GEOTHERMAL:
THE SOLUTION UNDERNEATH

The value of Geothermal for a Clean Energy Transition

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About the Global Geothermal Alliance (GGA)

The GGA is a multi-stakeholder platform for dialogue, co-operation and co-ordinated action to foster geothermal development globally. It was established in 2015 at COP21 in Paris as a coalition for action bringing together geothermal industry, policy makers and other stakeholders worldwide to increase the deployment and use of geothermal energy.

www.globalgeothermalalliance.org

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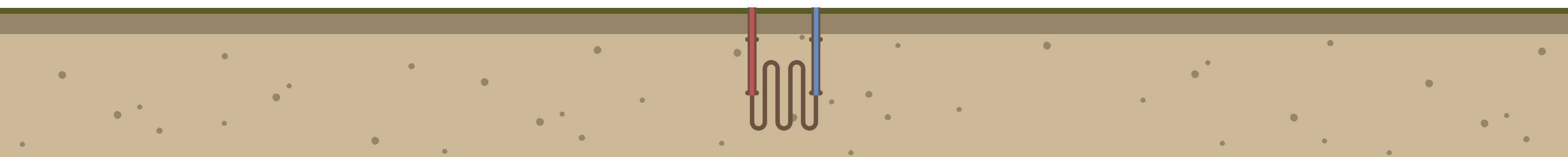

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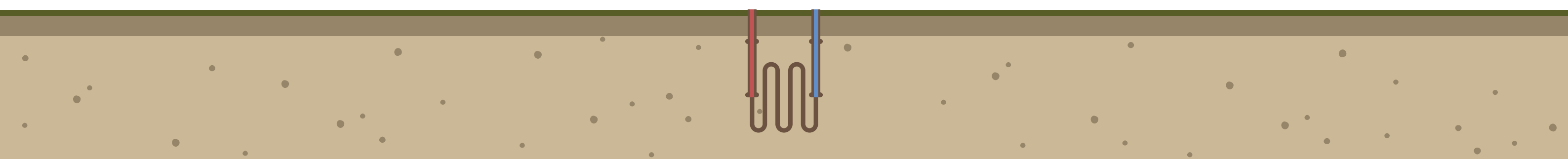


Introduction

Geothermal energy is heat derived within the interior of the Earth. Water and/or steam carry the geothermal energy to the Earth's surface. Depending on its characteristics, geothermal energy can be used for heating and cooling purposes or be harnessed to generate clean electricity.

The most common geothermal resources exist as hot fluids circulating in the permeable layers of Earth's crust where they are heated by the surrounding hot rocks. These resources are referred to as hydrothermal resources and are characterised as high, medium and low temperature resources. High and medium temperature resources have potential to generate electricity and are usually located close to regions with volcanic or tectonic activity. Medium and low temperature resources can be used for heating and cooling purposes, in industrial processes that require heat, and other applications as greenhouses.

As previously mentioned, geothermal is found mainly in active volcanic areas like Iceland, Western United States of America, Indonesia, East Africa, etc., and can be accessed by drilling down to 2-3 km to generate electricity. In the sedimentary basins, like in Germany, Netherlands and Hungary, etc., good quality geothermal reservoirs can be found, and the energy harnessed by drilling deeper down to around 3-5 km. Research is ongoing to extract energy from hot dry rocks where natural geothermal reservoir are non-existent for instance in parts of France and South Korea due to lack of rock permeability. Furthermore, shallow ground geothermal resources (usually <400m), are being explored worldwide mainly for space heating, including with the help of heat pumps.

In that context, this document highlights the main characteristics and benefits of geothermal energy, aiming to position it as an excellent alternative in the energy transition to cleaner sources and climate action to mitigate global warming.

Volcanic eruption - Iceland.

Image credit: Flickr

A clean and abundant energy source

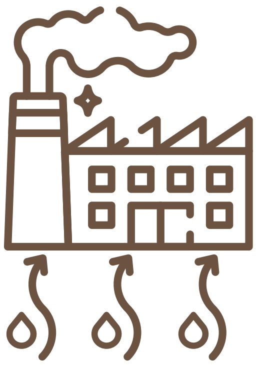
Humans have long used the small fraction of heat from the Earth's interior that rises to the surface through geothermal manifestations, primarily for heating and cooling in buildings and for leisure activities. The first time this energy was used for electricity generation was in 1904 in Larderello, Italy. Ever since, geothermal energy has been improving in efficiency, and there are now more than 15.4 gigawatts (GW) of installed geothermal power plants globally, while it is estimated that there is global technical potential as high as 200 GW of geothermal electric power from hydrothermal systems (IPCC, 2012). The economic potential of exploiting hydrothermal systems for electricity generation using existing technologies is estimated at 70 GW by 2050 (Bertani, 2010). In comparison, geothermal heating and cooling installations, including heating and cooling of buildings, as well as bathing, swimming, industrial and agricultural applications, have grown to 107 GWt. The technical potential for geothermal heating is estimated at 5 000 GWt globally.

Geothermal technology can produce clean, baseload and flexible power generation, making it a promising option for the transition to clean energy and a more sustainable economic model. In addition to power generation, geothermal energy has multiple applications as a heat source or sink in end-use sectors such as building, agri-food and industry. New technologies currently being tested, such as enhanced geothermal systems, and the development of closed-loop systems are poised to cause a breakthrough in geothermal energy development, which may become key to achieving a low-carbon economy. To achieve this, the support of the public sector will be necessary to create a conducive financial and regulatory environment for geothermal energy.

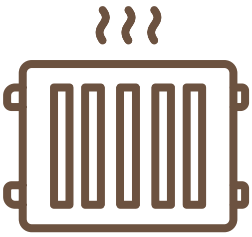
Estimates show that geothermal energy can supply about 8.3% of the total electricity needs of the world and serve about 17% of the global population (IPCC, 2007)

Geothermal energy resource are widespread around the world and can be utilised for both electricity generation and heating-cooling applications to support the global decarbonisation agenda.

Geothermal energy has the key to supply about 8.3% of the total electricity needs of the world and serve about 17% of the global population.



Total installed capacity of 15.4 GW and global technical potential of 200GW of electricity from hydrothermal systems.



Global technical potential of 5 000 GWt for geothermal heat applications.

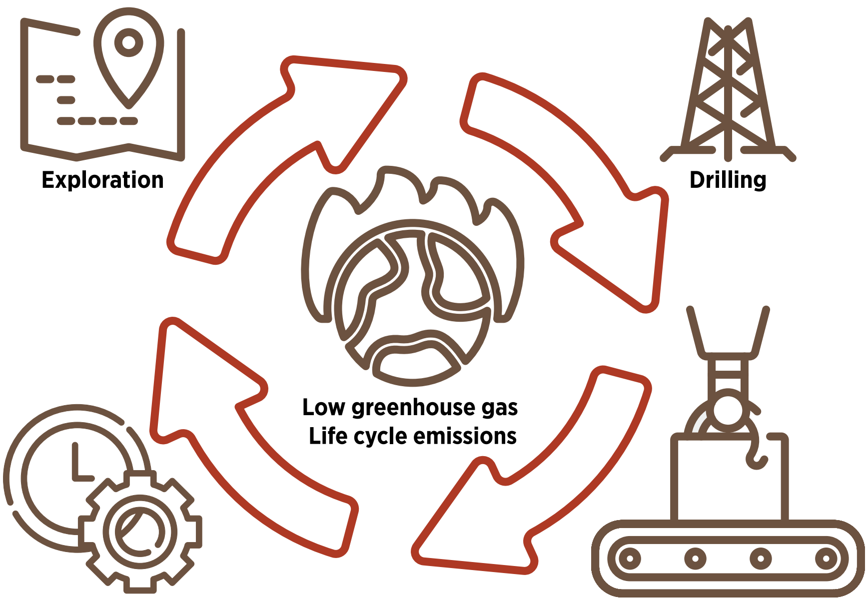
The annual utilisation of geothermal heat was 1 020 887 terajoules (TJ) in 2020, an increase of about 72% compared with 2015; installed capacity for heating reached 107 GWt (from 70 GWt) during the same period (Lund and Toth, 2020).

A sustainable energy option

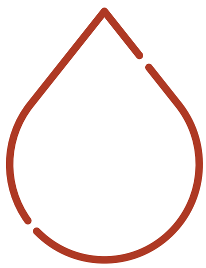
The main geothermal electricity generation technologies are dry steam power plants, flash power plants and binary power plants. Geothermal power plants do not rely on burning fuels but instead directly harness the energy stored underground. As such, geothermal power plants produce negligible emissions related to greenhouse gases during their operation. In fact, binary power plants have the potential to generate electricity with zero emissions in the case of 100% reinjection, making this technology completely emission-free. Moreover, if full life cycle emissions are calculated, it is estimated that a geothermal binary power plant is one of the most favourable technologies, with 11.3 grammes (g) of carbon dioxide equivalent (CO_2eq) per kilowatt hour (kWh) (NREL, 2017).

Geothermal plants use underground water for their operation, later reinjecting it to maintain the pressure and sustainability of the resource. These high-temperature aquifers can be more than 2 000 metres (m) deep and are therefore not used for human consumption or irrigation activities because they may contain high concentration of dissolved minerals. With adequately designed geothermal wells and good reinjection practices, geothermal fluids can be used without causing contamination of the environment or underground drinking water resources. The average life cycle use of water by a binary geothermal plant is 0.66 litres (L)/kWh, while the land occupancy of a geothermal power plant averages approximately 7.5 square kilometres (km²) per terawatt hour(TWh) (McDonnald *et al.*, 2009).

Geothermal energy production generates negligible emissions and requires low water use and low land occupancy, while mitigating the effects of climate change.



The land occupancy of a geothermal power plant averages **7.5 km²/TWh.**



The full life cycle water usage of a binary power plant is **0.66 L/kWh.**

A reliable, flexible and resilient energy supply

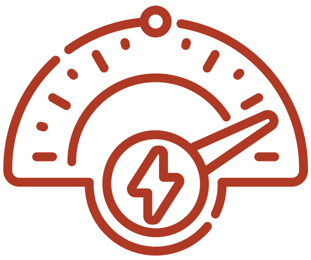
Geothermal generation provides negligible emissions and a reliable and continuous supply of energy for electricity and heating–cooling. In a diverse energy matrix like the one in Nevada, United States of America, geothermal power plants provide baseload power, and in 2019, an average annual capacity factor[1] above 80% was achieved (EIA, 2019). With good reservoir management practices, this capacity factor could be above 90% in smaller systems, as the main limitation for operation is scheduled maintenance activities, since geothermal energy is not affected by vagaries of weather. As such, geothermal plants can provide, in electricity systems, firm baseload generation and reliable reserves that are also not exposed to price volatility like fossil fuels.

Another key feature of geothermal plants is their ability to provide flexibility and other ancillary services to electricity systems, facilitating the integration of intermittent power such as solar or wind. When the electricity generated from intermittent sources varies through the day due to changes in weather, geothermal plants can ramp up and down multiple times a day to balance the supply and demand for electricity in the grid. As an example, a binary-ORC (organic Rankine cycle) turbine ramp rate is usually around 15% of the nominal value per minute, although it can reach 30% if operated in flexible mode (GEA, 2013). This is a better performance than most natural gas plants: combined cycle gas turbine plants have an average ramp rate not higher than 4%, and open cycle gas turbine plants not higher than 12% (IRENA, 2019).

Moreover, the reliability of geothermal energy is also associated with its high resiliency to climate events such as strong winds or periods of drought, which are becoming more frequent and intense with the effects of climate change.

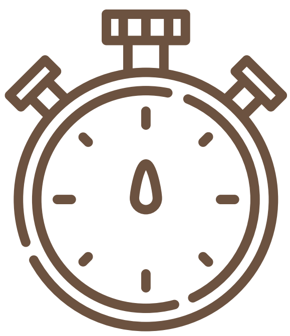
Geothermal generation can provide a reliable energy supply that helps adapt to the effects of climate change and is resilient to drought periods, strong winds and fuel price shocks.

It can act as a baseload energy source that operates in complementarity with variable sources and has the ability to be operated in a flexible manner to stabilise the grid.



Capacity factor above

80-90%



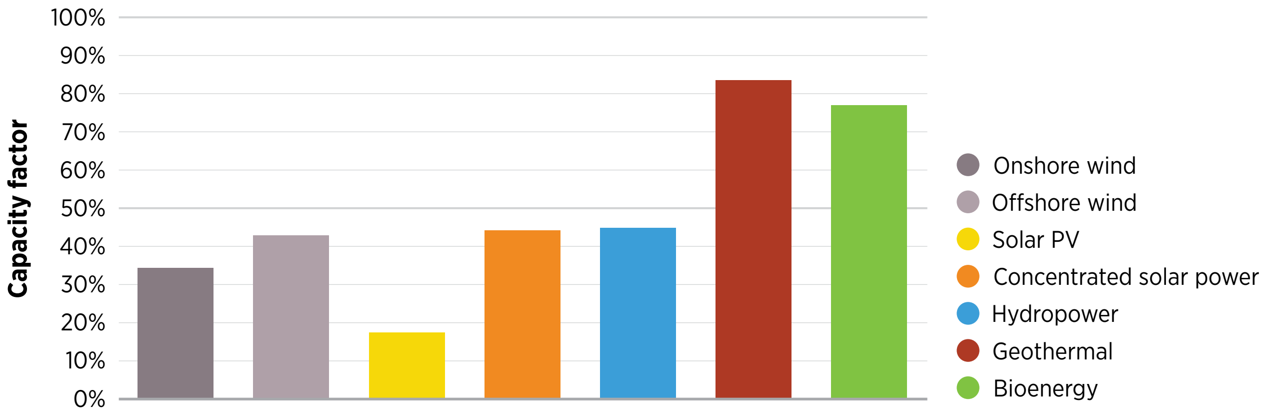
Ramp rate at

15%

of nominal value per minute

[1] The proportion of an actual electrical energy output over a given period to the maximum possible electrical energy output over that period. A high capacity factor means a higher utility rate of the installed capacity to generate electricity.

Weighted capacity factors for electricity generation by technologies



Source: IRENA, 2020

Geothermal resilience and adaptation to extreme climate change events examples

In October 2015, Hurricane Patricia, the strongest tropical cyclone on record in terms of wind speed, hit the western coast of Mexico, where the first private geothermal plant is located. It was also the second-most intense cyclone on record in terms of pressure. The geothermal plant was only a few months old, and the worst was expected; however, the geothermal plant did not suffer any damage, proving the resilience of geothermal energy to natural disasters derived from climate change.

Another example of geothermal as a resilient solution can be found in Kenya. There, hydropower accounts for the most extensive installed power capacity, and over the years, electricity generation from these plants has been erratic due to frequent droughts. The power generation gap created by reduced hydropower production during periods of drought, coupled with the growing demand for electricity, is mainly being addressed through increased generation from geothermal power plants. In 2018, generation from geothermal was about 5 TWh from an installed capacity of 663 MW, compared with 3.4 TWh from hydropower from an installed capacity of 830 MW. Geothermal provided 46% of electricity generation in Kenya, compared with 31% from hydropower, despite having a lower installed capacity (IRENA, 2020).

An energy source that makes economic sense

The development of geothermal resources is characterised by high upfront investment costs for the construction of a geothermal power plant, at around USD 4.5 million/MW. The operation and maintenance costs of geothermal plants are estimated at around USD 0.12/MW/year. They remain stable in time and not dependent on fuel supply, resulting in an average levelised energy cost of USD 71 per megawatt hour (MWh) (IRENA, 2021). This falls within the lower band of fossil fuel generation and is competitive with other renewable energy options. According to the US Energy Information Administration (EIA), the average levelised energy cost for new geothermal plants expected to be commissioned in 2026 is estimated at the very competitive price of USD 36.40/MWh (EIA, 2021). Besides providing baseload electricity, the ability of geothermal binary power plants to operate flexibly with a high ramp rate ensures that more variable renewable energy (VRE) sources can be integrated into the grid with minimal curtailment in generation. This complementarity between geothermal and VRE ensures that grid stability can be achieved with limited additional cost to the system. The additional costs for the system to connect a VRE project to the grid have been estimated at 5% of the VRE project cost. In the case of a high share of integration (about 30% VRE share), the cost of upgrading the grid ranges between USD 0.56/MWh and USD 3.33/MWh, while that of operating the system ranges between USD 16.65/MWh and USD 27.75/MWh (IEA-ETSAP and IRENA, 2015). In the case of the United States of America, the EIA estimates that generation of electricity from geothermal resources would result in an avoided cost[2] to the system of USD 40.89/MWh (EIA, 2021).

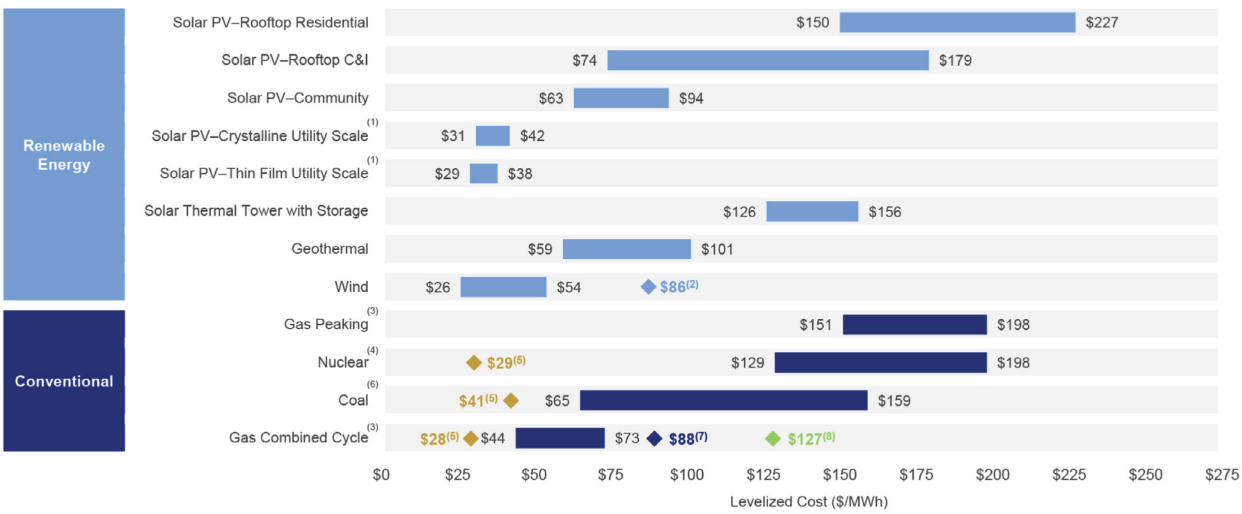
Geothermal electricity generation is competitive with other renewables and falls within the lower band of cost for fossil fuel electricity generation.

The global average levelised energy cost for geothermal electricity is USD 71/MWh.

The average levelised avoided energy cost of geothermal electricity in the United States of America is estimated at USD 40.89/MWh for plants coming online in 2026.

[2] The EIA urges that levelised energy cost does not capture all factors that contribute to actual investment decisions to assess the economic competitiveness of various generation alternatives. EIA, in addition, compares economic competitiveness between generation technologies by considering the value of a plant in serving the electric grid. This value provides a proxy measure for potential revenues from sale of electricity generated from a candidate project displacing (or the cost of avoiding) another marginal asset. Using levelised avoided cost along with the levelised energy cost provides a more intuitive indication of economic competitiveness for each technology than either metric separately when several technologies are available to meet load.

Levelised cost of energy for different technologies



1. Low case represents single axis tracking system and high case represents fixed-tilt system.
2. Estimated midpoint LCOE for offshore wind.
3. Assumes unsubsidised fuel cost of USD 3.45/MMBTU (Metric Million British Thermal Units)
4. Excluding decommissioning costs, ongoing maintenance related capital cost, and subsidies.
5. Midpoint of the marginal cost of operating fully depreciated nuclear, coal and gas combined cycle facilities, including decommissioning costs for nuclear plants.
6. High case includes 90% carbon capture, excludes transportation and storage.
7. Represents LCOE of high case parameters for combined gas cycle with a blend of 20% *blue hydrogen* [hydrogen made using natural gas and carbon capture and storage].
8. Represents LCOE of high case parameters for combined gas cycle with a blend of 20% *green hydrogen* [hygrogen made via electrolysis with renewable energy].

Source: Lazard, 2020

City heated with geothermal energy - Reykjavik, Iceland.

Image credit: Flickr

Much more than electricity for a just transition

Geothermal power plants are vectors for social and economic development in the regions where they are built. In 2020, about 96 000 people were employed in the geothermal industry (IRENA and ILO, 2021). The distribution of jobs per region included about 40 000 in the European Union, 8 000 in the United States of America and 3 000 in China. These jobs are in both the electricity and heating–cooling sectors.

And the impact of a geothermal plant goes further than power generation, as the hot fluids obtained from the underground can be used in multiple productive activities, linked in a "cascade scheme" to the operation of the plant. The energy in these fluids can be used in buildings' heating systems, agricultural greenhouses, food processing and agro-industry, aquaculture, and other applications. In Olkaria, Kenya, geothermal energy has allowed the development of a flourishing flower cultivation and export industry. By using geothermal fluids to regulate temperature and avoid pests, energy consumption costs have been reduced by 30% and flower exports increased by 10% (ThinkGeoEnergy, 2012). In the Domo San Pedro geothermal power plant in Mexico, a fruit dehydration factory has been installed that can process 3 000 kilogrammes (kg) of fruit a day, providing a business opportunity for local communities and contributing to the food security of the area (Aviña, 2021) . Geothermal energy has also been seen as an investment opportunity for the Maori indigenous communities of New Zealand: the Maori-owned 158 MW Nga Awa Purua power plant provides more than USD 4 million in revenues annually, which are redirected to develop programmes for the community (Blair *et al.*, 2018). In Iceland, the nine companies located in the geothermal resource park that use excess heat and other by-products of a geothermal resource generated a combined income of USD 165 million, which accounted for 1% of the Icelandic economy in 2013 (IRENA, 2020).

Geothermal energy could also allow the hydrocarbon industry to explore cleaner business opportunities, particularly for drilling service companies. In 2021, in Colombia, Parex inaugurated the first pilot of a geothermal power plant generating electricity, contributing to the decarbonisation of the oil and gas industry.

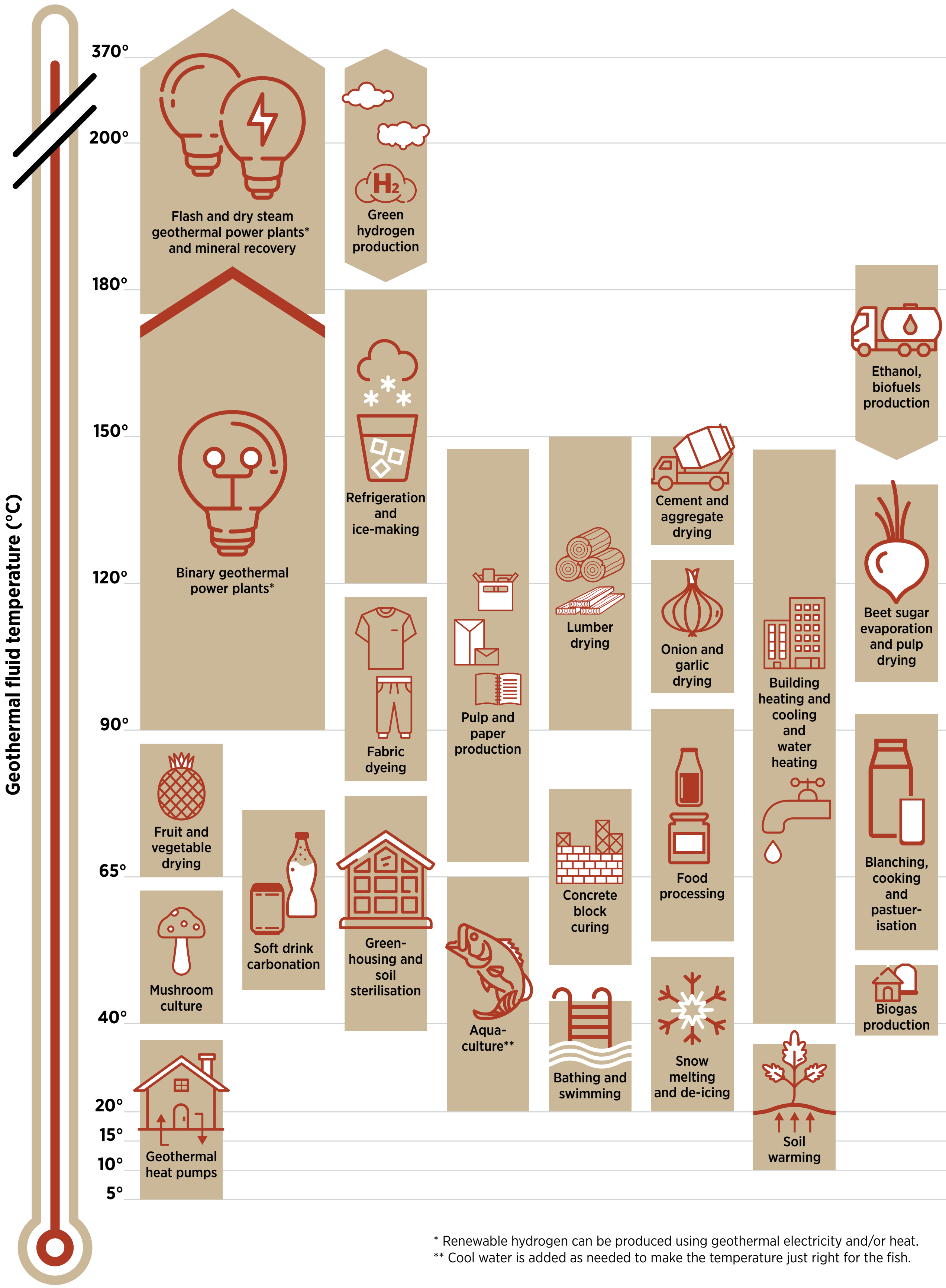
In addition, the geothermal industry offers a natural path for oil and gas personnel to transition to renewable energy jobs, particularly in drilling, where similar technologies and expertise are applicable.

The social and economic impacts of geothermal energy go further than electricity generation; geothermal energy can be a catalyser of productive activities in the agro-industry sector, help in food security programmes, promote indigenous community development, and provide a just transition option for hydrocarbon industry workers.

96 000 people were employed globally in the geothermal industry in 2020.

Section 6

Multiple applications of geothermal energy



* Renewable hydrogen can be produced using geothermal electricity and/or heat.
** Cool water is added as needed to make the temperature just right for the fish.

Source: Adapted from Lindal, 1973

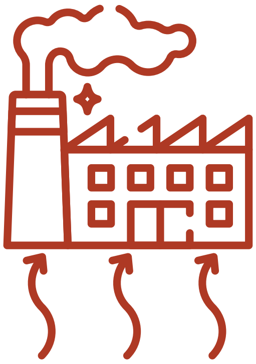
A technology looking towards the future

Geothermal technology is a well-established and proven technology. Nevertheless, in recent years, there have been some technological breakthroughs, providing solutions to the traditional two technical challenges for the sector: depth of the heat and permeability of the terrain. Enhanced geothermal systems are being developed to improve performance in these aspects, for example creating micro-fissures in the rock with pressurised water to increase permeability, using millimetre wave drilling systems to enable deeper super-hot-rock layers to be reached, and implementing closed-loop systems that drastically improve efficiency and enable exploitation of lower temperature geothermal fields. Although still being tested, these new advances may make geothermal energy available in areas of the globe without natural geothermal reservoirs. Based on global subsurface temperature distribution, an additional 1 000 GW of electricity can be extracted from hot, dry rock using emerging technologies. Depending on the success of these emerging technologies, up to 70 GW could be installed economically using energy from hot, dry rock by 2050 (Bertani, 2010). Geothermal may also be a promising technology to produce green hydrogen, and in fields with temperatures above 200°C, it may be able to do it at competitive prices (Yimlaz & Kanoglu, 2017). This possibility is already being tested at the Mokai geothermal project in New Zealand and the Reykjanes power plant in Iceland. In Australia, there are plans to test the production of green hydrogen by installing a 10 MW electrolyser that feeds from a geothermal power plant, which will use the underground heat of the Perth natural gas basin.

In addition, extraction of minerals such as lithium from geothermal brines could power the energy transition by supporting the production of batteries for energy storage and electric vehicles in a more environmentally sustainable manner, as demonstrated in Germany, New Zealand, the United Kingdom and the United States. In 2021 in Germany, a pilot project produced battery-grade lithium from geothermal brine, with commercial production envisaged for 2024 (Vulcan Energy, 2021).

The success of ongoing development in new technologies has the potential to make it easier to access the heat underground, facilitating the scalability of geothermal installations and the concept of "geothermal anywhere", while bringing new opportunities for green hydrogen and lithium production.

Estimated technical potential for geothermal electricity from hot, dry rocks is 1 000 GW.

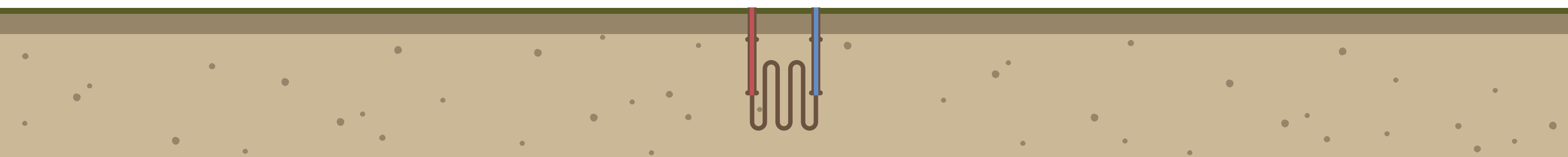


H_2

Geothermal can produce green hydrogen.

Estimated potential for geothermal energy

Estimated Geothermal Potential		Electricity (GW)	Heat utilisation (GWt)
Technical Potential	Hydrothermal systems	200	5 000
	Engineered systems	1 000	
Economic Potential	Hydrothermal systems (by 2050)	70	800
	Engineered systems (by 2050)	70	



What needs to be done?

Collaboration could benefit various aspects of geothermal development and could include sharing experiences and best practices in establishing enabling frameworks; innovation, research and development; capacity building; and outreach and impactful messaging.

The main barriers to the full development of this promising technology are the uncertainties associated with the exploration of the resource and the lack of legal frameworks that recognise the particularities of geothermal technologies.

The risk of uncertainty about finding geothermal resources can be mitigated through collaborative characterisation of the resource by academia, utilities and public research institutions, together with concessional financing and grants provided by the public sector and international institutions.

To create legal frameworks that recognise the particularities of geothermal technologies, the public sector can support the development of specific regulations for geothermal energy, creating licensing processes that recognise the time and natural resource use particular to geothermal developments. Also, the public need to be made aware of geothermal energy, via media and informational campaigns, to increase understanding of its potential, opportunities and benefits.

Likewise, collaboration among stakeholders is required to accelerate the development of geothermal energy globally by leveraging their collective synergies. These stakeholders include government agencies, private sector players, international development agencies, financiers and academia.

Finally, the geothermal sector should collaborate with other relevant industries, including the oil and gas sector, for technology transfer, as well as with end-use sectors to promote geothermal utilisation in sectors such as agri-food and industries.

Increased awareness creation and collaboration among stakeholders is required to accelerate the development of geothermal energy globally by leveraging their collective synergies.

Meeting of the Global Geothermal Alliance.

Section 9

Conclusions

Geothermal energy can provide clean, firm, resilient and flexible power generation at competitive costs, facilitating the integration of intermittent renewable sources into the power grid. It is also a catalyst of economic development for the communities where it is installed, creating numerous jobs and supporting productive activities using geothermal fluids. Geothermal energy is now innovating with drilling technologies and plant layouts, making it a promising option for a more sustainable power system and for the production of clean fuels such as green hydrogen. Nevertheless, policy makers and the general public lack the knowledge about this technology, and it will require support from the public sector and other stakeholders to exploit its full possibilities.

The crater at Mt. Longonot - Kenya.

Image credit: Flickr

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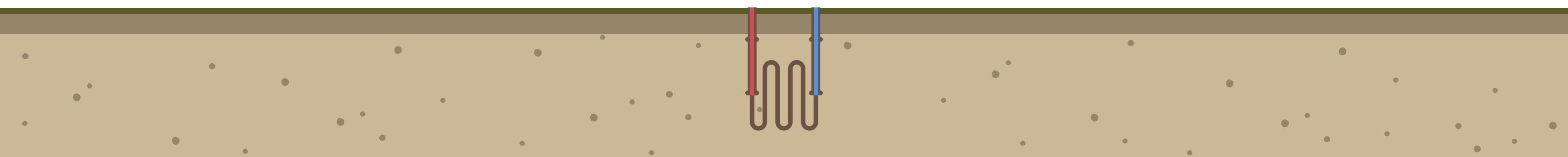

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