Geothermal - Earth’s natural battery power

Geothermal energy, found in rocks and fluids beneath the earth crust, is one of the oldest sources of renewable energy.

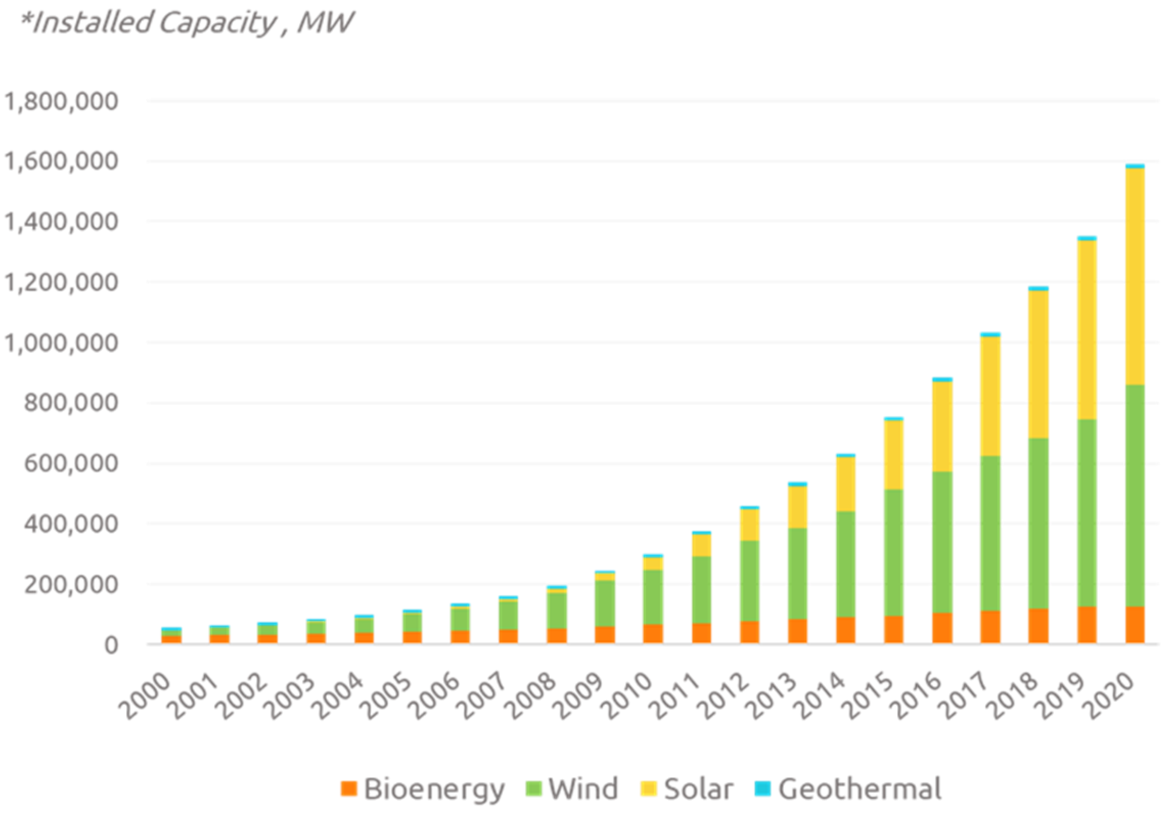
Residing from the shallow surface to several kilometers or more below the earth's surface, geothermal energy could naturally rise to the surface through volcanoes and fumaroles (holes in the earth where volcanic gasses are released), hot springs, and geysers[1].

Geothermal resources could also be brought to the surface by drilling and capturing steam and high-temperature water, harnessed for energy applications through two primary pathways (similar to solar- and bioenergy), either through the generation of electricity or through various “direct-use” thermal applications (without conversion to electricity), such as space heating and industrial heat input.

Geothermal electricity generation was around 97 TWh in 2020, while direct useful thermal output was about 128 TWh (462 PJ). In some instances, geothermal plants produce both electricity and heat for thermal applications (co-generation), but this option depends on location-specific thermal demand coinciding with the geothermal resource[2].

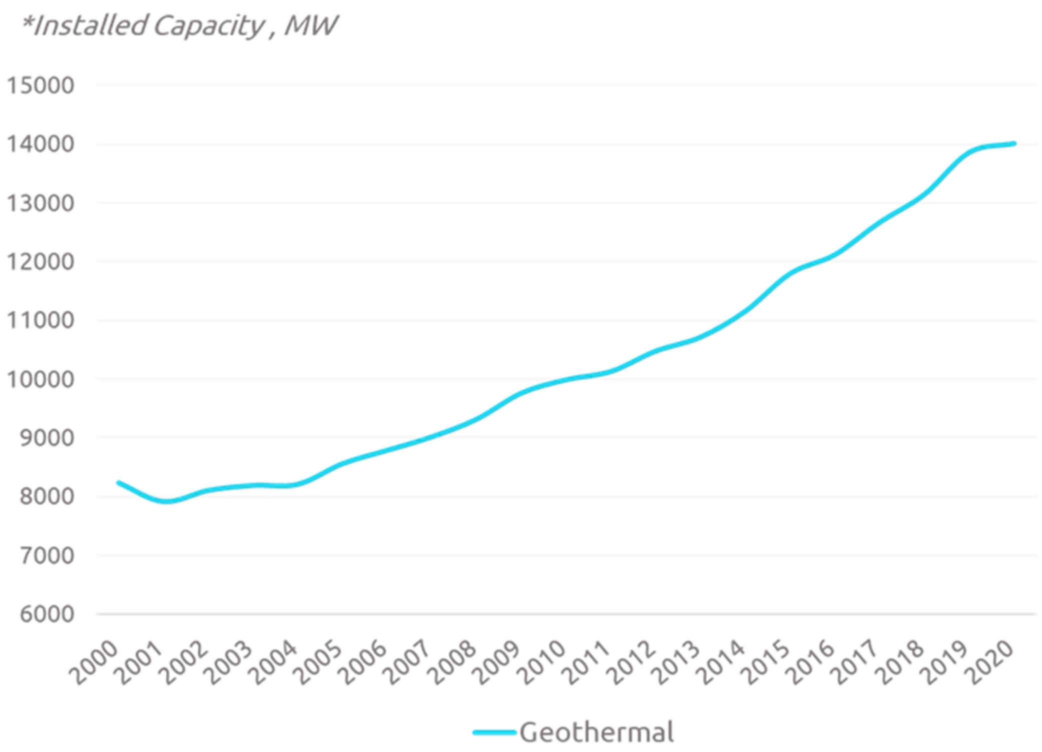
Compared to other rapidly growing renewable energy technologies however, the development of geothermal energy has been lukewarm. In 2020, the installed capacity of hydropower, photovoltaic power generation and onshore wind power has reached 1,154GW, 710GW and 698GW respectively, accounting for 88% of the total installed renewable energy power generation; meanwhile, the total installed global geothermal capacity in 2020 is 14GW, accounting for only 0.5% of the total installed global renewable energy capacity[3].

Figure 1 Installed Capacity of Major Non-hydropower Renewable Energy Sources, 2000-2020 (MW)



Source: IRENA, MioTech Research

Figure 2 Installed Capacity of Geothermal Power Generation, 2000-2020



Source: IRENA, MioTech Research

Benefits of geothermal energy

1. **A sustainable energy source:** Geothermal energy comes from the **almost unlimited amount of heat** generated by the Earth's core. Even in geothermal areas dependent on a reservoir of hot water, the volume taken out can be reinjected, making it a sustainable energy source.

2. **Clean energy and clean extraction:** Energy can be extracted without burning fossil fuel such as coal, gas, or oil. Geothermal fields produce only about one-sixth of the carbon dioxide that a relatively clean natural-gas-fueled power plant produces, and very little if any, of the nitrous oxide or sulfur-bearing gasses. Binary plants, which are closed cycle operations, release essentially no emissions.
   Some geothermal plants do produce some solid materials, or sludges, that require disposal in approved sites. Some of these solids are now being extracted for sale (zinc, silica, and sulfur, for example), making the resource even more valuable and environmentally friendly.

3. **Stable source of energy:** Geothermal energy is available 24 hours a day, 365 days a year. Geothermal power plants have average availability (utilization rate) of 90% or higher, compared to about 75% for coal plants. As mentioned earlier, industries such as aluminum smelters need high level of reliability to prevent the high cost from possible energy shutdowns, expanding geothermal energy sources has helped countries such as Iceland attract industries to its economy.

4. **Energy security:** Geothermal energy is harvested from local areas with a high concentration of volcanic and hot springs presence around the world. Its homegrown nature has helped these countries to gain energy independence by reducing its reliance on imported energy sources.

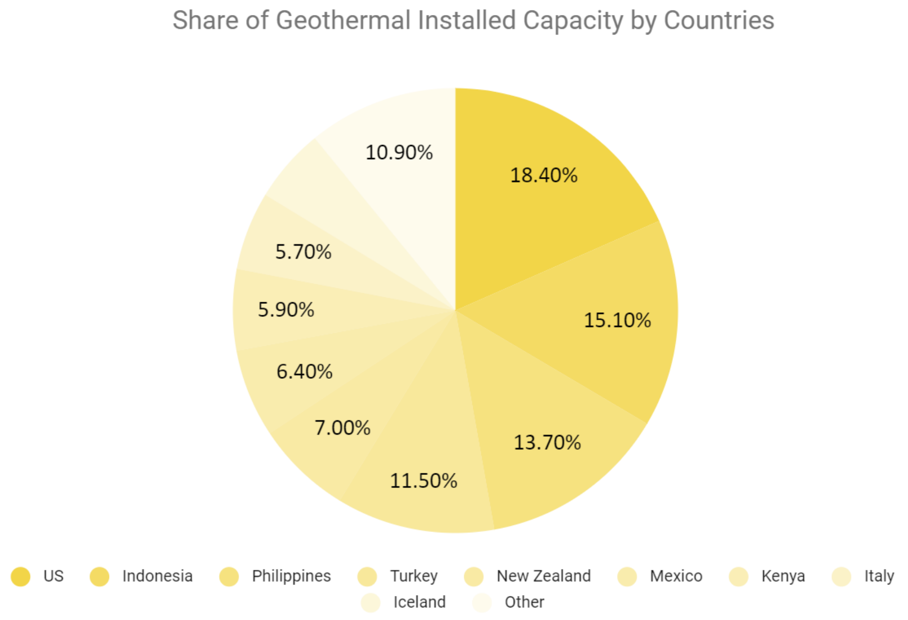
Where can we find geothermal energy?

The most active geothermal resources are usually found along major tectonic plate boundaries where most volcanoes are located. Geothermal power generation is currently deployed in more than 20 countries.

I. Geothermal Energy for Power Generation

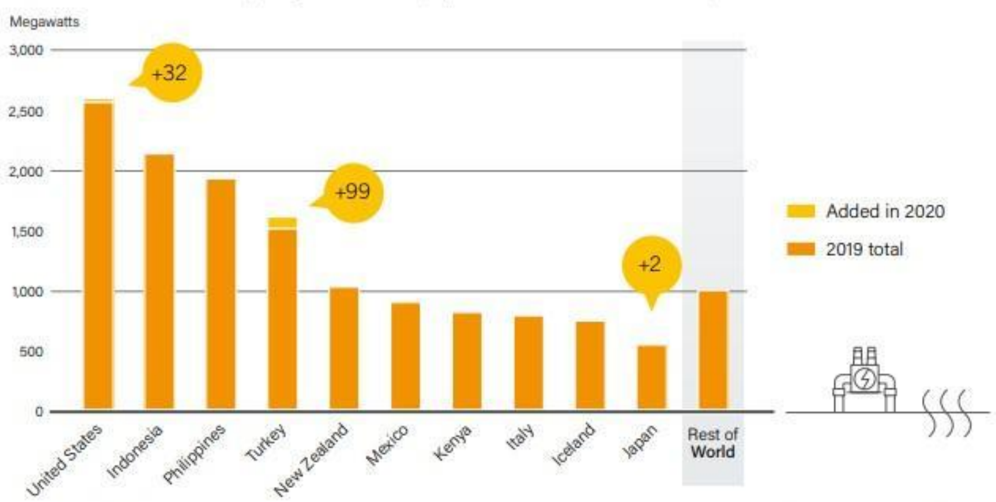
The US is the leader in the world's capacity of geothermal power generation, making up 18.4% of the world's total installed geothermal capacity. North America has a quarter of the world's total when one considers Mexico's 6.4% share. Asia Pacific holds 40% of the world's geothermal energy capacity with leaders from the island nations of Indonesia and Philippines representing 15% and 14% respectively, followed by New Zealand's 7% and Japan's 7%. Turkey, Kenya and Italy all make it to the top-10 list of world's geothermal capacity with 12%, 6% and 6% of total respectively.

An estimated 0.1 GW of new geothermal power generating capacity came online in 2020, bringing the global total to around 14.1 GW. The distinct feature of 2020 was the disproportionately small growth in capacity relative to recent years (attributable in part to pandemic-related disruption), with almost all new facilities located in Turkey. Other countries that added minor amounts of geothermal power capacity in 2020 were the United States and Japan.



Source: BP Statistical Review, MioTech Research

Geothermal Power Capacity and Additions, Top 10 Countries and Rest of World, 2020



Note: Figure shows known new capacity and capacity increases at existing facilities but does not indicate known capacity decommissioning or derating of existing facilities, although those may be reflected (at least partially) in total capacity values.

Source: Renewables 2021 Global Status Report, MioTech

Geothermal power capacity	*1*	*2*	*3*	*4*	*5*
Total Power Capacity or Demand/Output as of End-2020	US	Indonesia	Philippines	Turkey	New Zealand
Annual Investment /Net Capacity Additions /Production in 2020	Turkey	US	Japan	–	–

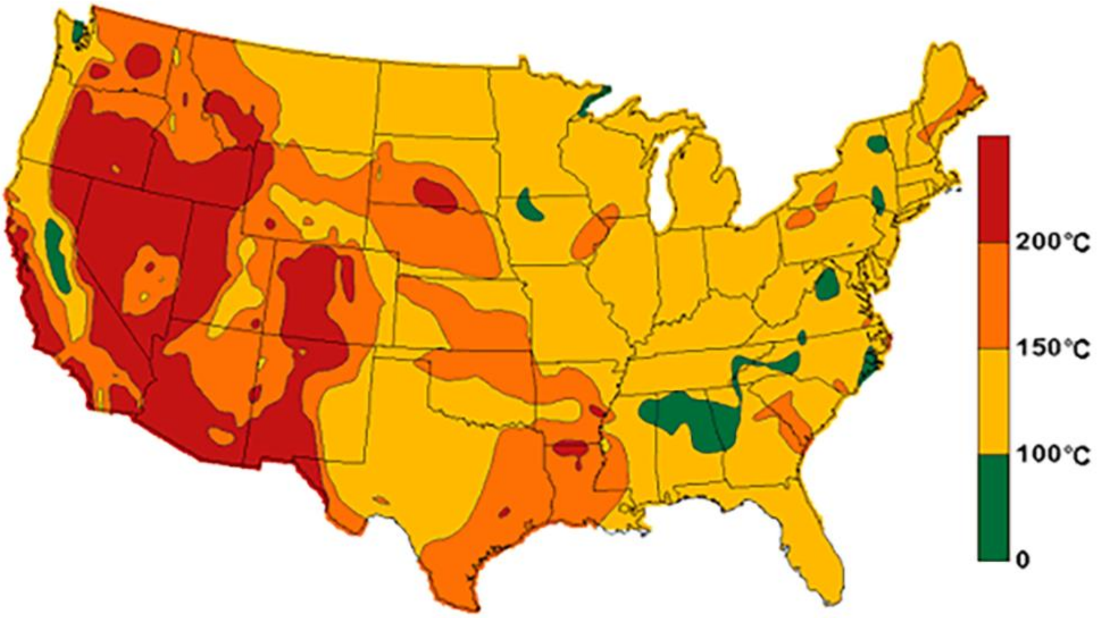
Source: Renewables 2021 Global Status Report, MioTech

US – Leader of the Pack in Geothermal Energy

Most of the geothermal power plants in the United States are in western states and Hawaii, where geothermal energy resources are close to the earth's surface. California generates the most electricity from geothermal energy.

The Geysers, located 72 miles north of San Francisco, California, is the world's largest geothermal field and has been producing electricity since 1960. With a complex of 18 geothermal power plants over 45 square miles, The Geysers has a combined installed capacity of 845 MW[4], meetings 60% of the power demand for coastal region between the Golden Gate Bridge and Oregon State line and providing half of all of California's geothermal generation. In 2019, The Geysers accounted for 20% of all renewable energy in California[5].

Geothermal resources of the United States



Source: US Department of Energy, Office of Energy Efficiency & Renewable Energy, MioTech

Iceland – Geothermal Energy Pioneer

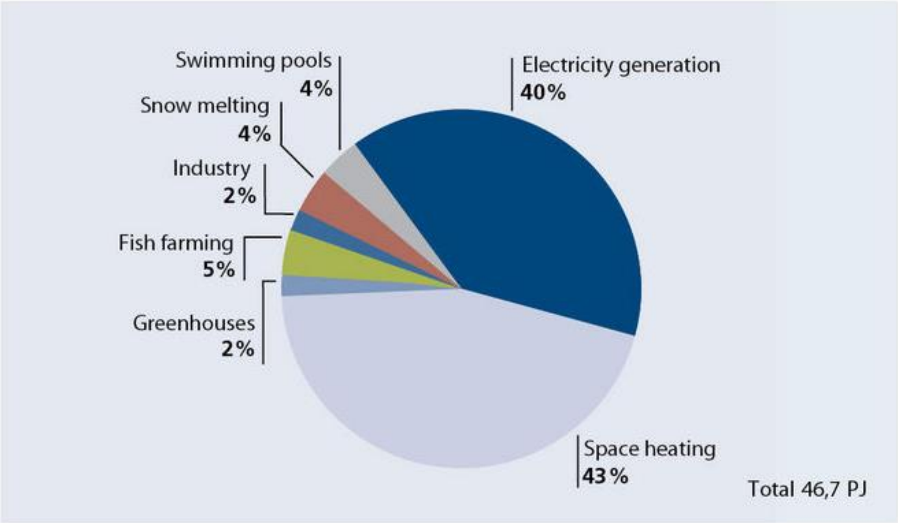
Another prominent user of geothermal energy is Iceland, home to more than 200 volcanoes and 600 hot springs. The small island nation of 360,000 residents holds 5% of the world's installed geothermal capacity and powers 100% of its electricity production with renewable energy, with 73% coming from hydropower and 27% from geothermal power. The country's five geothermal power stations meet more than 90% of the country's heating needs.

Iceland made the political decision to switch from fossil fuel to renewable energy for space heating during the oil crisis of the 1970s, making significant infrastructure investment for its energy security. Aluminum smelters, which require a constant stream of energy, flocked to the island country in the 1990s. Geothermal energy rose to the challenge to meet the explosive demand. Between 1990 and 2014, Iceland's geothermal electricity production increased 17 times, while the population grew only 25%[6].

The National Energy Authority estimates that in 2018 the economic benefits of using geothermal energy instead of oil for space heating was equivalent to 3.5% of

Iceland's GDP. It is now set to become among the first nations to be free of fossil fuels and realize its goals of reducing carbon emissions by 55% by 2030 and achieving carbon neutrality by 2040[7].

Iceland's Utilization of geothermal energy 2013



Source: Iceland National Energy Association, MioTech

II. Geothermal Energy for Direct Use[2]

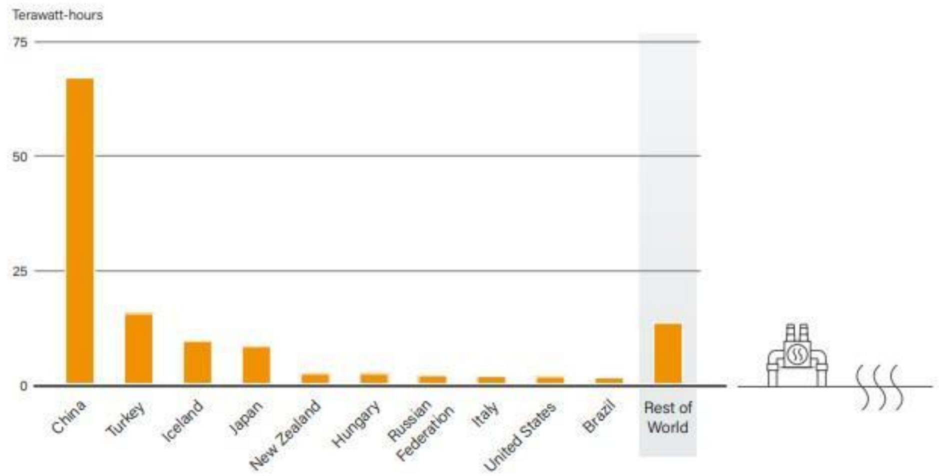
China is both the largest user of geothermal heat (47% of the total) and the fastest growing market, with its installed capacity growing more than 18% annually on average during 2015 through 2019, and consumption growing more than 21% annually on average. That period of growth coincides with the government's first geothermal industry plan, issued in 2017, for rapid expansion of geothermal energy use, especially for heat applications.

As of 2019, China had an estimated 14.2 TWh of installed geothermal capacity for direct use (excluding heat pumps), with 7 TWh allocated to district heating, 5.7 TWh serving bathing and swimming applications, and the rest used for food production and other industries. Most of China's hydrothermal resources are relatively low enthalpy; of the 546 production wells drilled during the period 2015 through 2019, 94% had a wellhead temperature below 100°C.

Other top countries (Turkey, Iceland and Japan) have experienced more moderate capacity growth of around 3-4% annually (consumption growth of 3-5%). In Turkey, geothermal development is devoted mainly to electricity generation, while investment in direct use has contracted somewhat over the last decade. Iceland has significant thermal demand served by district heat networks and continues limited drilling of reinjection and make-up wells for those systems as well as for existing power plants.

In Japan, more than 80% of direct use is believed to be associated with bathing facilities located near geothermal springs, but due to limited data gathering, information is lacking on immediate prospects for further development. The remaining countries that rely on geothermal heat, each representing less than 3% of direct use, include (in descending order) New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil.

Geothermal Direct Use, Estimates for Top 10 Countries and Rest of World, 2020



Source: Renewables 2021 Global Status Report, MioTech

Developing geothermal energy

The cost of geothermal power generation is heavily skewed toward the front-end initial development cost rather than operating cost. Drilling and pipeline construction are the first steps to building a geothermal power plant, followed by the actual design.

The initial cost of site development and plant construction for a geothermal power plant is approximately \$3 - \$5 million per MW installed[8]. Operation and maintenance costs range from \$0.01 to \$0.03 per kWh. Most geothermal power plants can operate at more than 90% availability/utilization (producing more than 90% of the time), though running at 97% or 98% availability increases maintenance costs[8].

Between 2007 and 2019, The levelized cost of electricity (LCOE) of geothermal power ranges from US$0.04/kWh for secondary development on existing sites to US$0.17/kWh for greenfield development in remote areas. According to IRENA's estimates, the global weighted average LCOE rises from about $0.05/kWh for projects commissioned in 2010 to about $0.07/kWh in 2019[3].

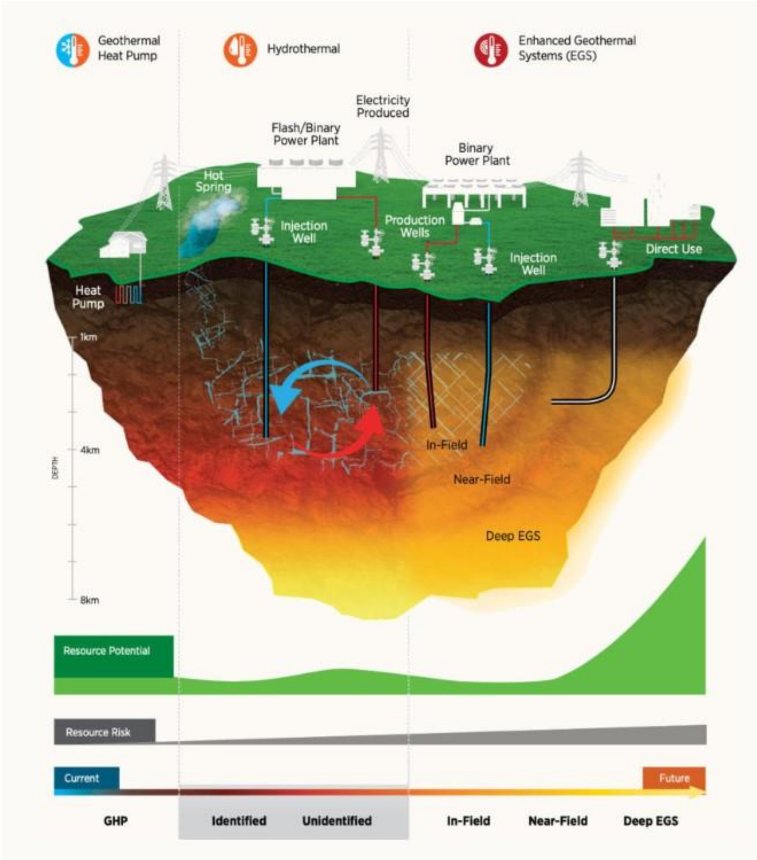
Due to the rapidly declining trend of wind and solar LCOE in recent years, this figure is no longer advantageous among renewables, but this is still significantly better than the LCOE of wind and solar energy paired with energy storage system, which illustrates that geothermal power can provide competitive tariffs as a baseload power source in case high-quality heat source is available.

Technology innovations

The current geothermal energy harvesting technologies are developing at different rates. Technologies for direct utilization of geothermal heat, such as district heating, geothermal heat pumps, are already widely implemented around the world.

Among geothermal power generation technologies, harvesting energy from high temperature (180°C and above) hydrothermal reservoirs has been a reliable and mature technology. Most of the geothermal power stations operating so far have used either dry steam or flash evaporation technology to harvest high-temperature geothermal resources, while binary cycle power generation is the leading geothermal power plant in the future.

An illustration of how various geothermal technologies work

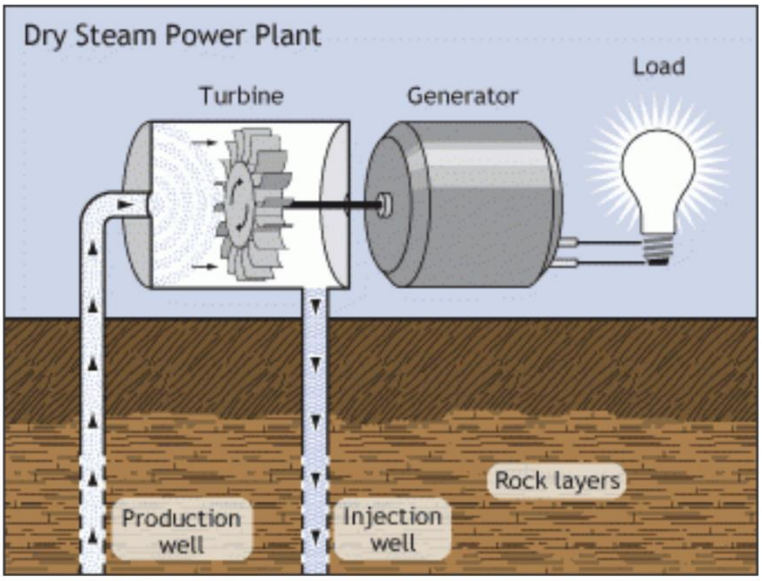


Source: US Department of Energy

★ **Dry steam power generation** is the oldest geothermal power generation technology, which is based on the principle of directly extracting steam from underground fractures to the generators for power generation.

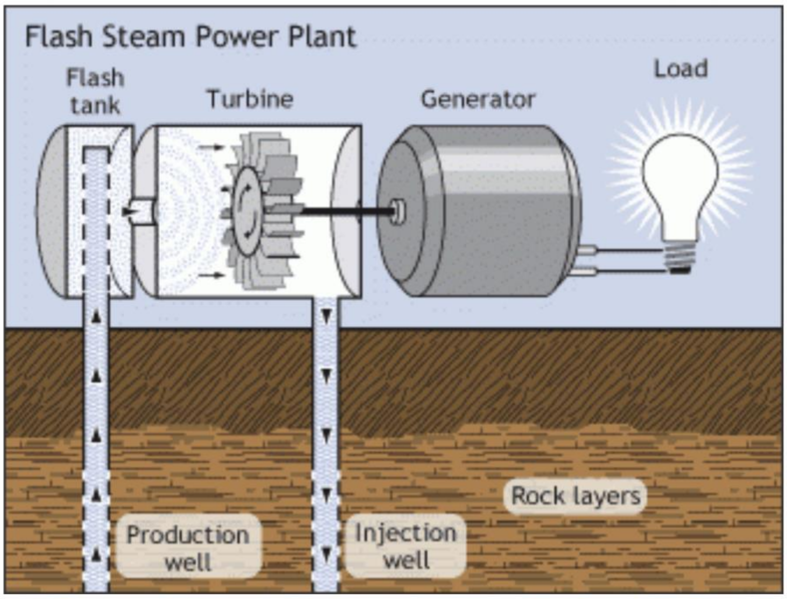
The power generation equipment used in dry steam power plants is basically the same as conventional thermal power plants. The dry steam is drawn from the steam well, passed through a separator to separate out solid impurities, and then enters the turbine to drive the generator to produce electricity.

The world's first geothermal power station used dry steam to generate electricity. The world's first geothermal power plant was built in 1904 in Tuscany, Italy, and all 18 of The Geysers project's geothermal power plants were built using dry steam power generation technology.



Source: Office of Energy Efficiency and Renewable Energy, MioTech

★ **Flash steam power generation** extracts high-pressure hot water from deep, separate water and dry saturated steam by pressure reduction, and then passes the steam through a turbine to drive electricity generation. The steam passing through the turbine condenses into water and is injected back into the deep underground along with the separated water. ***Most geothermal power plants in the world today are flash steam power plants.***

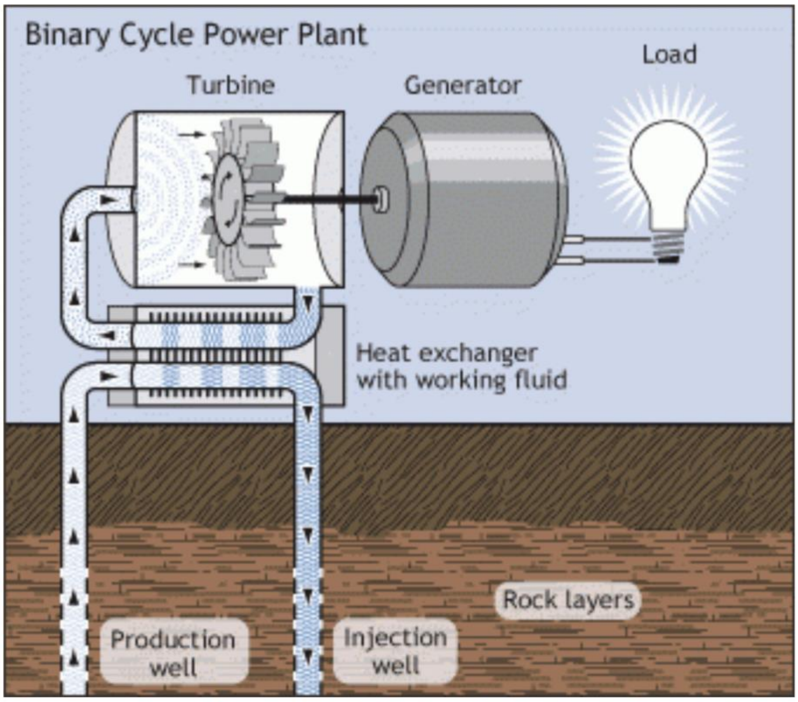


Source: Office of energy efficiency and renewable energy, MioTech

★ **Binary cycle power generation technology** over the past decade has led to the increasing use of medium temperature (90°C - 180°C) geothermal sources.

In a binary cycle power plant, geothermal hot water is passed through a heat exchanger that heats a process fluid with a lower boiling point than water into steam, which then enters a turbine to drive electricity generation. This differs from Dry Steam and Flash Steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units.

Binary cycle power plants are closed-loop systems, and virtually nothing (except water vapor) is emitted to the atmosphere. Because resources below 300°F represent the most common geothermal resource, **a significant proportion of geothermal electricity in the future could come from binary-cycle plants.**



Source: Office of Energy Efficiency and Renewable Energy, MioTech

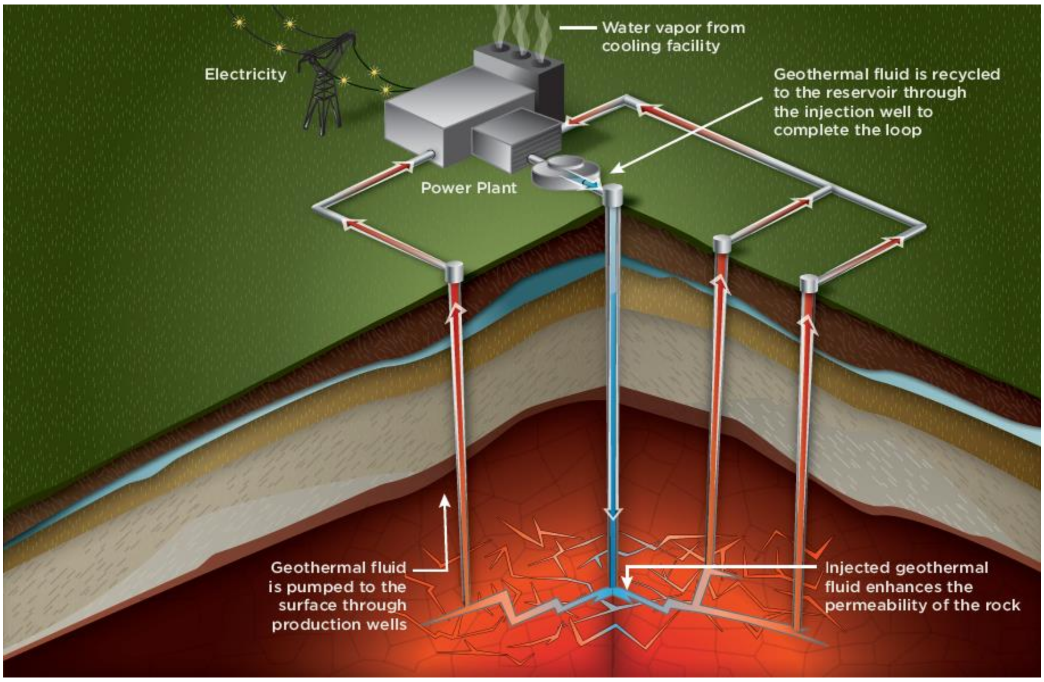
In addition, a few emerging technologies are surfacing that allow sites and heat sources with more complex conditions to be harvested.

★ **Enhanced Geothermal System (EGS):** Thanks especially to the deep-drilling techniques and knowledge about underground formations developed by the oil and gas industry during the fracking boom, a type of geothermal energy called deep geothermal can access hot temperatures in the earth's mantle as far down as two to three miles. At various depths up to this level, much of the planet contains extremely hot water or there is hot rock into which water can be injected and heated, a technology known as enhanced geothermal systems.

Compared with the conventional available geothermal sites, the reservoirs of dry rock systems are largely waterless. This category of otherwise unreachable geothermal resources has a potential capacity of more than 100 GW through EGS development[9].

Currently, experimental EGS power plants have been constructed in the United States, the European Union, South Korea, etc., however have not yet been developed on a commercial scale.

Illustration of a typical EGS system



Source: U.S. Department of Energy

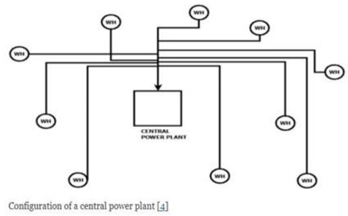
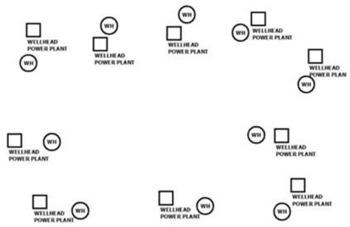
★ **Distributed Wellhead Power Plants:** Another technology under development is distributed wellhead power plants. Conventional geothermal power plants are centralized, i.e., fluids from multiple wellheads are pooled into a centralized power plant to generate electricity, which generally uses a large (>30 MW) turbine as the work drive generator and requires the construction of a long-distance fluid transportation pipeline.

In terms of construction time, for centralized power plants, actual construction needs to wait for the completion of drilling of all thermal wells and logging data before design starts. In addition, **the construction of transportation pipelines also requires a relatively long period, resulting in a long investment development horizon of 5-7 years for the whole power plant.**

The initial capital expenditure for large centralized plants is also high - for example, a 30 MW centralized geothermal power plant requires an initial investment of $90 to $150 million.

Wellhead power plants could be used temporarily to generate electricity from wells that had been drilled and tested to supply electricity for field development and to the grid, hence generating early financial benefits and return on investment ahead of project completion. However, the operation of geothermal wellhead plants is associated with challenges such as noise pollution, emission of gasses like hydrogen sulfide and carbon dioxide, which air pollution, while atmospheric venting of wellheads due to trips or lost load could lead to conflict with the surrounding community due to deposits which could spread to nearby settlements as witnessed in cases like the Eburru wellhead plant in Kenya.

Comparisons between Central vs. Wellhead Power Plants[10]

Configuration of a central power plant	Demonstrates the arrangement of wellhead power plants in a steam field.
	
Nesjavellir power station in Iceland, a central geothermal power plant	A GEG 5-MW C50 wellhead plant at Olkaria in Kenya
	

Source: BMC, MioTech

The implementation of distributed plants is made possible mainly by the screw expander as an alternative to the turbine. Screw expanders are characterized by lower power, typically 50KW-8MW.

The lower power characteristic makes the wellhead model feasible (generally the power of a single wellhead is at the level of several MW). Thus, power plants can be built on one wellhead with modular installation. If profitable, subsequent distributed plant development can be done with sustainable cash flow from operating well, which effectively reduces development risks and initial capital expenditure[11].

Overlapping development with waste heat recovery: It is worth mentioning that, in terms of technical principles and engineering processes, **harvesting medium and high temperature geothermal energy is quite similar to the utilization of waste heat in industrial and building sectors.** These waste heat resources from factories and office buildings also usually exist in the form of high-temperature water and steam. The overlapping needs from the two markets could potentially drive faster development of the technology.

Industry Players from Japan, the US and China

In the field of high-temperature geothermal equipment, turbine manufacturers gain the upper hand, among which Japanese manufacturers dominate the share, including **Mitsubishi Heavy Industries (7011.T), Toshiba (6502.T), and Fuji Electric (6504.T).** In China, **Harbin Electric (01133.HK) and Dongfang Electric (600875.SH)** provide similar products to their domestic clients. It is worth mentioning that the turbine itself has many applications and has a very large market, reaching US$ 20bn annual sales globally.

In terms of **binary cycle power generation technology, Ormat (ORA)** from the U.S. is the absolute leader. Originally established in Israel in 1965, Ormat has built more than 190 geothermal power plants so far, with a total installed capacity of more than 3,200MW, accounting for **more than 70% of the market share. Atlas Copco (Sweden), Turboden (Italy) and Exergy (Italy, subsidiary of Tica Group of China since 2019)** are also players in the binary cycle power generation.

Kaishan Group Co (300257.SZ) is a strong Chinese competitor in the field of binary cycle power generation technology. The company's proprietary screw expander is world-leading in mechanical performance, which helps the company's business venture into the development of distributed wellhead power plants. According to public disclosure, Kaishan currently has 50MW of geothermal projects in operation and a reserved capacity of 540MW.

Startups enter into Geothermal Energy

The technology in the field of **enhanced geothermal systems (EGS)** is still in the early stage of development, so the representative companies in this field are mainly **start-ups, including Fervo, AltaRock. Ormat is also one of the companies actively promoting the development of EGS.**

US-based **Fervo Energy** takes inspiration from the oil and gas industry, applying horizontal drilling and distributed fiber optic sensing in a novel way in geothermal reservoirs. **Quaise Energy** develops drilling technology using fusion power. The MIT spinoff achieves drilling down to 20 kilometers deep under the surface.

Some of them are closer to commercialization. **Canadian startup Eavor** develops a closed-loop system which is more deployable and flexible than traditional technologies. The company is scaling its demonstration facility in Alberta to a commercial scale plant. **AltaRock, another U.S.-based startup**, focuses on the development of scalable EGS technology, and is initiating the development of First EGS plant in Oregon, U.S.

Top 8 Energy Startups[12]

1. Dandelion Energy

   Dandelion is an Alphabet spinout that develops geothermal heating, air-conditioning and cooling systems

   The #1 Geothermal Installer in the Northeast: The Dandelion Energy home geothermal system replaces your home's existing air conditioning and heating equipment with a powerful heat pump and safe, underground pipes that move heat between the earth and your home.

2. Eavor

Eavor's solution, Eavor-Loop, takes a traditional niche energy source (geothermal) and makes it scalable by removing the need for either volcanic-type temperature or permeable aquifers.

Eavor is a geothermal technology-based energy company led by a team dedicated to creating a clean, reliable and affordable energy future on a global scale. Eavor's technology consists of several Patent Pending innovations. The Eavor-Loop is a closed system within which a proprietary working fluid is contained and circulated.

3. Quaise

   Quaise is an energy company pioneering millimeter wave drilling technology to access deep geothermal energy.

   Quaise is developing and commercializing novel millimeter wave drilling systems to harness geothermal energy around the globe, overcoming the geographic constraints limiting this energy source today. Quaise's technology enables the clean energy transition by accessing the largest source of power-dense clean energy on Earth.

4. Fervo Energy

   Fervo Energy commercializes proprietary technology to own, develop, and operate geothermal assets as the dispatchable foundation to a 100% clean energy future

   Fervo's innovations include technologies such as advanced computational models, horizontal drilling, and distributed fiber optic sensing that the company has developed with partners including Schlumberger, ARPA-E, and the Lawrence Berkeley National Lab.

5. AltaRock Energy

   AltaRock Energy focuses on the development of geothermal energy resources and Enhanced Geothermal Systems (EGS)

   Over the past decade, AltaRock has developed innovative engineered geothermal systems (EGS) technologies critical to advancing SHR development. Working with partners in advanced drilling, well completion, reservoir engineering and power conversion, the company aims to revolutionize geothermal power.

6. GreenFire Energy

GreenFire Energy develops and deploys innovative technology to unlock the world's largest source of continuous renewable energy

GreenFire Energy develops and implements innovative geothermal technology to accelerate the world's transition to clean, continuous renewable energy. GreenFire'sGreenLoop™ is closed-loop technology that extracts and transports heat from deep in the earth to be used for power generation. GreenFire Energy delivers fast, low-cost, and high ROI geothermal retrofit, expansion, and greenfield projects.

7. Loki Geothermal

Loki Geothermal specializes in the production and service of geothermal equipment and is currently developing wellhead valves for high-temperature geothermal wells. The company's main objective is to develop equipment that is more reliable and easier to use than equipment that is currently available on the market.

Loki Geothermal was founded in 2014. The company is currently developing expanding gate valves for high temperature geothermal wells. The valves are specifically designed to operate under severe conditions, including wellhead temperatures above 250°C and corrosive media, e.g., hydrogen sulfide and silica scaling. The founders have extensive experience in the geothermal sector - ranging from engineering and operation to finance and business development.

8. Sage Geosystems

Sage combines innovative approaches to heat harvesting with modern oilfield expertise and methodologies to enable geothermal energy anywhere in the world.

Sage is a rapidly growing business dedicated to the advancement and widespread deployment of geothermal technologies. Founded in 2020, Sage brings innovative geothermal technology and a team with a proven track record of action and delivery. This tool, GeoTwin™, is based on decades of experience modeling subsurface fluids and processes in the drilling of oil and gas wells and will allow Sage to rapidly target surface and subsurface designs and combinations thereof to optimize the power generated from the geothermal systems and their cost.

Riding on the Net Zero Future

As the global campaign for Net Zero is in full scale with mandated renewable energy targets in many locales, interest in geothermal energy is growing rapidly. It is an essential component of the world's green-energy future as it provides carbon-free heat and around-the-clock baseload power to compensate for the intermittency of wind and solar[13].

Because of the high initial development costs of accessing deep geothermal energy, government support is generally seen as a necessary ingredient for the success. **Geothermal output in Europe could increase eight-fold by 2050** by IRENA estimate and geothermal energy could **generating electricity could increase 26-fold by 2050, providing 8.5 percent of the United States' electricity, as well as direct heat.** It is destined to play a larger role, coupled with other renewable technologies on the path to a net zero future[13].

Table 1 Valuation table of selected companies

	Code	Stock Price	Mkt Cap	P/E(x)		EPS Growth (%)		Net debt-equity (%)		Dividend Yield (%)		ROE (%)		Abs Perf (%)		
			USD m	23E	24E	23E	24E	23E	24E	23E	24E	23E	24E	1W	1M	YTD
Toshiba Corp	6502.T	5428.00	18,109	13.4	12.6	16.3	11.7	16.0	20.8	1.7	2.0	14.2	13.5	2.8	(10.8)	(18.5
Mitsubishi Heavy Industries Ltd	7011.T	4437.00	11,530	12.2	10.9	15.8	6.0	47.3	38.4	2.5	2.7	8.2	8.6	4.4	(15.0)	(27.9
Fuji Electric Co Ltd	6504.T	5660.00	6,509	14.2	13.0	2.2	9.9	16.9	13.1	1.9	2.1	11.7	11.7	3.0	(4.5)	(12.3
Dongfang Electric Corp Ltd	600875.SH	12.86	5,781	12.5	12.7	66.7	17.8	(75.1)	(106.9)	2.1	2.3	10.0	8.2	(2.0)	3.2	(7.4)
Ormat Technologies Inc	ORA	79.10	4,436	41.1	33.1	17.2	-1.6	105.3	97.6	0.7	0.7	9.8	5.6	2.0	4.1	(10.6
Kaishan Group Co Ltd	300257.SZ	13.65	2,053	18.6	n.a	48.6	26.1	n.a	n.a	n.a	n.a	13.3	0.0	2.8	6.9	7.8
Harbin Electric Co Ltd	1133.HK	2.04	444	12.3	10.4	55.3	0.0	n.a	n.a	1.2	1.5	1.9	2.2	(6.2)	13.8	12.6

Source: Refinitiv Eikon, MioTech Research, as of 05/06/2022

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