WHITEPAPER

Geothermal Energy
Clean energy from deep inside the Earth

Geothermal energy is a sustainable, renewable resource that can play a useful role in the transition from fossil fuels to a low or zero carbon future. It has a major advantage over renewables like wind and solar in that it is not intermittent. As a reliable and consistent source of power, it can meet demands for continuous baseload electricity.

Geothermal energy can be harnessed to generate electricity, and it can be utilized directly as a source of heating. It has been estimated that by 2050 geothermal could potentially meet 3-5% of overall global demand for power and heating. This paper focuses on geothermal power and the technologies required to produce electricity from the Earth's internal heat.

Origins of geothermal energy

Geothermal energy is thermal energy (i.e. heat) within the Earth. Some of this internal heat originates from friction and gravitational pull created when the planet was formed more than four billion years ago, but the majority is generated by the decay of naturally occurring radioactive isotopes[01].

Radioactive decay is a continual process in the Earth's core, which is the hottest part of the planet. The upper bound of the core is located around 2,900 km below the surface, and at this point the temperature is estimated to be in the range 2,700 to 4,000°C.

Heat from the core radiates outwards, towards the surface. When rocks are heated to temperatures around 700-1,300°C, they can become partly melted, taking the form of magma. Magma that makes its way to the surface can be ejected from volcanos as lava. Magma can heat rocks and underground aquifers (layers of rock, gravel, sand or silt where groundwater can gather), causing hot water to be released at the surface through geysers, hot springs and steam vents.

While these phenomena can be observed on the Earth's surface, most geothermal energy remains deep underground. It collects in pockets in the Earth's mantle, which is the layer between the crust and core.

The most favorable locations for utilizing geothermal energy are the geothermal hotspots – regions where high temperatures are found at relatively shallow depths. Depth is important because drilling is expensive and typically accounts for around half the total cost of a power generating facility. These regions – such as the "Ring of Fire" around the Pacific Ocean – are typically associated with volcanic and seismic activity.

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01 https://education.nationalgeographic.org/resource/geothermal-energy

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Geothermal hotspots where higher temperatures are relatively near to the Earth's surface

Current utilization and expected growth

Geothermal power currently has a low share in the overall energy mix. The relative share is highest in the Asia Pacific region, while the largest numbers of geothermal power stations are located in North America and Southern Europe.

Asia Pacific
Europe
Middle East and Africa
North America
South and Central America

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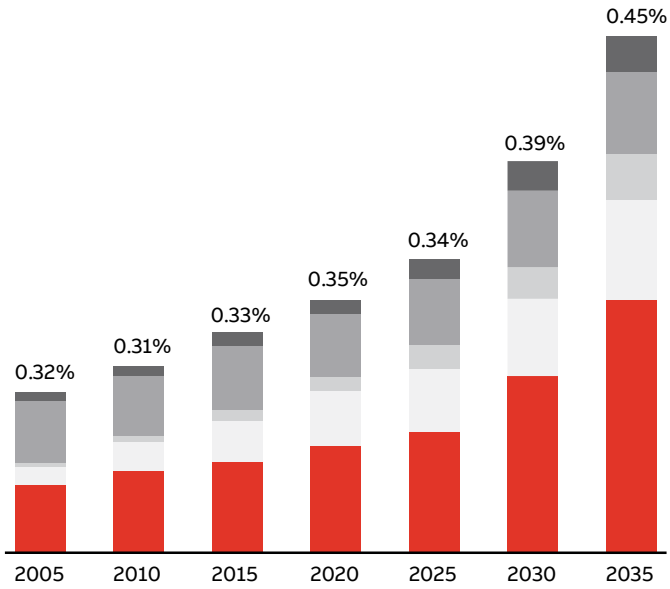
Global geothermal generation and % within the global mix



A total of 26 countries presently generate power from geothermal sources. Countries where geothermal power accounts for more than 15% of the total include Costa Rica, El Salvador, Iceland, Kenya, New Zealand and the Philippines. Indonesia is considered to be the country with the world's foremost geothermal resources. At the moment it is using less than 5% of its overall potential, but is increasing capacity rapidly.

Global geothermal power capacity amounted to 14.2 GW in 2019, of which 2.6 GW or 18.3% was located in the U.S. By 2021 capacity had increased to 16 GW and geothermal plants generated a total of 96.7 TWh of electricity. The expected annual growth rate in capacity is 7% up to 2030. Based on the IEA's Net Zero Scenario, the growth rate should be double this figure, and capacity should reach 98 GW by 2030 and 126 GW by 2050[02].

It is estimated that only around 7% of the total global potential for geothermal power is being used at the moment, providing plenty of scope to increase utilization.

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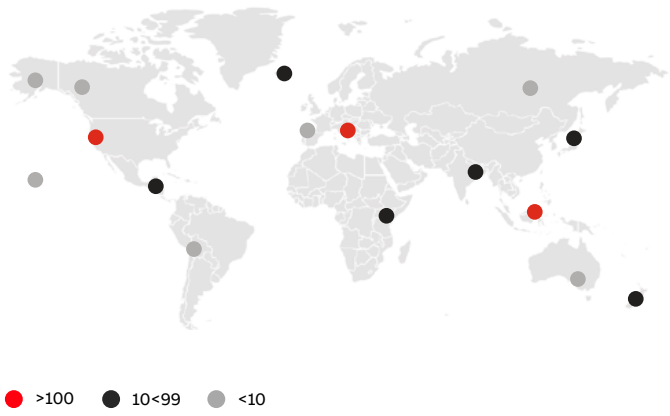
Geothermal power plants worldwide



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IEA, International Energy Agency, www.iea.org

Geothermal power plants

Geothermal power plants utilize heat that is found a number of kilometers below the Earth's surface. In some cases this heat takes the form of steam or hot water, and can be utilized directly. In most cases, however, water is injected, i.e. pumped down, into the heat pocket to produce steam. This process is known as 'enhancing'.

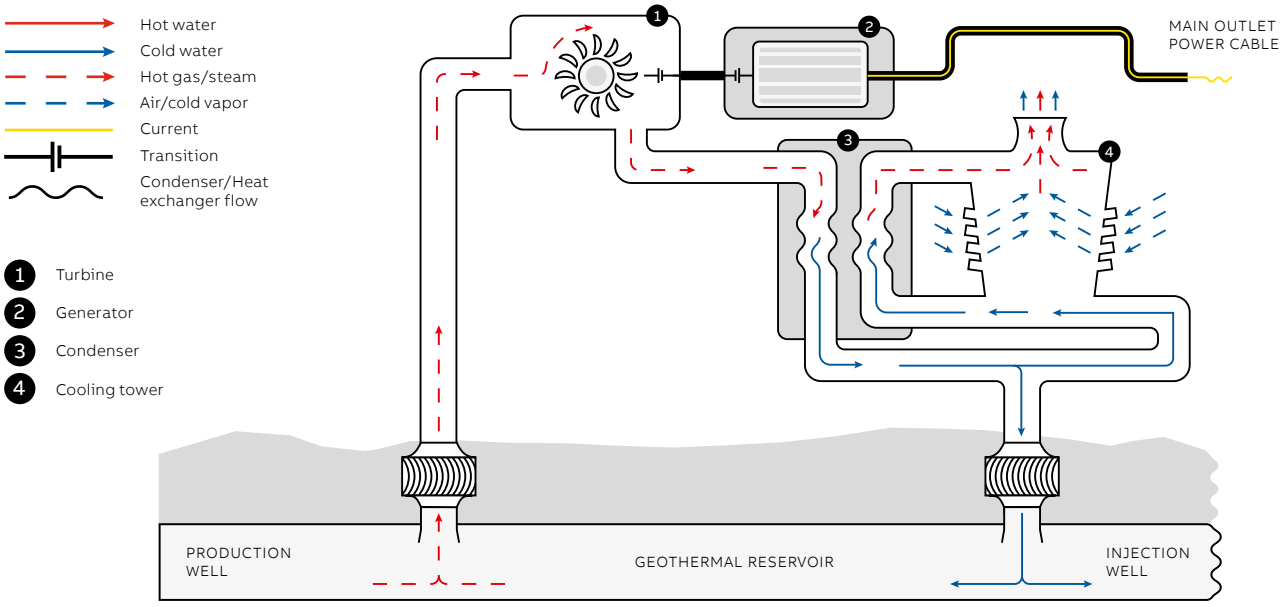
Geothermal resources are generally classified as low or high temperature, based on the temperature of the fluid that is utilized. High temperature resources are those with a fluid temperature over 150°C.

Four types of geothermal power plant are currently in commercial use: dry steam, flash, binary and flash/binary combined[03].

— 03 IRENA, International Renewable Energy Agency, Geothermal Power: Technology Brief

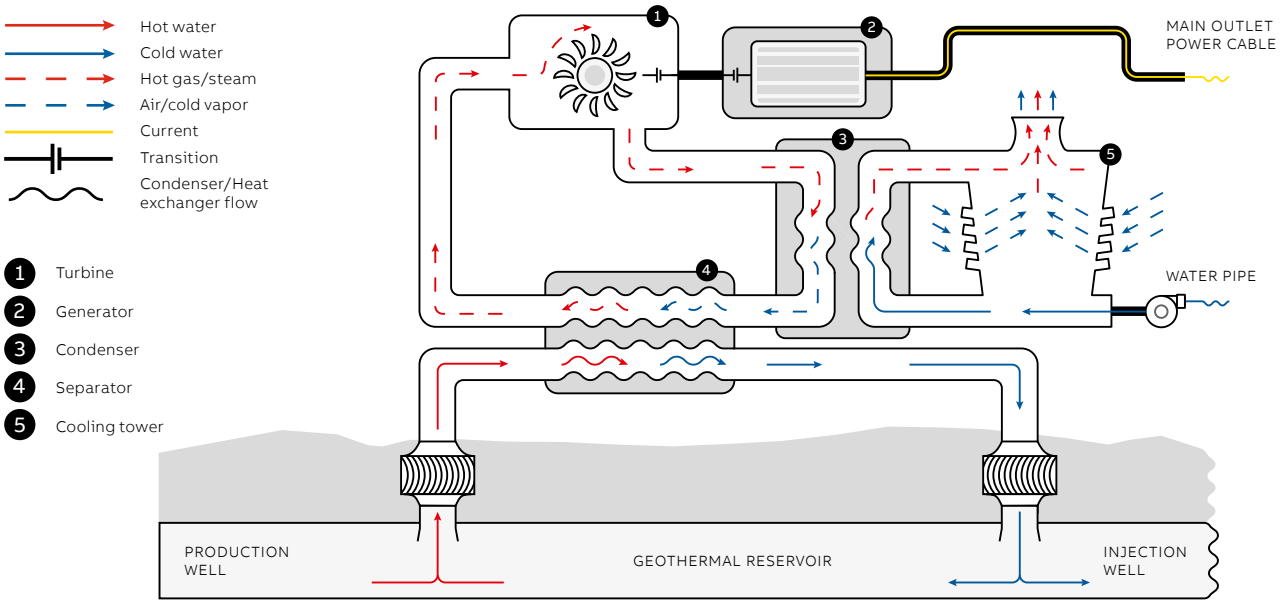
Dry steam power plant

The dry steam process is straightforward and efficient. However, it represents the oldest type of geothermal power plant and few remain in use today. Steam at a temperature of 150°C or higher is brought to the surface directly from the geothermal reservoir and passed through the turbine to power the generator. The steam is then fed into a condenser where it turns into water. It is subsequently injected back into the geothermal reservoir where it is reheated to produce more steam.



Flash steam power plant

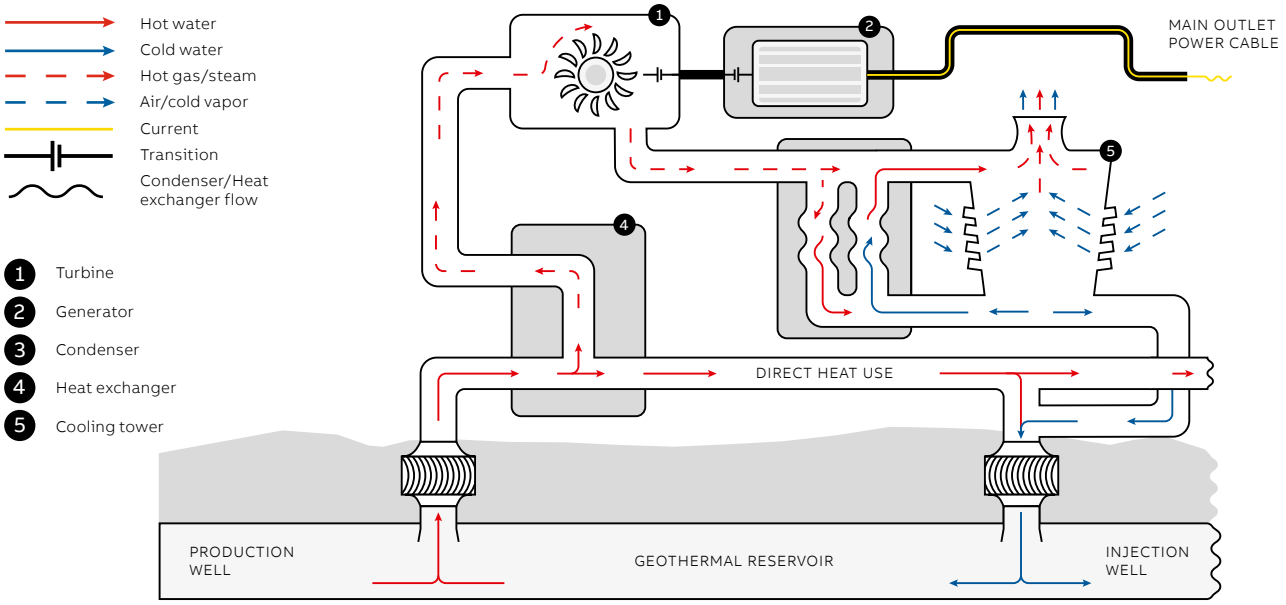
Water at high pressure and a temperature of at least 180°C flows under its own pressure into a separator vessel. The drop in pressure causes some of it to 'flash' to steam, which separates from the water and powers the turbine. The remaining water and condensed steam are cooled and injected back into the geothermal reservoir.



Binary cycle power plant

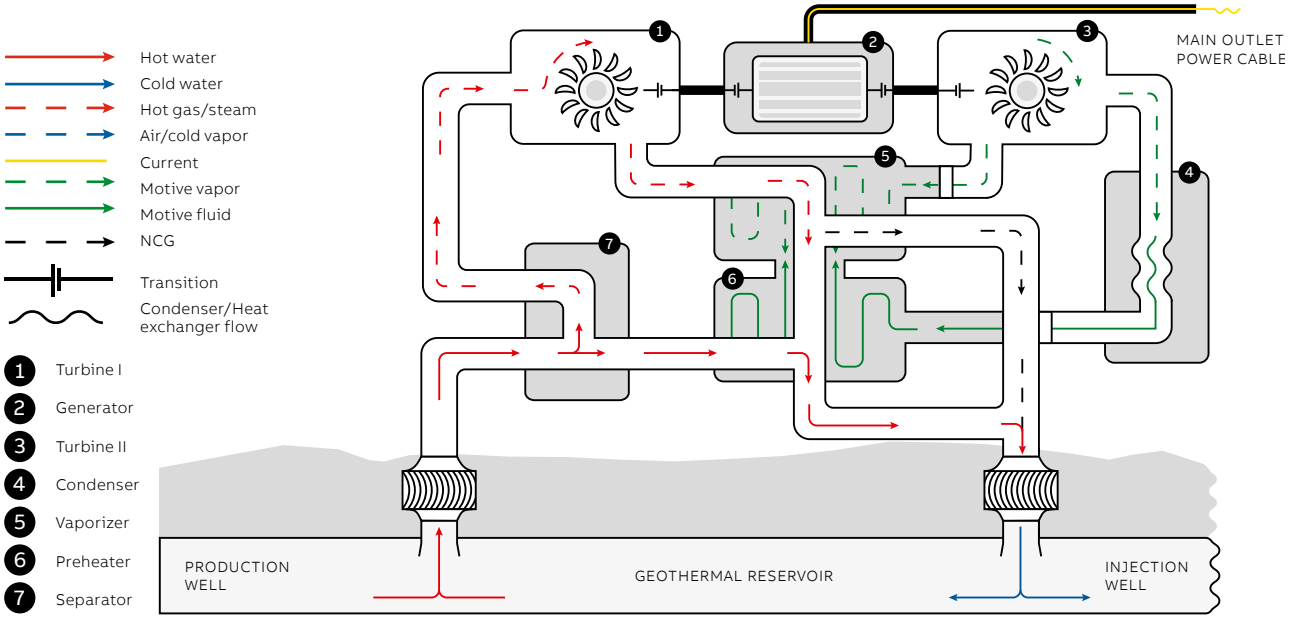
Binary cycle plants offer the major advantage of being able to generate power using low temperature fluids, down to as low as 57°C. Hot water from the geothermal reservoir is pumped through a heat exchanger, with the cooled water being injected back into the reservoir.

In the heat exchanger heat from the water transfers to a secondary or working fluid such as isobutane, which has a lower boiling point than water. This working fluid expands into a gaseous vapor, and the resulting force drives the turbine. The vapor then returns to liquid form in a condenser and passes to the heat exchanger to begin its next circuit.



Flash/binary combined cycle power plant

Water at high pressure and high temperature from the geothermal well is fed into a separator, where lower pressure causes some of it to flash to steam. The steam drives the plant's level I turbine. The remaining water passes to a preheater where it heats the secondary working fluid in a binary system. The working fluid then enters a vaporizer where it is further heated by the steam leaving the level I turbine. The vaporized working fluid drives the level II turbine.



Advantages of geothermal power

Geothermal energy is truly renewable: heat continuously radiates out from the Earth's core, and is expected to continue doing so for billions of years. By contrast, fossil fuels like coal, oil and natural gas are finite resources which are depleting and will eventually be exhausted.

Provided that geothermal reservoirs are managed effectively, maintaining a balance between the amount of energy taken out and the rate at which the heat in the rock is renewed, geothermal power plants can continue to produce for many years. They also generate consistently and can deliver baseload power.

Geothermal plants have a high capacity factor, which is a measure of how much electrical power is produced relative to how much could be generated at peak capacity. In terms of global production, geothermal has a mean capacity factor of 0.74, which compares favorably with other renewables. The figure for biomass is 0.55, hydro 0.43 and solar 0.11. The equivalent figure for nuclear is 0.79, and for fossil fuels 0.46[04].

Geothermal power is highly scalable, and the facilities require relatively little space compared to other types of power plant. The table shows the footprint in square kilometers required to produce 1 GWh of electricity from different energy sources.

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Space required to generate 1 GWh from different energy sources

Type of plant	Space requirement Km2 / GWh
Geothermal	1,046
Wind	3,458
Solar PV	8,384
Coal	9,433

At the same time it should be noted that geothermal power has certain drawbacks, including the high initial investment necessary to establish generating plants. This is a significant barrier to wider adoption of geothermal power.

The process of injecting water at high pressure into the Earth to en hance geothermal sources is not without risk. In some areas seismic activity has been reported as a result of these operations.

Geothermal power generation is generally clean, and the only emission is water vapor. However, in some cases geothermal systems can emit small amounts of the greenhouse gases hydrogen sulfide and carbon dioxide, as well as very small amounts of sulfur dioxide, nitrous oxides, and particulates. There is also a risk that water flowing through underground reservoirs can become contaminated with trace amounts of elements such as arsenic, mercury, and selenium. If the geothermal system is not isolated effectively, these elements can leak into water sources.

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N Bolson, P Prieto and T Patzek. Proceedings of the National Academy of Sciences (USA), Vol. 119 No. 52, December 2022, Capacity factors for electrical power generation from renewable and nonrenewable sources. https://www.pnas.org/doi/10.1073/pnas.2205429119

Equipment for geothermal power plants

ABB is an established supplier of equipment for power generation. It has an installed base of approximately 500 MVA in generators at geothermal plants, and has shipped more than 50,000 MVA in turbine generators overall. Its portfolio of large motors and generators covers the geothermal value chain.

Motors

Typical motor driven applications include condensate, hotwell, re-injection and cooling water circulation pumps, cooling tower fans and gas rejection compressors.

- Induction – robust, reliable solutions for high power density, efficiency and optimal performance. Built-in flexibility enables the motors to be configured to match the plant's specific needs.
- Permanent magnet – for premium efficiency. Can be combined with a VSD or used in a direct drive configuration to maximize system efficiency.

Generators

- Synchronous 4-pole steam turbine generators. High voltage versions up to 70 MVA.

Products can be tailored to match the customer's needs. In the case of generators, for example, the entire package can be customized around the specific application. In addition to the generator itself, ABB can provide the cooling system, main terminal box, maintenance tools and control equipment. System monitoring and protection solutions are also available, as well as special support to ensure grid code compliance. Local support is available with fast response times from 60 service centers and more than 150 authorized service providers around the world. ABB motors and generators comply with all relevant standards, including IEC, NEMA and ISO.

In addition to large motors and generators, ABB's portfolio for geothermal power generation includes variable speed drives and low voltage motors, as well as complete turnkey instrumentation, control, electrical and optimization solutions.

Equipment efficiency and reliability

The electrical and mechanical features of ABB motors and generators are optimized for efficiency and reliability, which helps to ensure they have a long lifetime and low total cost of ownership.

Efficient equipment is key to maximizing the power generated from the geothermal resource. High efficiency means lower losses, lower operating costs and greater power output from the same resource. Even a small increase in efficiency can make a big difference in terms of profitability. As geothermal plants replace fossil fuel generation, efficient motors and generators also help to reduce CO_2 emissions.

The robust design of ABB motors and generators ensures reliable operation over a long lifetime.

Reliability is enhanced by cool operating temperatures and low vibration. High reliability reduces unexpected plant downtime and therefore boosts productivity.

For geothermal plants where motors and generators operate in areas with the presence of hydrogen sulfide gas, ABB can supply special anti-corrosion protection. It is important to protect all metal parts, either with proper painting or coating, or by tinning or other means. Active parts can be further protected by pressurizing the enclosure to prevent hydrogen sulfide from entering. The measures required for a particular plant depend on site-specific conditions, and ABB works with the customer to ensure the equipment will operate reliably over a long lifetime.

Case: Kaishan Group, geothermal power generation in Indonesia

ABB is helping Kaishan Group to produce geothermal power in Indonesia. Kaishan is a diversified engineering company based in China and has developed innovative modular geothermal power stations. It is strongly committed to energy saving and sustainable development.

Kaishan has built two geothermal power plants in Indonesia. The Sorik Marapi project in Sumatra has a capacity of 240 MW, while the Sokoria project in East Nusa has a capacity of 30 MW. ABB has supplied two synchronous steam turbine generators rated at 12 MVA for Kaishan's plants. The specification required an efficiency level of 97% and this was surpassed in type testing, where the actual efficiency level was shown to be 98.37%.

With their high efficiency, the two generators will together reduce annual carbon dioxide emissions by around 1,310 tonnes, which is equivalent to the emissions produced in generating the power for 255 homes for a year.

Conclusion

Geothermal energy is clean and renewable, and it will be available for billions of years. It can produce baseload electricity and is an excellent complement to intermittent renewables like wind and solar. Geothermal is set to make a useful contribution to the world's efforts to boost sustainability while cutting emissions of greenhouse gases.

New technologies for generating electricity from geothermal energy have been developed over the years, with four types of power plant currently in commercial use. As the newer technologies enable utilization of lower temperature heat sources, more and more locations around the world can take advantage of their geothermal resources.

The relatively high initial investment required to establish a geothermal plant underlines the importance of efficient and reliable equipment to maximize productivity while reducing operating costs. Downtime is further reduced by sourcing equipment from dependable suppliers with a solid track record who can deliver support over the entire life cycle.

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new.abb.com/motors-generators