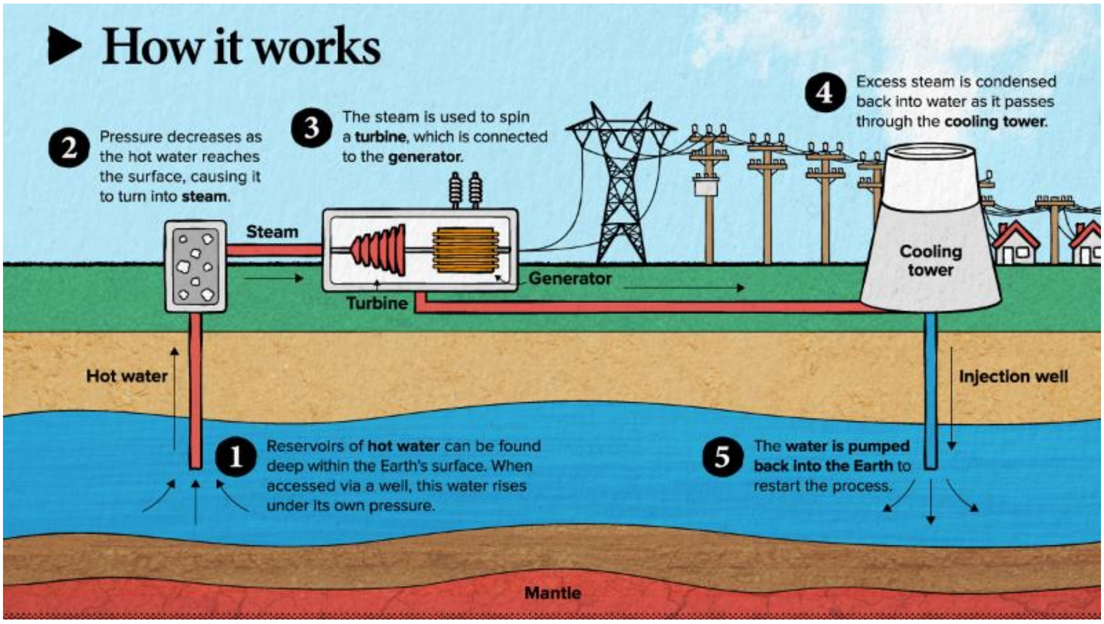


Geothermal Energy and its Uses [25]

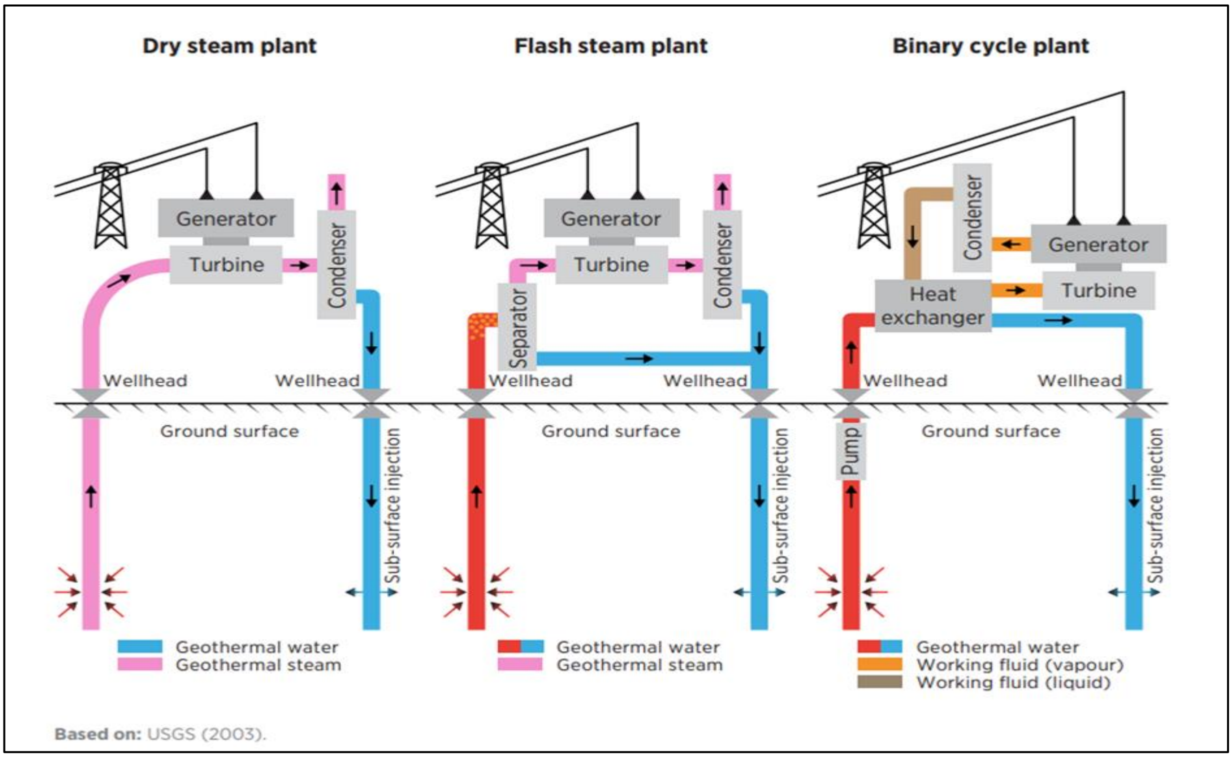
"Geothermal energy holds a unique place in the renewable energy ecosystem. In contrast to other renewable energy sources, it can provide both electricity and heat, as well as value-added mineral extraction. As an electricity source, it provides reliable generation with high plant efficiency, low greenhouse gas emissions and a small ecological footprint; it is a long-lasting sustainable source when properly managed. As a heat source, geothermal is scalable, has low operating costs, offers increased efficiency (by supplying heat directly) and reduces electricity consumption for heating and cooling. Here, too, it can provide a long-lasting source of sustainable heat." - International Renewable Energy Agency (IRENA)[26]

How is it extracted?

Geothermal power is generated by using steam to turn a turbine-generator. The three key technologies currently used to generate electricity from geothermal energy are dry steam, flash steam, and binary cycle. Each method involves drilling wells to access the geothermal reservoirs (a naturally occurring underground hydrothermal resource), and the specific technology used depends on the temperature and characteristics of the resource.



Geothermal Energy: How it works[27]



Geothermal: How it works [28]

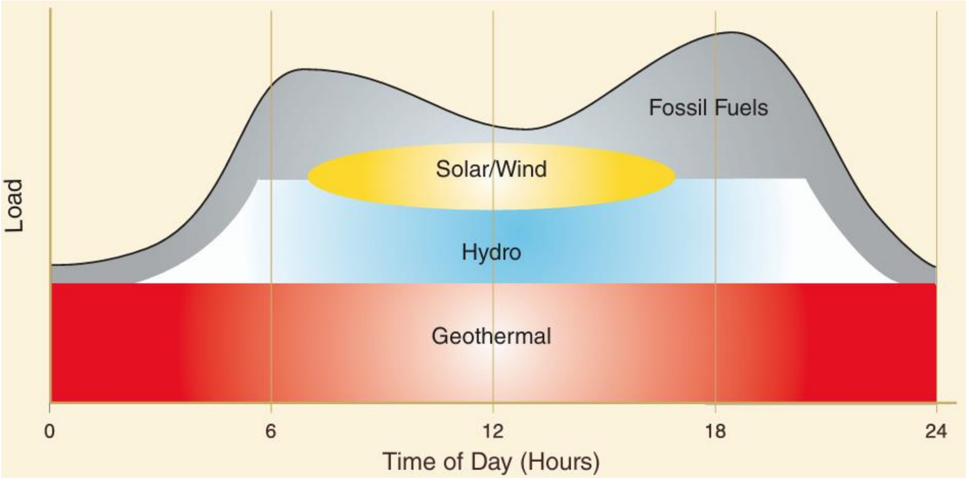
Technology	Description
Dry Steam Power Plants	These plants take steam directly from geothermal reservoirs to turn turbines, which then generate electricity. This method is used where steam is naturally available.
Flash Steam Power Plants	These plants extract high-pressure hot water from the ground, which is then depressurized, or "flashed" into steam. The steam is used to drive turbines, and any remaining water can be reinjected into the reservoir.
Binary Cycle Power Plants	In this method, geothermal water heats a secondary fluid with a lower boiling point than water (such as isobutane) in a heat exchanger. The secondary fluid vaporizes and drives a turbine. This method is effective for lower temperature geothermal resources.

Global geothermal market and technology assessment [29]

Most geothermal plants in operation for electricity generation are dry steam or flash plants. These plants operate at temperatures of more than 150°C. At lower temperatures binary cycle power plants are preferred.

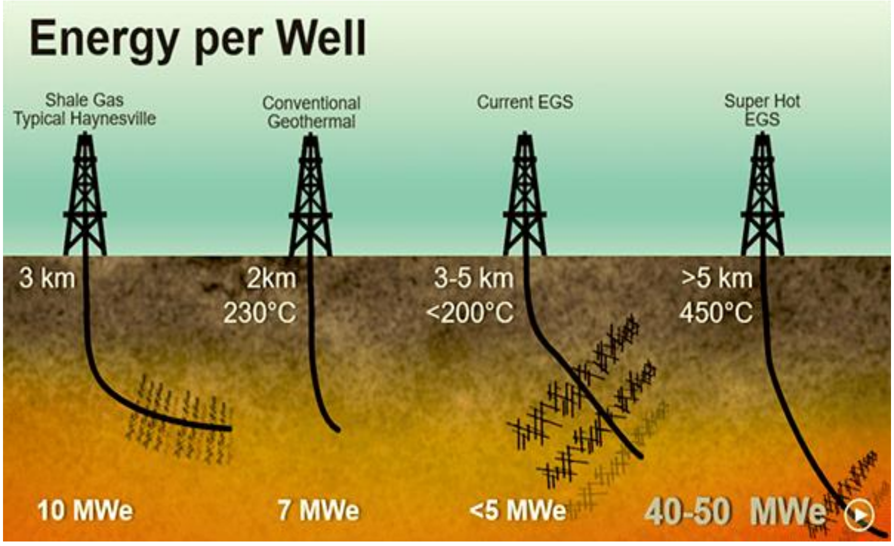
Energy Production

Geothermal energy is different to solar and wind energy in that it can produce baseload energy around the clock regardless of the weather. It is this differentiation which has driven interest and investment into the sector. There is only one other form of carbon-free baseload power besides geothermal: nuclear. Nuclear energy, however, requires fuel. Geothermal is therefore the only baseload power source without a fuel supply chain.

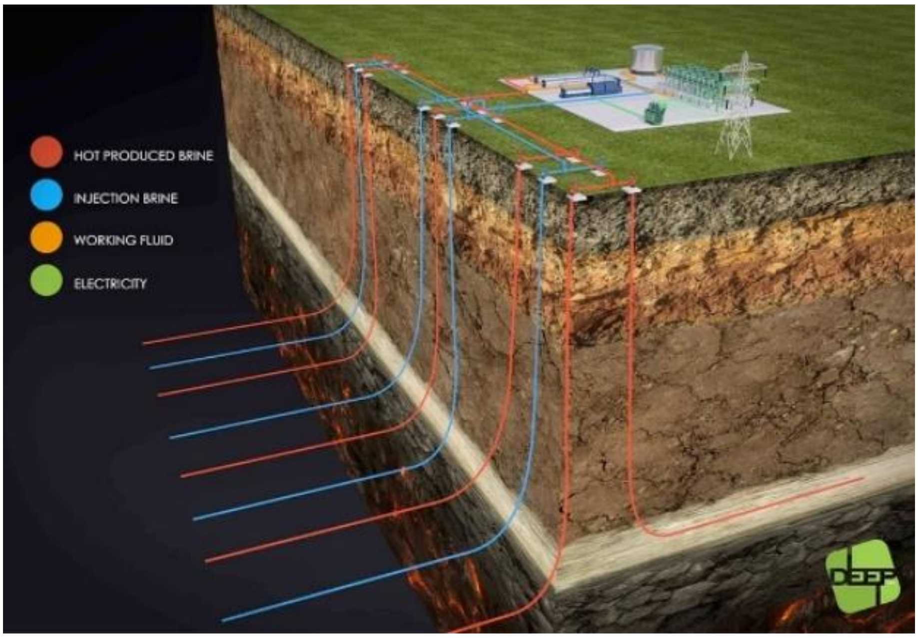


Energy Sources Power Profile [30]

The energy output from individual wells is highly variable, depending on the flow rate and the enthalpy (heat content) of the fluid.[31] Conventional geothermal wells (3-5km) generate electricity in the range of 5–10 MWe. Wells can be cascaded to drive larger turbines that can generate energy in excess of 10 MWe.

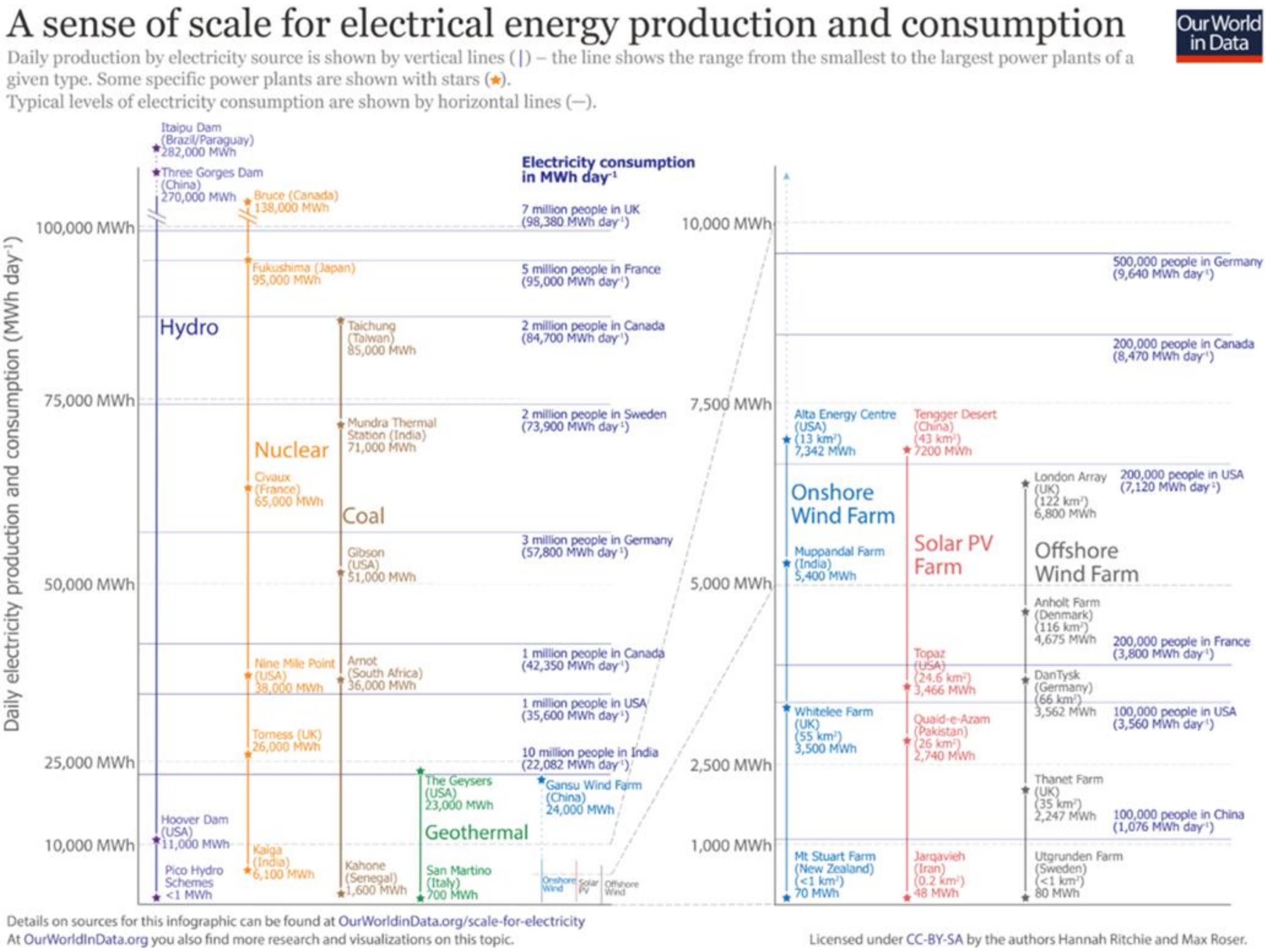


Deep Earth Energy Pilot Plant Plan [32] ; Energy per Well [33]



It is estimated that at depths greater than 5km, with technology that can access to super-hot rock, energy output in the region of 40-50 MWe can be achieved. Combining multiple plants has the potential to provide significant energy and heating.

Calpine, the largest geothermal power producer in the US, operates 13 power plants at The Geysers in California, with a net generating capacity of about 725 MW of electricity. This is enough to power 725,000 homes, or a city the size of San Francisco.[34]



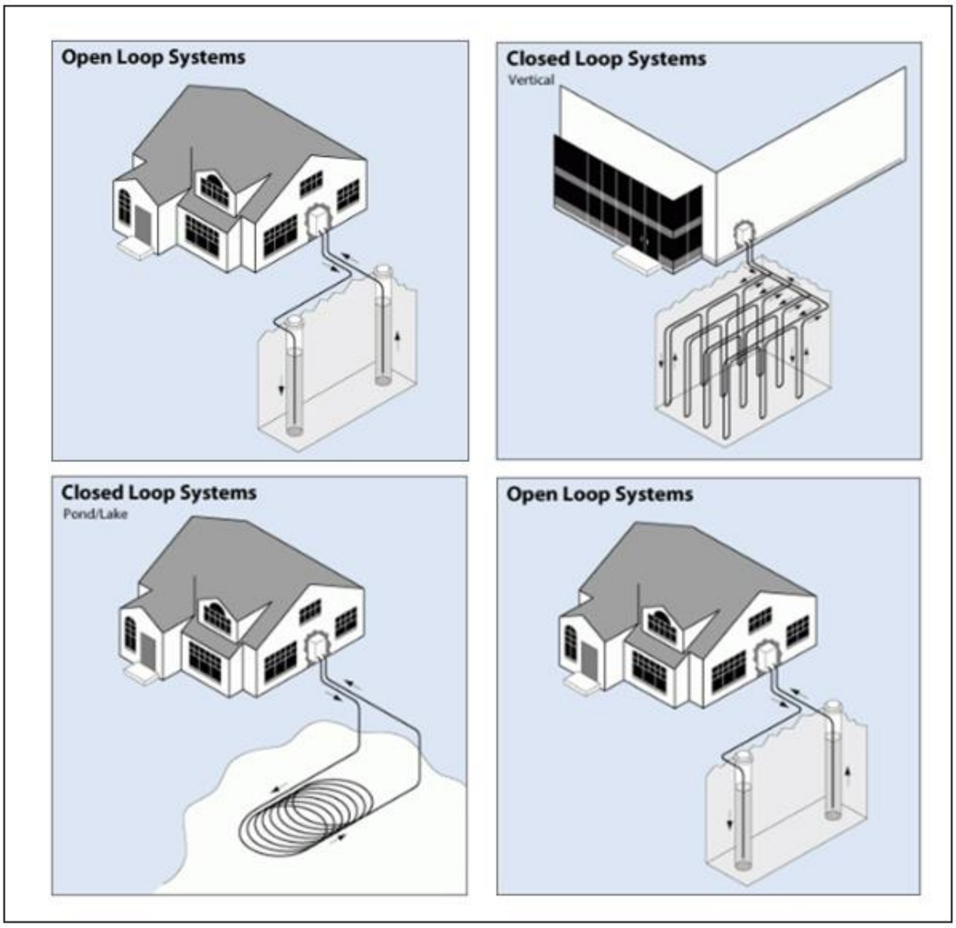
Global Daily Electrical Energy Production by Source [35]

Heating

Geothermal Heat Pumps (GHPs)

GHPs use the relatively constant temperature of the earth as the exchange medium for heat. Ground temperatures can range from 7-21°C depending on latitude. During the winter, ground temperature is warmer than the air above. GHPs take advantage of the difference in temperature, exchanging heat with the earth through a ground heat exchanger. Geothermal and water-source heat pumps are able to heat, cool, and in some cases supply hot water.[36]

"There are four basic types of ground loop systems. Three of these -- horizontal, vertical, and pond/lake -- are closed-loop systems. The fourth type of system is the open-loop option. Several factors such as climate, soil conditions, available land, and local installation costs determine which is best for the site. All of these approaches can be used for residential and commercial building applications" – US Department of Energy [37]



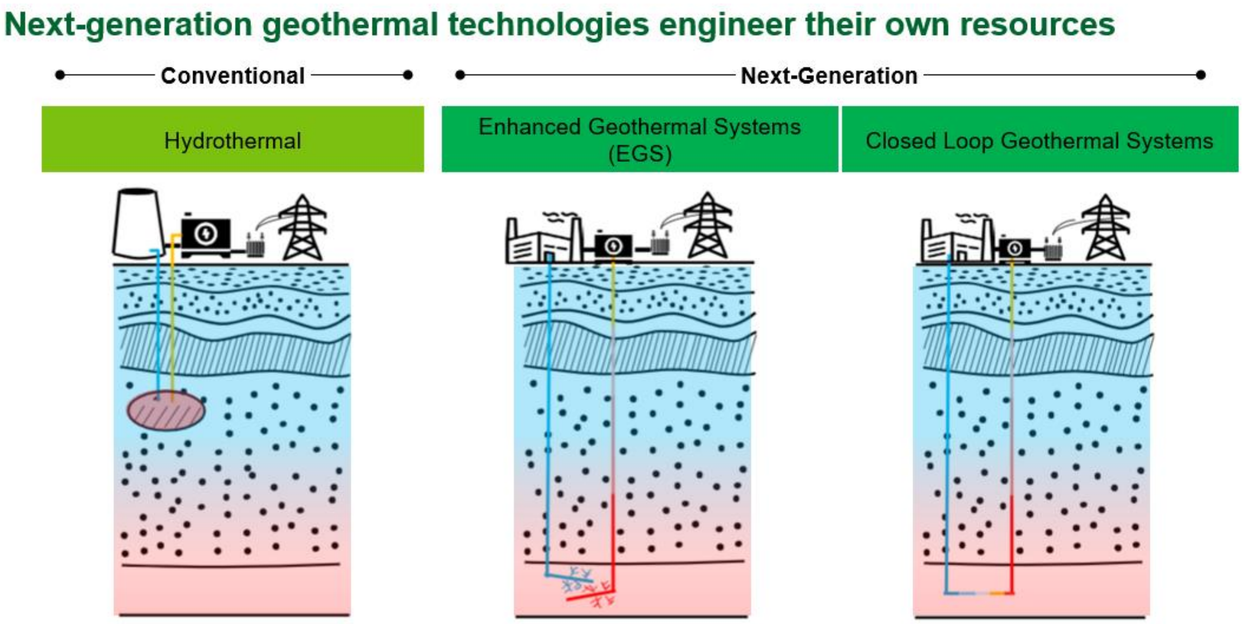
Types of Geothermal Heat Pump Systems [38]

Scaling this technology can achieve significant cost savings and reduce greenhouse gas emissions. The geothermal heating network in Szeged, Hungary is the largest in Europe outside Iceland. Hot water from 2km below the surface flows to heat 28,000 households. The operation uses 27 wells, 16 heating plants, and 250km of distribution pipe network. The EU funded project has successfully halved carbon dioxide emissions in Szeged and reduced reliance on natural gas.[39]

Emerging Technologies

Conventional technologies exploit shallow, high heat resources. Emerging technologies are already demonstrating the potential to unlock geothermal resources anywhere.[40] A reminder, traditional geothermal requires heat, water, and permeability.

i. Enhanced Geothermal Systems (EGS) - EGS technology hopes to solve the permeability issue, and involves injecting water into hot, dry rock formations to create artificial geothermal reservoirs. This process often uses hydraulic fracturing to enhance the permeability of the rock and allow water to circulate and heat up.
ii. Advanced Geothermal Systems (AGS) - IRENA describes AGS as “deep, large, artificial closed-loop circuits in which a working fluid is circulated and heated by sub-surface rocks through conductive heat transfer.” This process provides the potential for applications in almost any location worldwide as it does not require a water-bearing reservoir with good permeability.
iii. Supercritical Geothermal Systems (SGS) - are characterised by very high temperatures and a natural reservoir containing fluid in the supercritical state (374°C for pure water).



Source: DOE Presentation

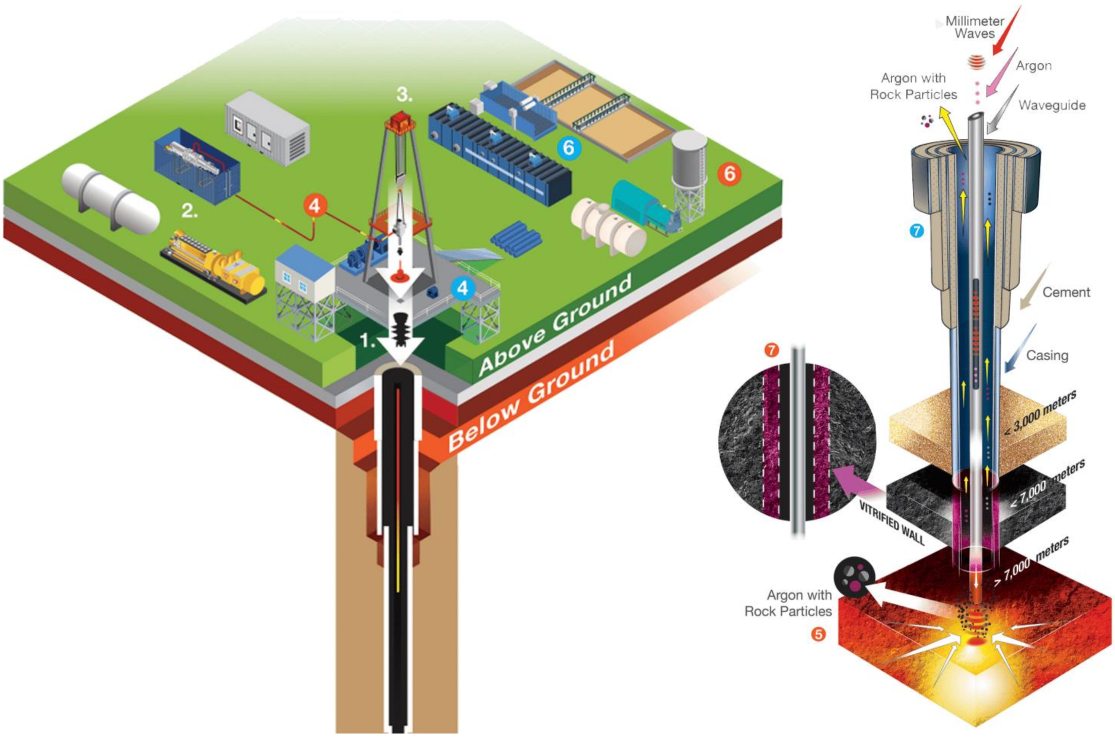
The depth required to drill for geothermal energy varies depending on the type of geothermal resource and the technology used to extract it:

Shallow Geothermal Systems	For direct use applications like heating buildings or greenhouses, shallow geothermal wells are typically drilled to depths ranging from 30 to 150 meters. These systems often exploit the relatively stable temperatures found just below the Earth's surface.
Low to Moderate Temperature Resources	For applications such as binary cycle power plants, wells are usually drilled to depths of 300 to 3,000 meters. These depths access warmer water that can be used to generate electricity or for direct heating purposes.
High-Temperature Resources	For high-temperature resources used in dry steam and flash steam power plants, wells can be much deeper, typically ranging from 1,500 to 3,000 meters, but in some cases, they can go as deep as 4,500 meters or more. These depths are necessary to reach the extremely hot water or steam reservoirs required for electricity generation.
EGS & SGS	These systems might require drilling even deeper, sometimes up to 6,000 meters or more, to access the hot dry rocks. Water is injected into these rocks to create steam, which can then be used to generate electricity.

Technology Spotlight

Quaise Energy

Spun out of an MIT lab in 2018, Quaise are developing the next generation of deep rock drilling technology.[41] Quaise have repurposed gyrotron technology, commonly used in nuclear fusion research to heat and control plasma. Using the gyrotron technology they can vaporise rock using powerful microwaves. When applied to conventional drilling rigs the microwaves will be able to vaporise the critical basement rock, unlocking geothermal at new depths and supercritical geothermal power. Now in their third iteration of field testing, Quaise hope to dramatically reduce the costs and timelines of drilling. [42]



Quaise's hybrid ultra-deep drilling rig [43]

To date, Quaise have raised $95m and are emerging as one of the market leaders in geothermal innovation. If successful, the technology would enable efficient drilling of up to 20 km deep. The company estimate that 25-50 MW of electricity can be generated from each well (~5x traditional), driving recommissioned fossil fuel turbines.

GA Drilling

Another company looking to unlock the power of geothermal is Slovakia-based GA Drilling. The GA stands for "Geothermal Anywhere". The company recently raised $15m to accelerate the development of their two proprietary drilling technologies which it is currently testing.

i. AnchorBit – a downhole walking system that prevents vibrations and improves stability when drilling with rotary systems. The technology should double the rate of penetration and drill bit lifetime. Currently, drilling in such conditions is accompanied by vibrations, a low rate of penetration, and frequent replacement of bits. It is compatible with conventional rotary drilling and designed to work in hybrid with their PLASMABIT technology.[44]
ii. PlasmaBit – Composed of four main subsystems (Pulse Plasma Drilling Head, Bottom Hole Assembly Modules, Transfer Line Subsystem and Surface Equipment with Control System) is an intelligent modular platform that can be connected to market standard equipment. Its improved rate of penetration (ROP) in hard rock environments aims to keep drilling costs linear rather than exponential – GA Drilling estimate that PlasmaBit reduces the costs of drilling per meter by an order of magnitude.[45]

AnchorBit and PlasmaBit [46]

By combining these two technologies GA Drilling believe it has a solution that will deliver ultra-deep geothermal energy at low cost anywhere.

Geothermal drilling parameter	Advanced conventional	Contactless PLASMABIT®	Hybrid integrated solution
Speed of drilling in sediments/soft rocks	●●●●●●●	●○○○○○○	●●●●●●●
Speed of drilling hard rocks	●○○○○○○	●●●●●○○	●●●●●○○
Price of drilling per km from depth of 5 km	✗ prohibitive	✓ efficient	✓ constant
Target Depth	✗ up to 2-3 km	✓ 3-10 km	✓ up to 10 km
Interventions – fishing, casing, repair	●●●○○○○	●○○○○○○	●●●○○○○

Technologies Matrix [47]

Eavor

Eavor Technologies is a Canadian company focused on automating the geothermal process to deliver scalable and dispatchable geothermal power. Eavor raised $182m in 2023, backed by Microsoft, to accelerate the deployment of its technologies.[48]

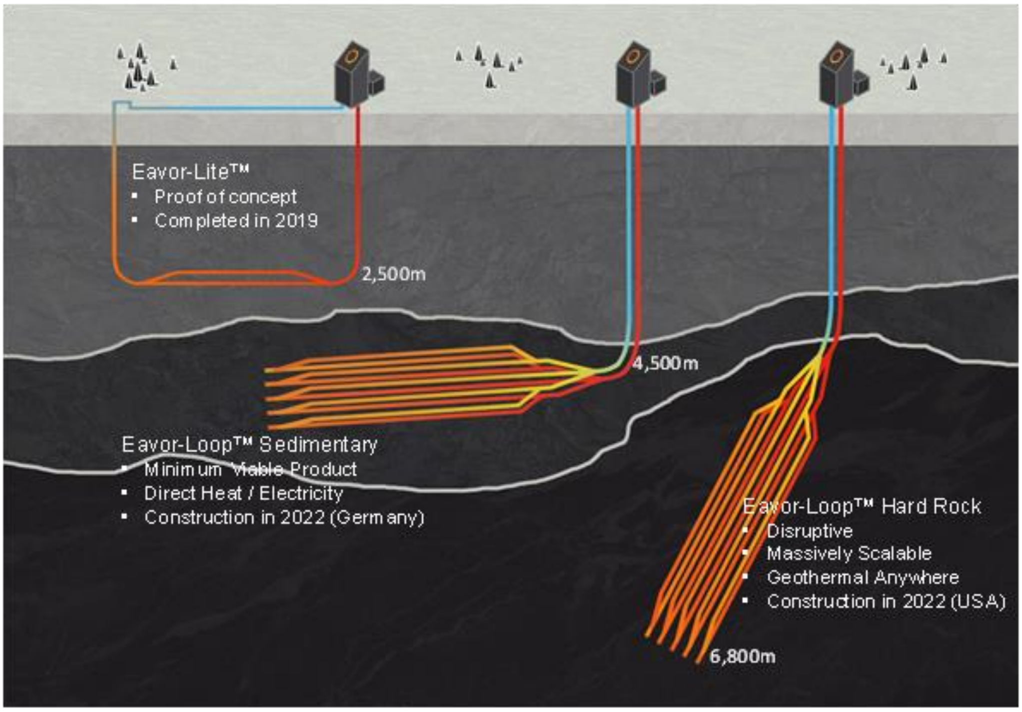
The Eavor-Loop is a closed loop geothermal system that uses a proprietary working fluid to transfer heat from the rock. The working fluid naturally circulates without requiring an external pump due to the thermosiphon effect of a hot fluid rising in the outlet well and a cool fluid falling in the inlet well. This heat can be used directly or converted into electricity. A single Eavor-Loop can heat 16,000 homes or generate large amounts of electricity.

Traditional Geothermal	Eavor-Loop™
Open System: water flows through reservoir, fluid exchange between system & reservoir	Closed System: Working fluid circulates in isolation from reservoir, no fluid exchange
Requires a permeable aquifer & hot convective zone	No need for permeable aquifer
Requires an electric pump to circulate brine; parasitic load	Driven by natural thermosiphon, no pumping required
Can require fracking to increase flow, potential for induced seismicity	No fracking required, no induced seismicity
Can produce GHG & CO_2 with produced brine	No GHG or CO_2
Continuous water use & ongoing treatment required	No water use, no production brine requiring treatment
Baseload, not Dispatchable	Baseload and Dispatchable

Eavor-Loop Comparison [49]

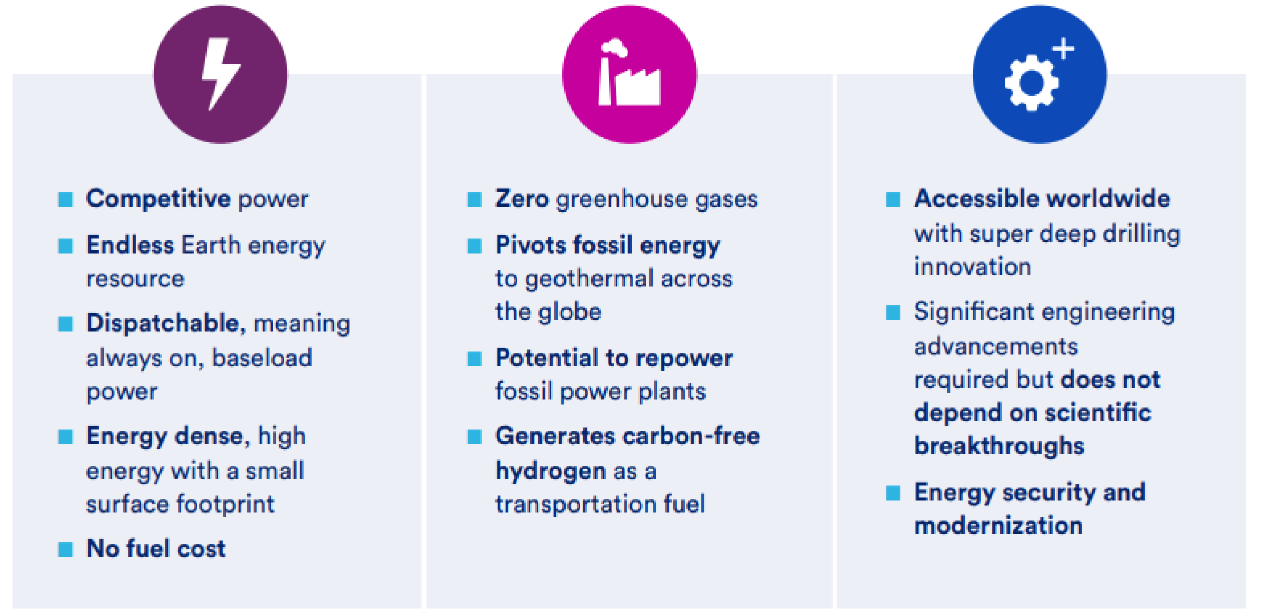
The difference between EGS and this, Eavor claim, is scalability. While EGS is more scalable than traditional geothermal, fracking its own aquifer and injecting liquid is also reliant on very specific geographic conditions.

Eavor's Geretsried project in Germany serves as the first commercial-scale deployment of the technology. Two drilling rigs will operate in parallel, drilling down to 4.5km vertical depth before deflecting horizontally to create its closed loop system. Financial backing from the Innovation Fund within the European Investment Bank totalling €130m, and a recent site visit from German Chancellor Olaf Scholz has provided the project with the necessary momentum. The plan is for the geothermal system to supply the entire region with district heating and electricity within the next four years.



Eavor Project Types [50]

The Opportunity in Geothermal



Snapshot of Geothermal Benefits [51]

Renewable and Clean Energy

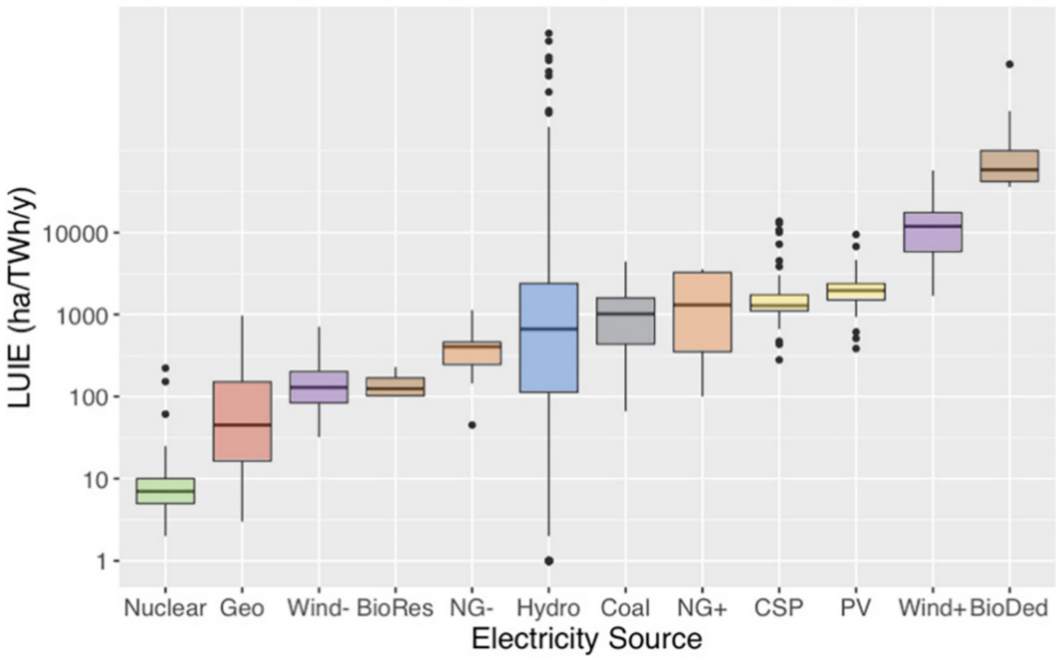
Geothermal energy is a renewable energy source. The Earth's heat is derived from its mantle and the decay of naturally radioactive isotopes of uranium, thorium and potassium. The World Energy Council estimate the Earth's surface heat flow averages 82 MW/m2 which is the equivalent to 42,000 GW of total heat content.[52] It is a virtually inexhaustible energy source.

Geothermal power plants emit ~99% less carbon dioxide than fossil fuel power plants of a similar size.[53] Its profile as a low emission, renewable energy source makes geothermal a compelling choice for economies transitioning towards net-zero. Additionally, geothermal energy provides consistent baseload power and a market leading capacity factor making it one of the most reliable carbon-free energy sources.

Energy Security

Energy security has become a major global focus in recent years. Countries are looking to diversify their energy portfolio mix, insulating themselves from the volatility brought about by geopolitical turbulence and black swan events. The transfer of heat from the earth cannot be regulated or controlled by entities like oil and gas, nor does it rely on a complex supply chain or require any fuel. Geothermal is secure and democratic in this sense. Currently, geothermal energy is restricted to select regions; the development of emerging technologies within the sector, however, promises to make geothermal energy geographically agnostic.

Small Land Footprint



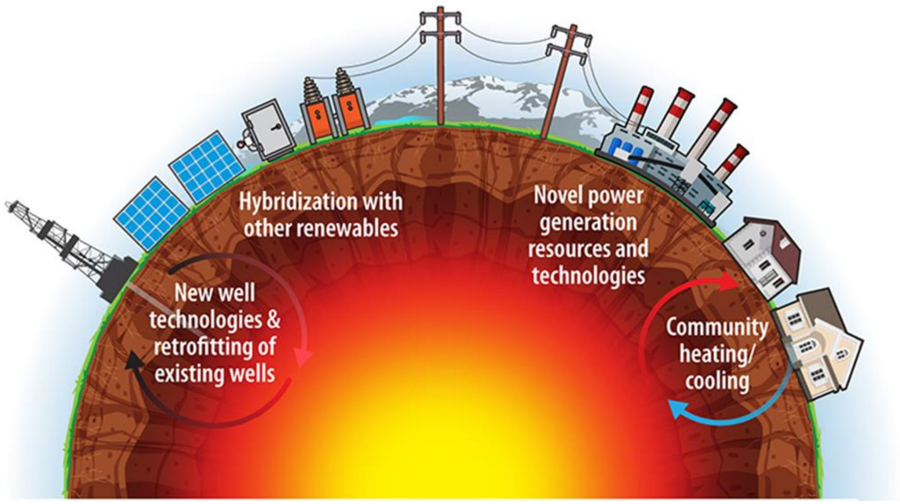
Land Use Intensity of Electricity by Energy Source [54]

Geothermal plants require less land area compared to other renewable energy sources like wind and solar farms. This minimises the environmental impact and land use conflicts. The graph above illustrates the land-use intensity of each energy source. Geothermal energy has a median land use intensity of electricity (LUIE) of 45 ha/TWh/y which ranks it as the second most efficient in terms of energy generated relative to land used.

"Although it's technically and economically feasible to get most of the way to 100% [renewable energy] with solar, wind and batteries alone, there are practical constraints. The more large-scale projects have been proposed, the more they've come into conflict with wildlife habitat, rural towns and lands sacred to Indigenous tribes — prompting a backlash that threatens to derail the energy transition. Geothermal plants, by contrast, take up far less land than solar or wind farms." – Sammy Roth, Los Angeles Times[55]

Versatility & Compatibility

Geothermal energy has applications beyond electricity generation including: direct use heating and cooling; carbon capture; mineral extraction; farming and hybridisation and storage. These additional use cases demonstrate the wider economic benefits of geothermal. Amanda Kolker from the National Renewable Energy Laboratory (NREL) describes it as a "triple resource".[56] The cascaded use of heat and power increases the net efficiency of a geothermal plant and improves the economic feasibility of the project.[57]



Source: Eavor [58]

In addition to hybridisation with existing renewables, geothermal has synergies with the fossil fuel industry and its workforce in terms of skill requirements.

Geographically Agnostic

Advancements in emerging sub-surface technologies have the potential to scale-up geothermal development worldwide. A major restriction for geothermal in the past has been that it was an energy source that was exclusive to countries that had geographically suitable sites for conventional technologies. Estimates indicate that conventional techniques can access as little as 2% of the Earth's geothermal resources. Consequently, enormous resources of geothermal energy remain untapped.[59]

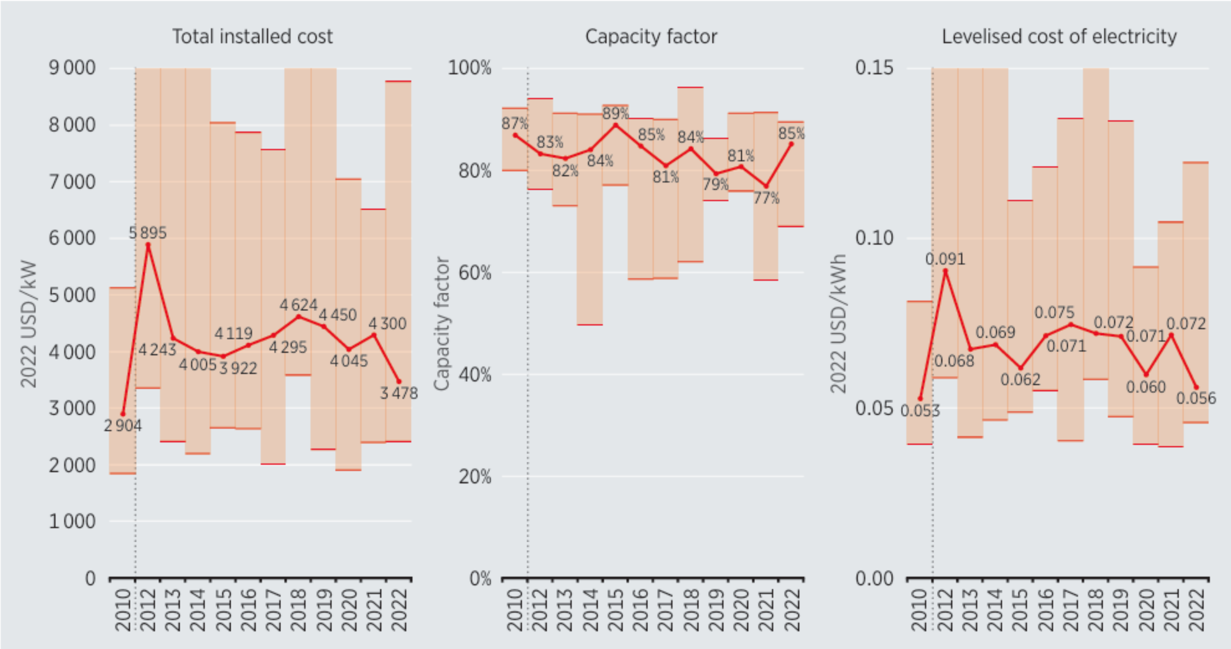
Competitive Economics

Capacity Factor

The capacity factor illustrates the efficiency and dependability of an energy source. It is measured as the ratio of actual electrical energy output over a certain period to the maximum possible output if the power source was operating at full capacity all the time.[60] The US Department of Energy report that geothermal has the second highest capacity factor across all energy sources, and with proper reservoir management, DOE estimate that modern geothermal power plants capacity factors may reach between 90-95%.[61]

Levelised Cost of Electricity (LCOE)

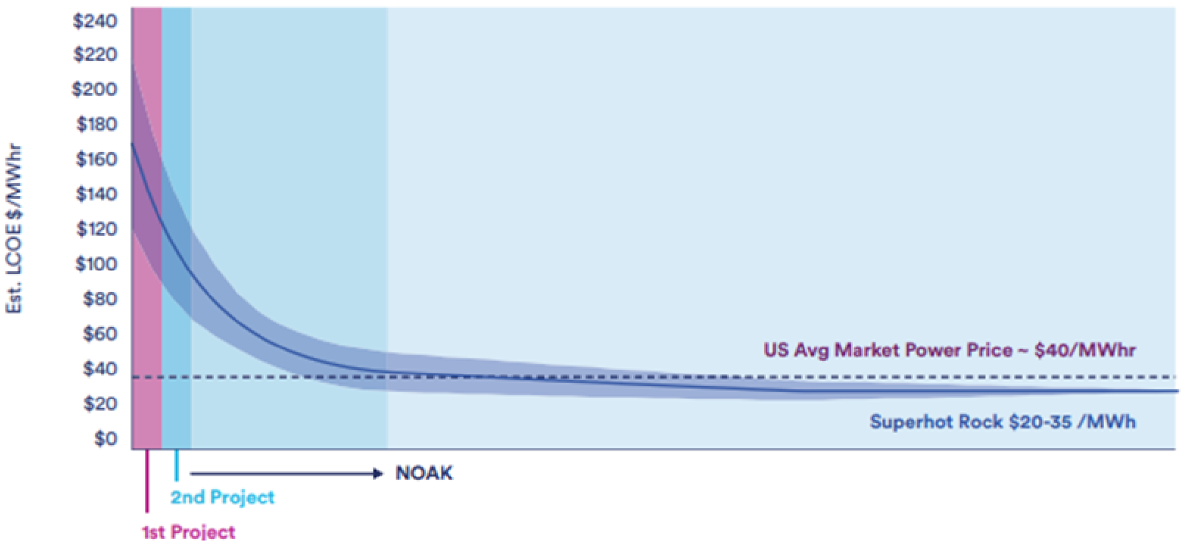
The levelised cost of energy can be thought of as the average minimum price at which the electricity generated by the asset is required to be sold to offset the total costs of production over its lifetime.[62]



Geothermal Energy Economics [63]

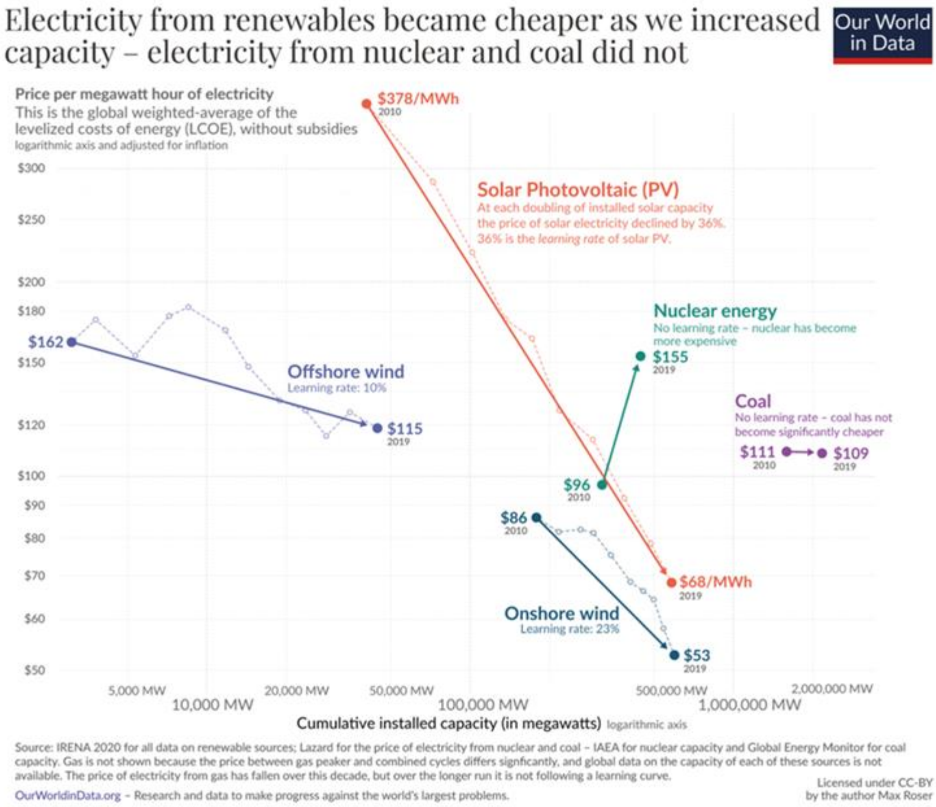
For conventional geothermal plants the LCOE is very competitive, ranging between $0.05-0.06 USD/KWh. From 2021-2022 IRENA reported a 22% YoY decrease in the global LCOE from newly commissioned, utility-scale renewable power technologies in geothermal.

Innovations in deep drilling technology will likely increase LCOE figures in the short-to-medium term, ranging between $0.06-0.16 KWh. In the long term however, LCOE should return to a more competitive range once the technology risk has been established. It is estimated that novel geothermal technologies will eventually reduce the LCOE towards $0.02-0.035 KWh.



Source: CATF Illustrative Cost Curve [64]

Solar and wind energy demonstrated that renewables could compete with fossil fuels through increased deployment and with support and conviction globally on renewable energy. Discounting subsidies, the price of electricity from solar declined 89% from 2009 to 2019, and onshore wind declined by 70% during the same period. Part of this reduction can be attributed to continuous innovation and learning in the renewables sector. With each additional unit of capacity deployed there is an opportunity to learn how to improve and refine the production process: "*The relative price decline associated with each doubling of experience is the learning rate of a technology*" - also known as Wright's law. [65] This learning curve explains the inverse relationship between additional capacity deployed and price of electricity.

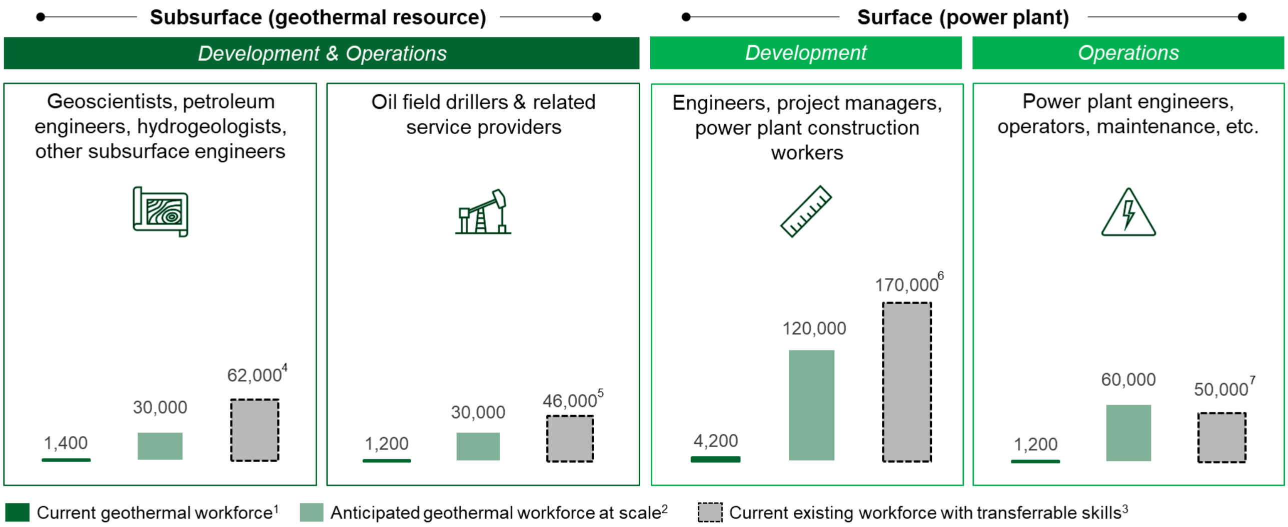


Learning Curve by Energy Source [66]

Next generation geothermal energy utilising EGS, closed loop and advanced drilling technology should follow a similar trend, paving the way for geothermal energy to be accessible anywhere.

Workforce

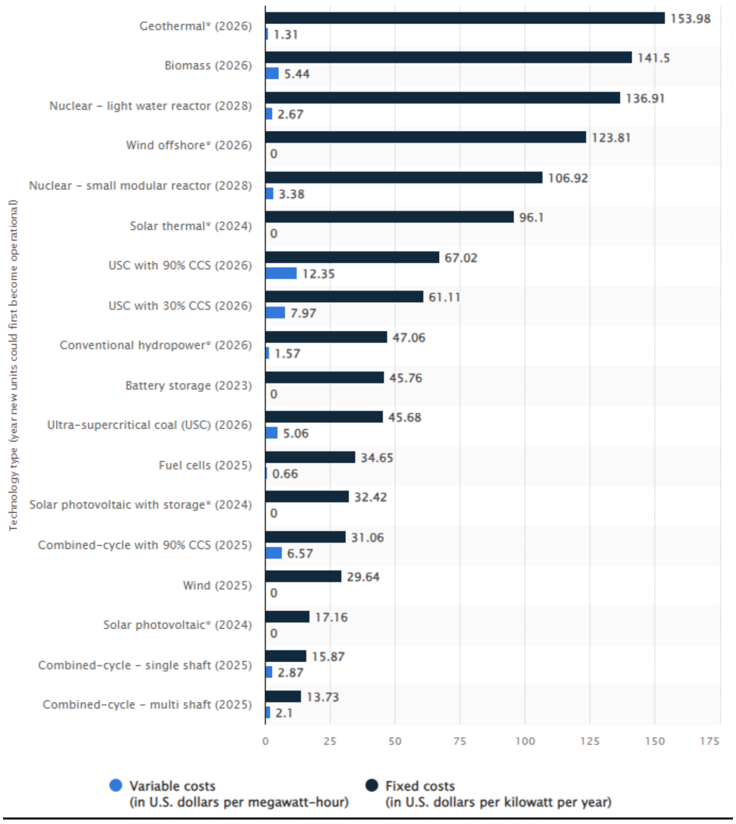
Next-gen geothermal can leverage and mobilise a pool of existing skilled labour from parallel industries. This is a major starting advantage for geothermal and will likely result in efficient deployment and a faster learning rate.



Transferable US Workforce [67]

Operations and Maintenance Costs

Geothermal installations are characterised by low operational costs. This is because unlike fossil fuels and nuclear, it does not depend on the supply or price of a commoditised fuel. Therefore, the cost is largely concentrated on the technology and power plant.[68]



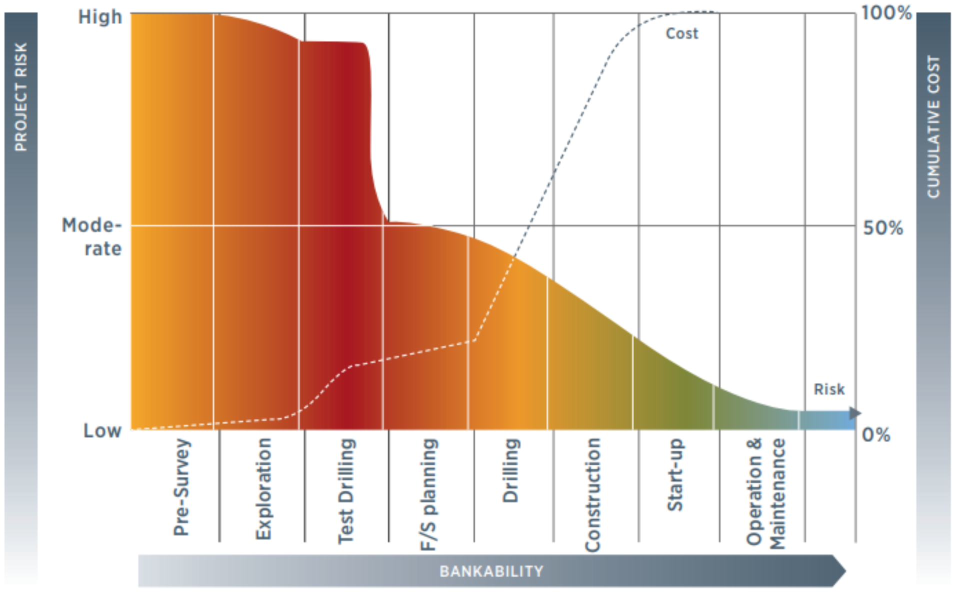
Fixed and variable costs for the operation and maintenance of new power plants in the United States as of 2022, by technology type [69]

Challenges in Geothermal

High Initial Costs for Advanced Geothermal Projects

The initial cost of drilling and developing geothermal power plants is high. To drill one 4km well it costs about $5m; at 10 kilometres, the drilling cost quadruples to $20m per well.[70] The high upfront cost and associated exploration risks have deterred development capital and limit geographic reach.

The key to driving this cost down will be advanced drilling technology and exploration techniques. Advanced geothermal company Fervo have demonstrated that drilling rate improvements led to cost decreases from $13m per well to $6m per well in their most recent pilot. Quaise's projections show geothermal holes can be drilled at a rate of $1,000/m at 3.5m per hour. At this rate of penetration (ROP) it is projected to drive costs down to that of conventional geothermal and shale (below $40 KWh LCOE). Drilling rates will be critical in geothermal development and expansion.[71] According to the US Department of energy, iterative improvements enabled by modularity in drilling operations have cut next-generation drilling costs in half over the last year.[72]



Geothermal Project Risk and Cumulative Investment Cost [73]

Induced Seismicity

In 2009 The New York Times published an article which highlighted the risk of induced earthquakes from deep geothermal drilling. The author referenced a 4.8km deep geothermal project in Switzerland which had triggered an earthquake in the region. The article was written in response to the development and funding toward AltaRocks's geothermal project in California.[74] While the article raised awareness of the risks it also had a lasting effect on public perception of geothermal.

To address public concern and gain acceptance from the public and policymakers for geothermal energy development, specifically EGS, in 2012 the US Department of Energy commissioned a group of experts in induced seismicity, geothermal power development, and risk assessment to construct a protocol detailing the necessary steps to evaluate and manage the effects of induced seismicity related to EGS projects. The protocol puts high importance on safety while allowing geothermal technology to move forward in a cost-effective manner.[75] Today, geothermal companies must complete extensive feasibility assessments and surveys before any drilling takes place to mitigate and minimise induced seismicity risk.

Environmental Concerns

Geothermal energy does not contribute to the emission of greenhouse gases, though during the excavation process, gases such as sulphur and carbon dioxide, may be released into the atmosphere. Geothermal power plants, however, emit 97% less acid rain-causing sulphur compounds and about 99% less carbon dioxide than fossil fuel power plants of similar size.

Technology Risk

The thesis for increasing global geothermal energy production is contingent, to an extent, on the commercialisation of the advanced technologies we have highlighted. While there is undoubtably room for growth using traditional geothermal processes, we view the much larger opportunity to be dependent on being able to unlock geothermal anywhere in the world. As such, one of the key challenges is technological risk.

Market Outlook

Despite having been commercialised over a century ago, geothermal remains a niche market in its relative infancy versus other green energy sources. While the more exponential growth in geothermal will likely be driven by next-generation extraction methods, current technologies still provide a substantial growth opportunity for geothermal given we have only tapped a fraction of hydrothermal resources. It is estimated that only ~5% of the total global potential for geothermal power is being used at the moment, providing plenty of scope to increase utilisation.[76]

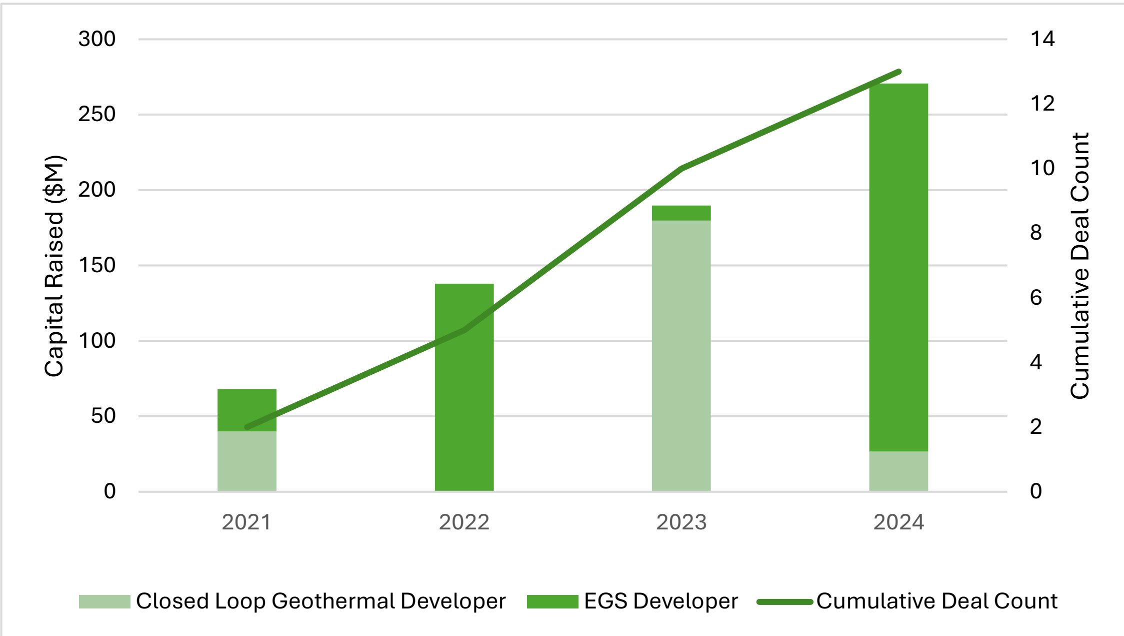
Electricity generation from geothermal energy has grown at a modest rate of around 3.5% annually, reaching a total installed capacity of approximately 16 gigawatts electric (GWe) in 2023. Geothermal energy still accounts for a mere 0.5% of renewables-based installed capacity for electricity generation, and heating and cooling, globally. On the other hand, geothermal deployment for consumer heating and cooling grew at an average rate of around 9% annually between 2015 and 2020 to reach 107 gigawatts thermal (GWth) in 2020.[77]

It has been estimated that by 2050 geothermal could potentially meet 3-5% of overall global demand for power and heating. Other estimates show that geothermal could account for more than 10% of global power demand by 2050, but we take a base case scenario of 3%, a >10x increase from today's levels.

There is some disparity between estimates for the role geothermal will play in the future energy mix, but across scenarios we see between a 4-20x global increase. As regards stated policies set out in the 2023 IEA World Energy Outlook, geothermal capacity is expected to quadruple from 16 GW of global installed capacity to >60 GW by 2050. However, this figure appears at the lower end of estimates, particularly in light of various recent reports focused on domestic geothermal strategies.

In the US, a recent report from the DOE titled "Pathways to Commercial Liftoff: Next-Generation Geothermal Power", found that geothermal could increase twentyfold by 2050 in the US alone. The report highlights how next-generation geothermal can economically provide 90 GW of the 700–900 GW of clean, firm power needed for a decarbonised economy by 2050, and technical and market factors such as limited land available for other renewables and the rate that other key technologies develop can triple expected deployment to over 300 GW.

Reaching these levels will require significant investment from both the public and private sectors, with the report noting that achieving liftoff will require 2-5 GW across 4-6 states and $20-25bn of investment by 2030, and achieving scale requires an additional 90-130GW of deployment and $225-250bn in investment by 2050.[78]



Capital raised and cumulative deal count in next-generation geothermal, 2021-2024 [79]

In the EU, a June 2024 proposal from over 200 stakeholders urged the European Commission to prioritise a European geothermal strategy, and called for 250 GW of geothermal energy across all verticals by 2040 compared with just 3.5 GW capacity in 2022.[80]

Globally, Wood Mackenzie estimate that the geothermal investment opportunity to 2050 could be over US$1 trillion, driven by 35,000 new deep wells.[81]

Market Drivers

A report from Global Market Insights found that the global market size for geothermal energy was $63.7bn in 2023 and is expected to grow at >8% CAGR between now and 2032. Other reports see CAGRs ranging from 5-13% over the next decade. Various factors will drive increased adoption and capacity build out for geothermal across its applications, but all will be underlined by rising electricity and energy costs and a global transition to green energy sources.

Supported by the energy transition, the geothermal energy sector will also see emerging demand and synergies with the data centre, renewables, oil and gas, and lithium exploration industries.[82]

Project	Date	Location	Size (MW)	Pricing ($/MWh)	Term (years)
Guadeloupe	Mar-24	Guadeloupe	10	68	30
Puna	Feb-24	Hawaii	46	70	30
Eden	Jun-23	Cornwall	1.4	65	37
Calpine	Jan-23	California	100	70	12
Fervo	Nov-22	California	20	70	15
Bottle Rock	Oct-22	Nevada	7.5	70	21
Microsoft	Sep-22	Te Huka NZ	51.4	65	10
Star Peak	Aug-21	Nevada	12.5	70.25	25
Genesis	Aug-21	Tauhara NZ	62.5	65	15
United Downs	Jan-21	Cornwall	3	65	10
Chena Power	Aug-20	Alaska	30	70	30
Whitegrass	Mar-20	Nevada	3	67.5	25
Hell's Kitchen	Jan-20	California	40	74	25
Casa Diablo	Mar-19	California	16	68	20
SCE	Aug-17	California	225	70	10
Muara Laboh	Jan-17	Indonesia	80	44	30
Agil	Apr-13	Kenya	140	44	25
Power 4	Apr-11	Kenya	36	44	20

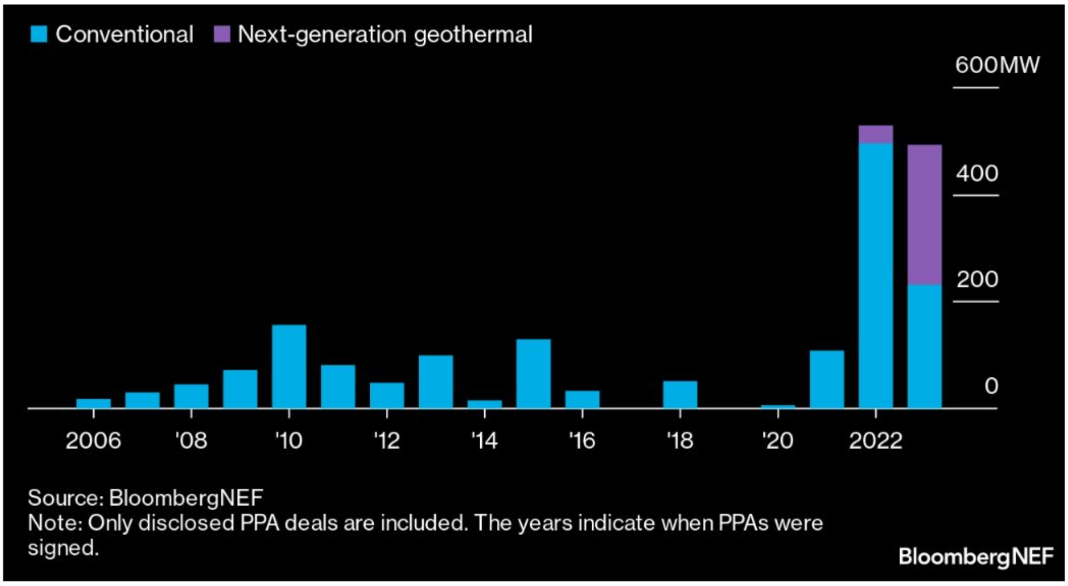
Examples of Global Geothermal PPAs 2011-2024

Given the current high upfront capital requirements for traditional geothermal, long-term power purchase agreements (PPAs) or feed-in tariffs (FiTs) have typically been necessary to get new geothermal projects financed and completed. These 15-25 year agreements between a utility and or other off-taker, provide a guarantee that someone will buy the power over a long period of time.

Similarly, contracts-for-difference (CfDs) are another tool which can provide revenue stabilisation for these projects, protecting both parties from market price fluctuations and ensuring a predictable revenue stream for the duration of the project. What makes geothermal projects potentially unique from an economic point of view is given the high associated capacity factors and renewable premium the projects can expect to receive, project revenues will not only be higher but also nearly constant.

Having policies in place that support the implementation of these financial tools is essential. As the world wakes up to the potential of geothermal energy, more supportive regulatory frameworks should emerge that would support both public and private investment into geothermal projects.

In the US, we have started to see not only increased appetite for PPAs with conventional geothermal, but also green shoots of interest in next-generation geothermal.

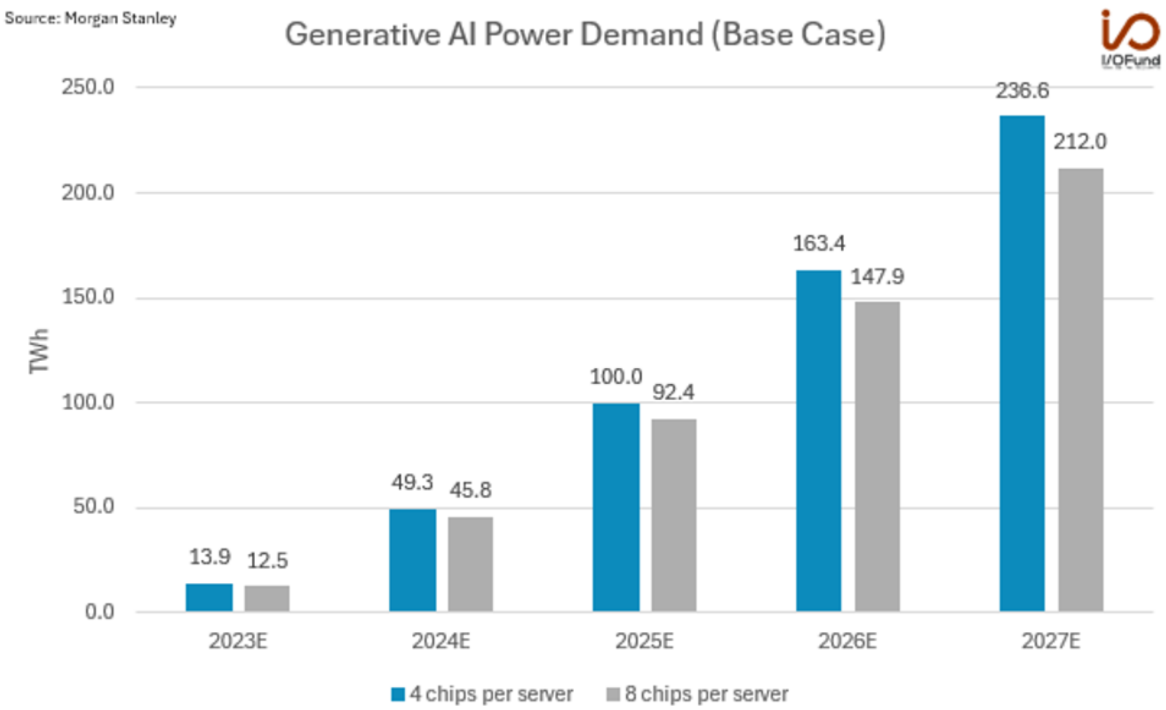


Geothermal PPAs in the US by Technology Type [83]

"The percentage of renewable PPAs that use geothermal is still quite low – less than 3% in 2022 in the US. However, the increase in geothermal PPAs and the transition to next-generation geothermal technologies marks a new phase in the commercialization of geothermal energy." – Bloomberg [84]

Data Centres

Data centre power demand is forecasted to grow at 15% CAGR from 2023-2030, according to Goldman Sachs' latest research, while Morgan Stanley estimates that global data centre power use will triple this year, from ~15 TWh in 2023 to ~46 TWh in 2024.[85] Driving this trend is the emergence of AI.



Morgan Stanley Generative AI Power Demand [86]

New AI technologies require far greater computing power than classical data centre services such as cloud storage, social media, video streaming and cybersecurity. A simple ChatGPT request, for example, consumes around 6-10x the power as a traditional Google search.

Chris Sharp, Chief Technology Officer at data centre operating company, Digital Realty, stated in an interview for the BBC that an AI data centre will need 80 MW of power compared to 32 MW a normal data centre requires.[87] Bloomberg estimate that such demand will see data centres globally eclipse India in electricity usage by 2030.[88] Reconciling such an increase in energy with regional grid capacity, ESG obligations and climate initiatives may prove to be challenging. The energy issue looms over the ambitions of Meta, Google, and Microsoft, who have committed billions in CAPEX towards developing AI and planning additional data centre capacity.

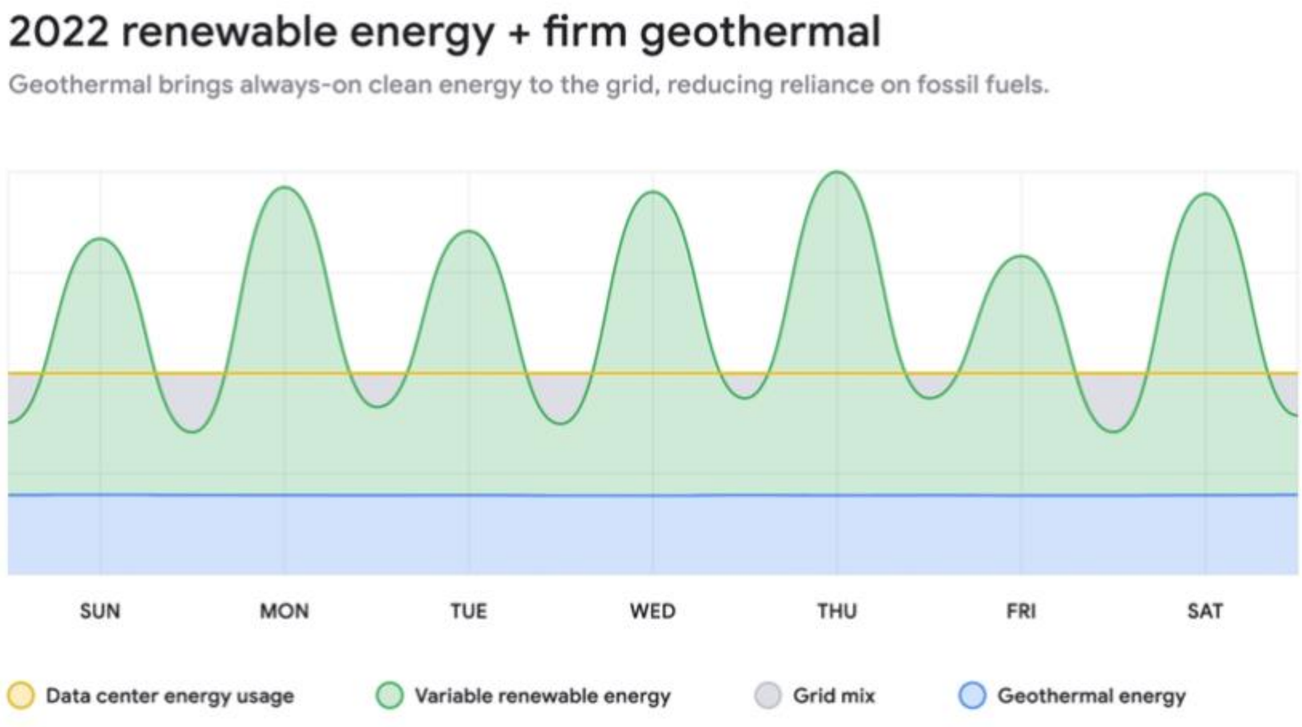
Data centres require energy-dense, baseload power systems, which is why natural gas has been the go-to solution for the recent roll-out of new units. New units can no longer rely on the grid to support their mammoth energy requirements, and therefore necessitate behind-the-meter, essentially 'off-grid' power.

Cindy Taff, CEO of Sage Geosystems, a start-up focused on delivering geopressured geothermal systems, notes that geothermal technologies do not have to connect to the utility grid, and can create 'microgrids' or 'island grids', which are behind the meter and can service an industry or a facility that needs energy that they don't want to be on the grid.

As such, geothermal presents a potentially compelling solution, particularly EGS which could provide location agnostic, baseload, carbon free power.

This is not lost on the hyperscalers looking at producing these power-hungry units at scale. The graphic below shows how geothermal can integrate with renewables to help data centres to balance their energy requirements and reduce reliance on fossils fuels.

"We need terawatts and terawatts more of traditional green energy, whether it's wind or solar, and that's across the globe." - Amanda Peterson Corio, Global Head of Data Centre Energy, Google



While geothermal is widely regarded as a renewable energy source itself, it also has interesting applications to overlap with other renewables as seen in the example provided by Google above. This is primarily due to its baseload, high capacity factor characteristics that allow it to essentially fill in the gaps when other renewables are experiencing outages.

Take solar for example, when the sun isn't shining, geothermal can provide a baseload fallback. Guangdong Zhu, Executive Director of the Heliostat Consortium for Concentrating Solar-Thermal Power says that by pairing solar and geothermal, we can design a system that naturally incorporates and takes advantage of the superior aspects of both technologies, whereby solar would increase the heat for the geothermal system, leading to more electricity generation, and the geothermal system can store excess energy from the solar.[89]

Microsoft

In May 2023, Microsoft signed a 10-year PPA to procure geothermal energy in New Zealand via an arrangement with Contact Energy. Microsoft plans to build a $180m data centre in Auckland, and Contact's 51 MW Te Hua Unit 3 is expected to be completed by the end of 2024.

"Microsoft has big plans in New Zealand. With the construction of the data centre region, this agreement aligns our New Zealand activities with Contact Energy's presence and capabilities around geothermal in New Zealand and will further strengthen our transition to 100% renewable energy by 2025. It will also support Microsoft's 100/100/0 commitment." – Vanessa Sorenson, MD, Microsoft New Zealand

A year later, Microsoft announced plans to spend $1bn building a geothermal-powered data centre in Kenya with UAE AI firm, G42, as part of a multi-year plan to dramatically increase cloud-computing capacity in East Africa. The first phase will have a capacity of 100 MW and is expected to be operational within two years.

The Olkaria region has abundant geothermal resources, and Kenya's state-owned energy provider, Kenya Electricity Generating Company, operates four geothermal power plants in the region, with installed capacity of over 700MW.[90]

Google

In 2021, Google announced an agreement with geothermal start-up, Fervo, to begin adding carbon-free energy to the electric grid that serves Google data centres in Nevada, as well as their cloud region in Las Vegas. This latest initiative is part of Google's plan to run on carbon-free energy everywhere, at all times.[91]

Using fibre-optic cables inside wells, Fervo can gather real-time data on flow, temperature, and performance of the geothermal resource. This data allows Fervo to identify precisely where the best resources exist, making it possible to control flow at various depths. Coupled with the AI and machine learning development outlined above, these capabilities can increase productivity and unlock flexible geothermal power in a range of new places.

"Traditional geothermal already provides carbon-free baseload energy to a number of power grids. But because of cost and location constraints, it accounts for a very small percentage of global clean energy production. As part of our agreement, Google is partnering with Fervo to develop AI and machine learning that could boost the productivity of next-generation geothermal and make it more effective at responding to demand, while also filling in the gaps left by variable renewable energy sources. Although this project is still in the early stages, it shows promise." - Google

In November 2023, Google announced that the enhanced geothermal project went operational, providing up to 3.5 MW after two years of development.[92] For why Google is spending billions to build a geothermal plant, see here.

Following this news, in June 2024, Google announced a partnership with Nevada-based utility NV Energy to power its data centres. The deal, which is currently under approval, would increase the amount of geothermal electricity injected into the power grid for Google's operations to 115 MW from 3.5 MW in about six years.[93]

Geothermal Cooling

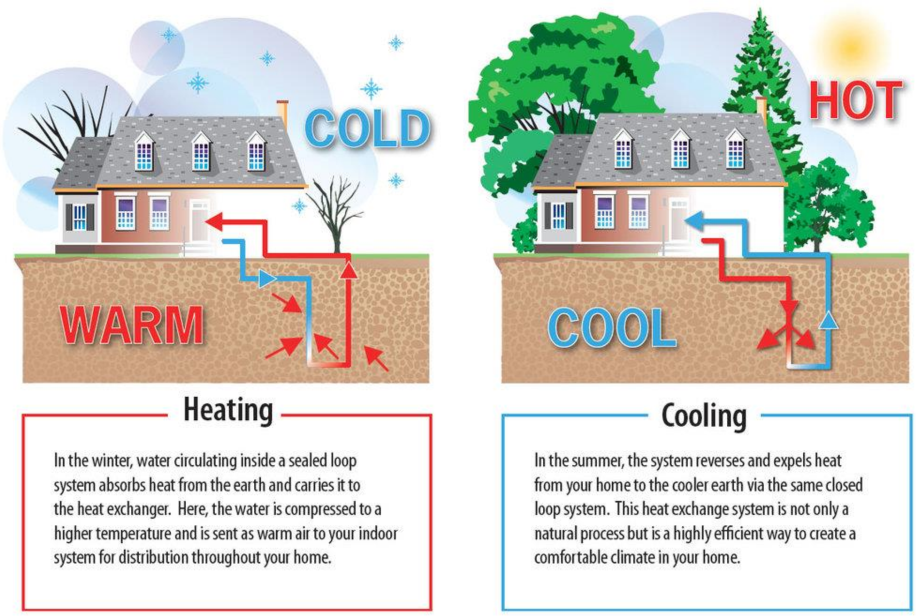
The electricity that data centres use ultimately turns into heat, resulting in as much as 50% of data centre energy use being dedicated to cooling systems.

Conventional methods use air cooling, fans, and vents to circulate ambient air, expelling hot air produced by computing equipment, but this can result in much higher energy consumption and therefore costs, particularly for facilities in warmer climates.

More recently, liquid cooling technologies have emerged as a popular solution, with almost 40% of data centres employing it in some way.[94]

Somewhat ironically, geothermal is emerging as a candidate to help data centres with their multi-billion dollar cooling issue by utilising the near-constant temperature of the earth just below the surface to provide cooling capabilities. At just 10 feet below the surface, the temperature remains the same year-round—around 55°F. Geothermal cooling is not new; throughout history, people have kept foods and beverages, such as wine, cool by storing them below ground in cellars.[95]

In practice, geothermal cooling acts in reverse to geothermal heating using heat pumps as the graphic below shows.



For data centres, geothermal cooling is implemented using a closed-loop piping system filled with water and/or a coolant that runs through vertical wells under the ground, filled with a heat-transferring fill.[96]

Because geothermal cooling capitalises on constant natural temperatures, it's remarkably efficient. Iron Mountain data centres in Pennsylvania, US, uses 34% less energy per year after implementing a geothermal solution. The system also reduces maintenance costs and offers more reliability by minimising moving parts.

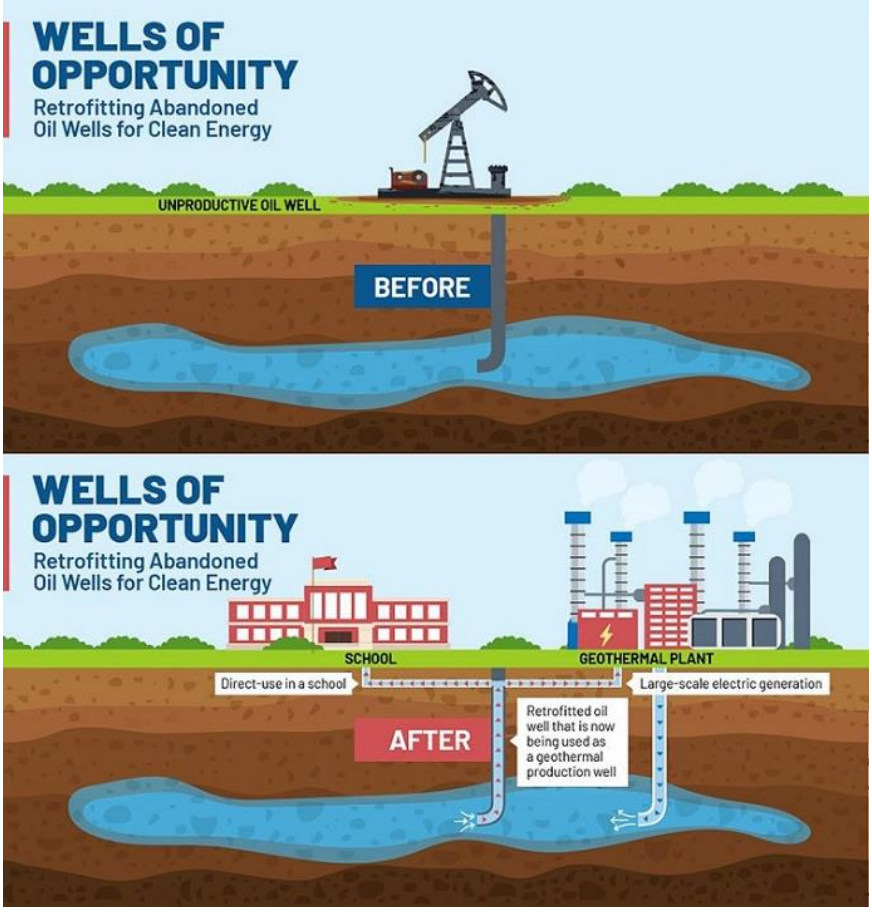
"The geothermal cooling mechanism consists of an underground reservoir and a supplementary surface-mounted free-cooling chiller plant. The reservoir is a low-humidity space with consistent water level and temperature year-round. The cooling mechanism has three major design components – reservoir pumps, heat exchangers, and building loop data center pumps – all of which are repeated for capacity and redundancy to meet Tier 3 Data Center Design Standards. The pump works by lifting the water into a heat exchanger where it receives the heat from the data center and rejects it when the warm water from the heat exchanger returns to the reservoir." - Better Buildings DOE

The market for data centre cooling was valued at $16bn in 2023, and is expected to register at CAGR of over 13.5% between now and 2032. Capturing a portion of this market could help force geothermal cooling into the mainstream, and bring with it meaningful revenues to sector.[97]

Synergies with Oil & Gas

The transition to geothermal energy represents a significant opportunity for the oil and gas industry, leveraging their extensive experience and infrastructure to support the global shift towards renewable energy. High capital expenditures for drilling and completion are a common challenge shared by both geothermal and petroleum industries.

However, innovative approaches such as retrofitting abandoned petroleum wells for geothermal energy production offer a cost-effective solution. This method not only addresses the high costs associated with well abandonment but also provides a sustainable pathway for energy generation.[98]



Retrofitting Abandoned Oil and Gas Wells for Clean Energy [99]

One promising area of synergy is the repurposing of inactive or unproductive oil and gas wells. The DOE has recognised this potential by awarding $8.4m to projects aimed at establishing geothermal energy production from these wells.

"Since the upstream infrastructure represents a large portion of the geothermal project capital expenditure, it is lucrative to consider retrofitting abandoned oil and gas wells for geothermal power generation. There are over three million abandoned oil and gas wells in the United States" – Stanford University [100]

Several major oil and gas companies are already investing heavily in geothermal projects. For instance, Chevron, BP, and Devon Energy are part of a consortium funding modern geothermal startups, highlighting the industry's commitment to diversifying into clean energy sources. This investment is driven by the recognition that geothermal energy aligns closely with their operational expertise, making it a natural fit for their existing capabilities.[101]

Additionally, the integration of carbon capture, utilisation, and storage (CCUS) with geothermal energy projects offers another layer of synergy. This combination not only enhances the efficiency of geothermal power generation but also contributes to reducing carbon emissions. Projects like CarbFix in Iceland and similar initiatives in Canada and Indonesia demonstrate the potential of this integrated approach to support the energy transition.[102]

To address the limitations of Li-ion batteries, NREL and Renewell Energy are repurposing inactive upstream oil and gas wells for long-term, cost-effective energy storage. Their Gravity Wells technology converts these wells into energy storage sites by raising and lowering heavy weights in wellbores, storing energy when electricity prices are low and generating power when prices are high. This method will utilise around $4 trillion worth of idle O&G infrastructure, sealing methane-emitting wells, and providing a highly resilient, reliable, and flexible energy storage solution that significantly reduces greenhouse gas emissions.[103]

Synergies with Lithium

Demand for lithium has surged due to its essential role in rechargeable lithium batteries, which power portable electronic devices, electric vehicles, and grid storage solutions. According to the IEA, global need for lithium is projected to increase by up to 10x by 2050 from 2023 levels, driven by the adoption of these technologies.[104/105]

The process of extracting lithium from geothermal brine involves pumping hot, salty water from deep underground. This brine, rich in dissolved lithium, is processed using technologies like ion exchange, solvent extraction, or selective adsorption to separate lithium from other elements. The extracted lithium is then concentrated and purified to produce lithium carbonate or lithium hydroxide, which are essential for battery production.

Extracting lithium from geothermal brine, especially in resource-rich areas like California's Salton Sea, reduces costs and environmental impact compared to traditional mining. This integrated approach addresses the rising demand for lithium, essential for batteries and electric vehicles while enhancing the viability and profitability of geothermal energy projects.[106]

The synergy between lithium extraction and geothermal energy production offers a transformative solution for clean energy. By coupling these processes, geothermal plants can become more profitable and efficient.

A Global Overview of Geothermal

Geothermal in the UK

The Eden Geothermal Project

The Eden Geothermal Project is an innovative initiative aimed at providing sustainable heat to the Eden Project's Biomes in Cornwall. The University of Exeter leads the research, focusing on harnessing geothermal resources. Their EG-1 well which reaches a depth of 4,871 meters and has helped to provide critical data on the region's geology.[107]

In practical terms, the project has installed a single well heat exchanger and a 3.8km heat main that transfers heat from the geothermal well to the Eden Project. This system replaces the previous gas heating system and demonstrates the viability of geothermal energy for large-scale heating needs. The Eden Geothermal Project not only serves the immediate needs of the Eden Project, but also contributes valuable insights into the potential of geothermal energy in the UK.

United Downs Deep Geothermal Power Project (UDDGP)

The UDDGP project marks the UK's first venture into geothermal electricity generation, located near Redruth in Cornwall. Funded by the European Regional Development Fund, Cornwall Council, and private investors, the project is spearheaded by Geothermal Engineering Ltd (GEL). It features two wells: a production well reaching 5,275 meters, the deepest in the UK, and an injection well at 2,393 meters, both drilled into the Porthtowan fault zone. The project is notable for discovering a significant lithium resource within the geothermal fluid, which could be instrumental in supporting the UK's electric vehicle industry as it transitions to net zero.

Set to begin operations this year, the UDDGP will deliver 2MWe of baseload electricity and additional zero-carbon heat. The plant will utilize a binary power plant design to minimize surface impact, and the geothermal system will generate power by cycling water through a naturally hot reservoir, using the heated water to drive a turbine.[108]

UK National Geothermal Centre (NGC)

A coalition of UK stakeholders from industry, academia, finance, and government, including The Net Zero Technology Centre (NZTC), have announced the creation of the NGC. The NGC will focus on expanding geothermal development efficiently by stimulating and supporting research and innovation and driving policy, regulation, and investment framework.

"Geothermal energy is the foundation of energy security in the UK. It is an inexhaustible source of clean heat and power beneath our feet. The new UK National Geothermal Centre will work to unearth geothermal energy." - Anne Murrell, Director at the NGC[109]

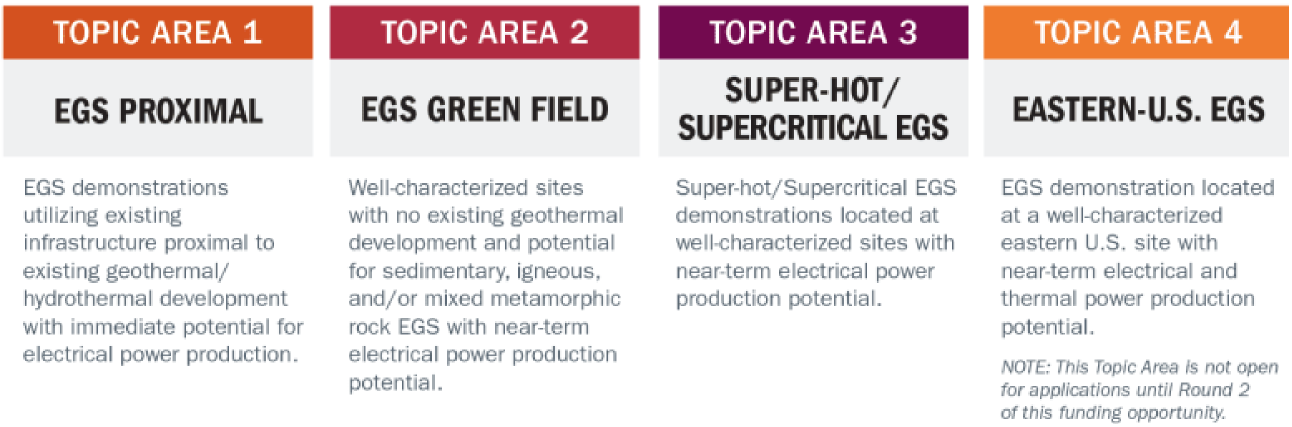
According to the NZTC, the geothermal industry could play a pivotal role in achieving the UK's energy goals and bolstering its economy. By 2050, it's projected that this sector could fulfil 10GW of the expected heating demand and 1.5GW of the forecasted electricity demand. The growth of the geothermal industry could potentially generate 50,000 future employment opportunities and lead to an annual decrease of 10 million tonnes in CO2 emissions.[110]

Geothermal in the US

The Geysers, the world's largest geothermal power plant complex, is situated in the Mayacamas Mountains and covers an area of 45 square miles. Operated by Calpine, it consists of 13 power plants with a combined net capacity of approximately 725 megawatts—enough to power a city the size of San Francisco or 725,000 homes. In 2018, The Geysers supplied power to multiple counties in California and accounted for 50% of the state's geothermal energy production.[111]

The DOE announced in November of 2023 that it has selected 13 research projects to receive a combined total of up to $44m for research that will build on the government's existing EGS work and focus on reproducible solutions. By investing in EGS technology development, the goal is to reduce the cost of EGS by 90%. [112]

The DOE have initiated their first selection of companies to participate in EGS pilot demonstrations including: Chevron New Energies, Fervo and Mazama Energy. The three projects selected in the first round are intended to increase geothermal power production in the United States in the near-term. The pilot scheme will focus on 4 key topic areas outlined below.



EGS Pilot Demonstrations Topic Areas [113]

Fervo has initiated its exploration drilling campaign at Cape Station in Beaver County, Utah. This project aims to deliver 400 MW of continuous, carbon-free electricity starting in 2026, with full-scale production by 2028. Cape Station is expected to create approximately 6,600 jobs during construction and 160 permanent jobs, contributing over $437m in wages.[114] The company has recently secured a 15-year deal to supply Southern California Edison, one of the nation's largest utility companies, with 300MW - enough electricity to power 350,000 homes. This marks a significant milestone for the company and advanced geothermal technology. The first 70 megawatts should come online by 2026, with the plant fully operational by 2028.[115]

Cape Station will capitalize on Utah's substantial geothermal potential, estimated at over 10 GW in the state's southwest region. The project promises to inject $1.1bn into local businesses and supply chains, positioning Beaver County as a hub for clean energy and economic growth.[116]

Geothermal in Europe

Iceland

The Hellisheidi geothermal power plant, located near Mount Hengill in Iceland, is one of the world's largest geothermal facilities, producing 303MW of electricity and 400MW of thermal energy. Commissioned in phases from 2006 to 2011, it supplies power primarily to Reykjavik's aluminium refineries. The plant features a significant carbon capture and storage (CCS) project, Orca, which began in 2021 and is touted as the world's largest direct air CCS plant. Utilizing geothermal energy, Orca captures CO_2 directly from the air and stores it as rocks underground. The power plant operates with a combination of high-pressure and low-pressure turbines, extracting steam from over 300 boreholes and is set for further expansion by 2030.[117]

Italy

Italy is a significant player in the geothermal energy sector, with an installed capacity of 1.1 GW producing 6 TWh hours per year and accounting for 5% of the nation's green energy. Tuscany, is the geothermal centre of Italy, hosting the historic Larderello plant and over thirty other geothermal plants. It is estimated that domestic energy needs could theoretically be met by the country's geothermal resources.

Despite its potential, geothermal energy contributes only a few percentage points to Italy's energy mix. However, Italy remains one of the main producers in Europe and globally, thanks to its natural geothermal wealth. The Larderello plant, the world's first geothermal power plant, has been central to innovation in this field. Geothermal capacity from other regions is forecasted to reach similar levels by 2030 and make up 30-40% of national production by 2050.[118]

Türkiye

Türkiye possesses a substantial geothermal energy potential, estimated to be around 31,500 MWt. Globally, it ranks 7th and holds the 1st position in Europe in terms of geothermal energy capacity at 1.7GW.[119] Türkiye operates 65 geothermal power plants, making it the 4th largest nation worldwide in installed geothermal power capacity, which accounts for 3% of its national electricity consumption.[120]

Switzerland

In terms of heating alone, geothermal energy is projected to supply up to 25 % of total household and industrial heating needs in Switzerland by 2050, accounting for at least 17 TWh/year. Currently, Switzerland produces 4 TWh/year of geothermal heat, mainly coming from shallow wells. This production at shallow depths the government estimate can be more than doubled.

The geological potential for heat supply for medium and deep geothermal energy in Switzerland is around 100 TWh/year. It is estimated that the economically exploitable potential of medium and deep geothermal energy is at least 8 TWh/year and can be developed in stages by 2050. Today, however, there is only 0.2 TWh/year installed capacity.

Switzerland hosts a cluster of advanced geothermal companies:

HammerDrum

HammerDrum's technology significantly reduces construction site size and costs. Their innovative approach allows for deep drilling in urban areas by shrinking the site to just 1% of conventional rigs. The technology boasts a high degree of automation, slashing drilling expenses by up to 80%. The centrepiece is a 6-meter-long, electric drill that operates autonomously within the borehole, eliminating the need for surface operations. This drill, lowered by a steel cable, employs a striking rotation mechanism to efficiently cut through the earth, achieving speeds of 15 km/h and a drilling rate of 5cm per minute. Remarkably, a 1 km well can be completed in just 3-4 weeks. The system's compactness enables it to operate in an area the size of two parking spaces, housed within a standard shipping container. The company reported this year the first successful deployment of its drilling technology. [121]

SwissGeoPower

SwissGeoPower have developed technology derived from "Plasma Pulse Geo-Drilling" (PPGD), a new type of contactless, electrical drilling method for hard rock. The company estimate that this technology will significantly reduce the costs associated with changing drill bits due to the low-wear and durability of their proprietary plasma drill.

“Put simply, high-voltage flashes are guided through the rock in a controlled manner in millionths of a second, breaking out relatively large "cuttings" and washing them to the surface with water.” – SwissGeoPower [122]

STRYDE

STRYDE has developed the world’s smallest, lightest, and most cost-effective autonomous nodal technology making high-resolution seismic data more accessible. Historically, significant CAPEX and OPEX costs associated with acquiring seismic surveying technology and data has made it a tool exclusive to the oil and gas industry. STRYDE’s miniature, low-cost seismic imaging technology, however, enables high-density seismic data acquisition to be affordable for emerging industries such as geothermal. [123]

The technology has proven critical in reducing the people, costs, and environmental footprint required to conduct a seismic survey while simultaneously accelerating the acquisition of high-quality seismic data. These efficiencies can potentially increase the deployment rate of geothermal projects globally, which are more likely to be conducted in urban environments, with smaller budgets and strict permitting requirements.[124]

The STRYDE Node [125]

Geothermal in Asia

Philippines

The Philippines has the third largest geothermal installed capacity in the world with 1.9 GW installed in 2023. This figure is expected to increase to 2.1 GW by 2031. Several geothermal initiatives have been developed in the past year, including the 17-MW Tiwi binary power plant, the 29-MW Palayan Bayan binary plant, and the 2-MW Biliran power plant. Collectively, these projects will contribute an additional 48 MW of additional capacity and are anticipated to commence operations this year. [126]

Indonesia

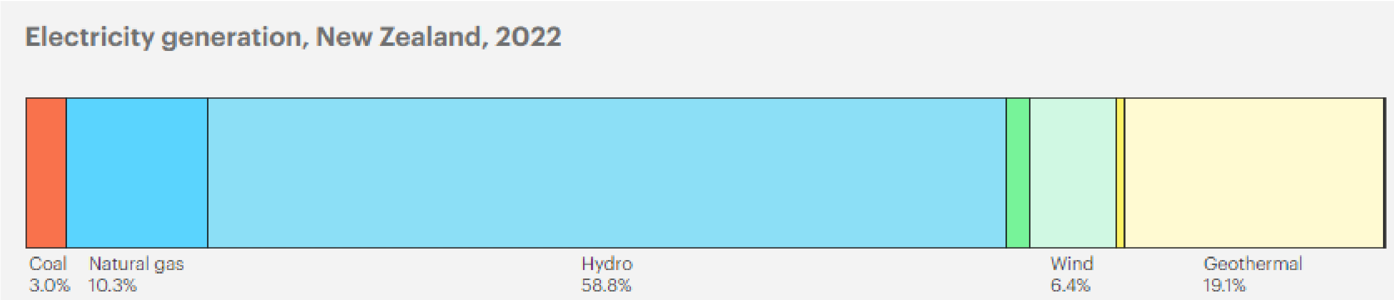
Indonesia have invested $20bn towards a renewable energy scheme titled ‘Just Energy Transition Partnership’ or JETP. According to the JETP scenario, by 2030 geothermal and hydro will produce 22% of Indonesia’s electricity. To achieve this ambitious goal, renewables need to grow rapidly over the next seven years. Fortunately, the Indonesian government are convicted, maintaining an active role in the energy market. The government hold a 94.5% stake in geothermal developer Geo Dipa. An additional 4.5% stake in the company is owned by the nationalised utilities company PLN. [127]

Geothermal in Oceania

New Zealand

Geothermal systems in New Zealand are primarily concentrated in the Taupō Volcanic Zone, with high temperature fields also found at Ngawha in Northland. The country boasts a total of 129 geothermal areas, with temperatures ranging from moderate to extremely high. The Taupō Volcanic Zone is particularly active and has led to the development of numerous geothermal fields. These fields are sustained by heat from magma intrusions at relatively shallow depths, resulting in temperatures of at least 350ºC. Approximately 29 geothermal areas have been identified within this zone, but only about half are considered to have potential for resource utilization.[128]

The geothermal fields in New Zealand vary in size and location. The Ohaaki-Broadlands, Mokai, Rotorua, Rotokawa, Kawerau, and Ngā Tamariki geothermal systems are some of the key fields, each covering areas ranging from 5 to 35 km². These geothermal resources play a significant role in New Zealand's energy landscape and offer potential for further development.[129]



New Zealand Electricity Generation Mix [130]

Geothermal in Africa

Kenya

Hell's Gate National Park in Kenya hosts several geothermal plants. It is located within the Great Rift Valley, a hotspot for tectonic activities, which result in shallower geothermal wells. Some wells in Kenya are as shallow as 900m in depth. Construction has begun to add new capacity to the park. The planned Olkaria VI power plant will generate 140MW of geothermal power and help Kenya to achieve its goal of moving to 100% clean energy by 2030. [131]

Since the 1990s, Kenya has been committed to renewable energy, leading to the establishment of the region's largest solar and wind projects. The country has produced close to 950 MW of geothermal energy so far, enough to power about 3,800,000 homes. The government estimates there is 10 GW of untapped geothermal resource which could theoretically power Kenya's current peak demand five times over.[132]

According to the IEA, more than three-quarters of all the people in the world that lack access to electricity and more than a third that lack access to clean cooking fuels and/or technologies are in Africa.[133] Reliable energy is a vital driver of economic growth.

"Geothermal contributes to power generation. The more you electrify your country, or you give people access to clean cooking alternatives, the more you find deforestation and charcoal burning declines" - Henry Paul Batchi Baldeh, Director for Power Systems Development, African Development Bank.[134]

Conclusion

Our geothermal future is, in part, contingent on the successful commercialisation of advanced geothermal systems that will allow us to unlock its potential anywhere in the world. Regardless, there is evidently scope to increase geothermal capacity using traditional methods if we are able to derisk exploration efforts.

The challenges for conventional geothermal remain in exploration risk, high upfront capital requirements, and our inability to 'go-deep' and therefore unlock geothermal anywhere in the world. Should the various efforts to commercialise next-generation geothermal fail, then in all likelihood geothermal will not reach its full potential.

However, the variety of benefits that geothermal presents once plants are operational are incontrovertible. Geothermal provides carbon-free, baseload energy, that does not rely on the complexity of most other energy supply chains. The potentially indiscriminate nature of geothermal should minimise its ability to be geopolitically weaponised as we have seen with the likes of oil, gas, and uranium.

What is clear is that the timing for geothermal, given the variety of projects, initiatives, and investments that we have outlined in this report, is now.

Note

We plan to release to our investor network our preferred way to play this theme in the coming weeks. For those interested in receiving these ideas please email ben@oceanwall.com

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