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# GEOTHERMAL POWER
## TECHNOLOGY BRIEF

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## About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

### Acknowledgements

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# Contents

# Insights for Policy Makers

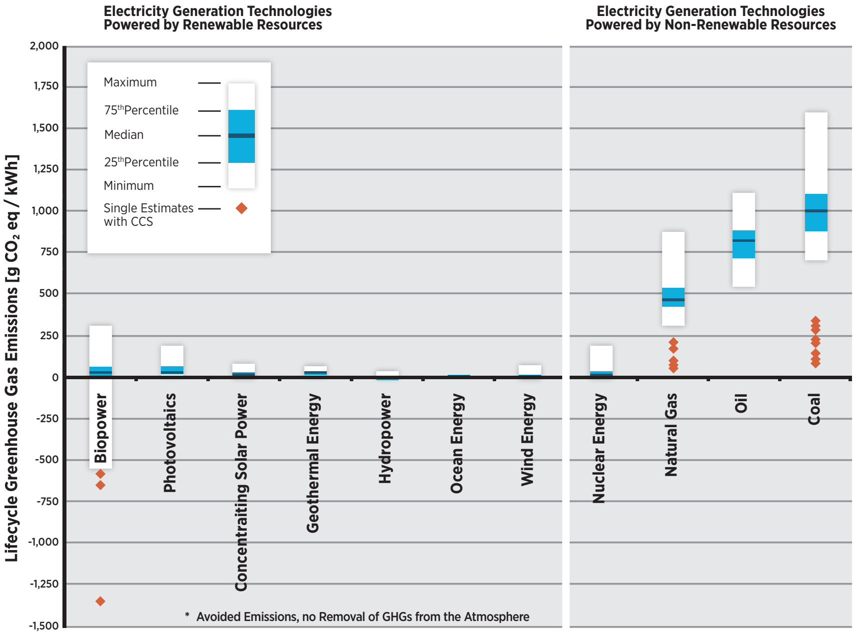
Geothermal energy is a type of renewable energy which is generated within the earth and can be used directly for heating or transformed into electricity. An advantage of geothermal energy over some other renewable energy sources is that it is available year-long (whereas solar and wind energy present higher variability and intermittence) and can be found around the globe. However, for electricity generation, medium- to high-temperature resources, which are usually close to volcanically active regions, are needed.

Geothermal power has considerable potential for growth. The amount of heat within 10 000 metres of the earth's surface is estimated to contain 50 000 times more energy than all oil and gas resources worldwide (Shere, 2013). Moreover, there is a strong economic case for the deployment of geothermal energy. The costs for electricity generation from geothermal technologies are becoming increasingly competitive, and they are expected to continue to drop through 2050 (Sigfusson and Uihlein, 2015).

Deploying geothermal energy has additional benefits, as it also contributes to reduced global warming effects and public health risks resulting from the use of conventional energy sources. Furthermore, the deployment of geothermal energy helps reduce a country's dependence on fossil fuels.

As a resource which is naturally replenished on a human time-scale, geothermal energy is not impacted by global depletion of resources or by rising fossil fuel prices. Hence, if the full potential of geothermal resources can be realised, this would deliver considerable advantages both at the national and international levels. In addition, compared to fossil energy resources, geothermal power generation brings a number of benefits, such as: lower life-cycle greenhouse gas emissions (Figure 1); lower running costs; capability to supply baseload electricity, flexibility and ancillary services to a system; and higher capacity factors.

## *Figure 1: Estimates of lifecycle greenhouse gas emissions by power generation source*




| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Count of Estimates | 222(+4) | 124 | 42 | 8 | 28 | 10 | 126 | 125 | 83(+7) | 24 | 169(+12) |
| Count of References | 52(+0) | 26 | 13 | 6 | 11 | 5 | 49 | 32 | 36(+4) | 10 | 50(+10) |

*Source: IPCC, 2011*

# *Global Geothermal Alliance*

Launched in December 2015 at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21), the Global Geothermal Alliance offers an inclusive and neutral multi-stakeholder platform for enhanced dialogue, co-operation and co-ordinated action among public, private, intergovernmental and non-governmental actors that share a common vision of accelerating the deployment of geothermal energy for power generation and direct use. The Alliance has an aspirational goal to achieve a five-fold growth in the installed capacity for geothermal power generation and more than two-fold growth in geothermal heating by 2030*.

**More specifically, the Alliance aims to:**

- foster an enabling environment to attract investments in geothermal energy.
- provide customised support to regions and countries with geothermal market potential.
- facilitate the exchange of insights and experience among key stakeholders along the geothermal value chain.
- identify and promote models for sharing and mitigating risks to attract private investment and integrate geothermal facilities into energy markets.
- promote the visibility of geothermal energy in the global energy and climate debates.

At present, the Alliance gathers over 70 Member countries and Partner institutions from geothermal industry, development partners, international finance institutions and academia.

* Based on IRENA REmap 2030 analysis
More information available at www.globalgeothermalalliance.org

# Highlights

**Process and Technology Status -** Global geothermal power capacity by the end of 2016 totalled 12.7 gigawatts (GW), with annual electricity generation reaching 80.9 terawatt-hours (TWh) in 2015 (most recent data), amounting to approximately 0.3% of global electricity generation (IRENA, 2017a). Geothermal electricity generation relies mainly on technologies that exploit conventional geothermal resources, such as: **dry steam plants, flash plants** (single, double and triple), **binary plants,** and **combined-cycle** or **hybrid plants.** However, as high-quality conventional resources become harder to access, deeper resources may become accessible in the future through the development of enhanced geothermal systems.

**Costs -** Geothermal project costs are highly site-sensitive. Typical costs for geothermal power plants range from USD 1 870 to USD 5 050 per kilowatt (kW), noting that binary plants are normally more expensive than direct dry steam and flash plants. The levelised cost of electricity (LCOE) of a geothermal power plant ranges from USD 0.04 to USD 0.14 per kilowatt-hour (kWh), assuming maintenance costs of USD 110 per kW per year and a 25-year economic life (IRENA, 2017b).

Costs for geothermal technologies are expected to continue to drop through 2050, further improving their business case and fostering their growth (Sigfusson and Uihlein, 2015).

**Potential and barriers -** Conservative estimates set the technical potential for geothermal power production at 200 GW (IPCC, 2011). This potential will only be realised if emerging technologies such as **enhanced geothermal systems** continue to mature and enable access to resources that previously were inaccessible.

Other promising opportunities for geothermal power production come from taking advantage of what otherwise would be wasted heat. These include: retrofitting flash plants with **low-temperature bottoming cycles**; coupling plants with **heating applications that rely on waste heat**; and exploiting **co-produced resources** (i.e., fluids that are a by-product of other industrial processes).

The main barrier to further geothermal development lies in the difficult task of securing funding for surface exploration and drilling operations. This can be addressed through public financing and the creation of public companies to exploit geothermal resources. Other barriers include environmental, social and administrative constraints. For instance, a project might be delayed due to lengthy administrative procedures for the issuance of licences and permits, or due to delayed discussions and negotiations (often of complex character) with local groups. Another difficulty is that different countries might have different regulations for performing environmental and social impact assessments, which are mandatory in most cases. Transparent government regulations which avoid causing unnecessary project delays are needed.

# Process and Technology Status

Geothermal energy is heat derived within the sub-surface of the earth. Water and/or steam carry the geothermal energy to the earth's surface. Depending on its characteristics, the geothermal energy can be used for heating and cooling purposes or can be harnessed to generate clean electricity. Geothermal power generation has higher capacity factors compared with some other renewable energy resources and is capable of supplying baseload electricity, as well as providing ancillary services for short- and long-term flexibility in some cases. Furthermore, geothermal power generation has lower life-cycle greenhouse gas emissions than fossil fuel-based generation (IPCC, 2011). Geothermal energy can be sourced from virtually everywhere. However, the vast majority of medium- and high-temperature geothermal systems, which are suitable for power generation, are located close to areas of volcanic activity – for example, situated along plate boundaries (subduction zones, such as the majority of the Pacific "Ring of Fire"), mid-oceanic ridges (such as Iceland and the Azores) and rift valleys (such as the East African Rift) or near hot spots (such as in Hawaii) (Figure 2).

*Figure 2: Tectonic plates and global geological activity*


*Adapted from National Park Service (U.S.), 2014*

In 2016, the global geothermal installed capacity was 12.7 GW (Figure 3). In 2015, geothermal power plants generated approximately 80.9 TWh, or approximately 0.3% of global electricity generation (IRENA, 2017a). As shown in Table 1, the United States (2.5 GW), the Philippines (1.9 GW) and Indonesia (1.5 GW) lead in installed geothermal power capacity.

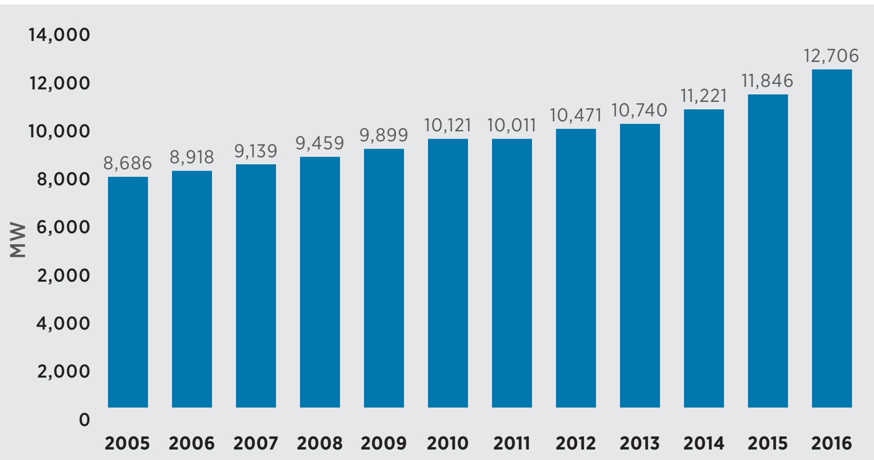
Global installed capacity additions in 2016 amounted to 901 megawatts (MW), the highest number in 10 years, which were installed in Kenya (518 MW), Turkey (197 MW) and Indonesia (95 MW) (IRENA, 2017a). With the growing momentum for utilising these geothermal resources, an increasing number of countries are showing interest in developing geothermal projects.

*Table 1: Net installed geothermal power capacity by country in 2016*

| Country | Capacity (MW) |
|---|---|
| USA | 2 511 |
| Philippines | 1 916 |
| Indonesia | 1 534 |
| Kenya | 1 116 |
| New Zealand | 986 |
| Mexico | 951 |
| Italy | 824 |
| Turkey | 821 |
| Iceland | 665 |
| Japan | 533 |
| Costa Rica | 207 |
| El Salvador | 204 |
| Nicaragua | 155 |
| Russian Federation | 78 |
| Papua New Guinea | 53 |

*Source: IRENA, 2017a*

*Figure 3: Global installed geothermal capacity*




*Source: IRENA, 2017a*

# Geothermal Power Generation

The heat content of a geothermal field will define the power generation technology to be used. Power generation from geothermal resources requires resources with high to medium heat content. Geothermal power generation currently is based on the following four technology options (Long et al., 2003):

**Direct dry steam plants -** In this case, the conversion device is a steam turbine designed to directly use the low-pressure, high-volume fluid produced in the steam field. Dry steam plants commonly use condensing turbines. The condensate is re-injected (closed cycle) or evaporated in wet cooling towers (IEA-ETSAP, 2010) *(Figure 4)*. This type of geothermal power plant uses steam of 150 degrees Celsius (°C) or higher, and, generally, the steam entering the turbine needs to be at least 99.995% dry (DiPippo, 2015) to avoid scaling and/or erosion of the turbine or piping components. Direct dry steam plants range in size from 8 MW to 140 MW (S&P Global Platts, 2016).

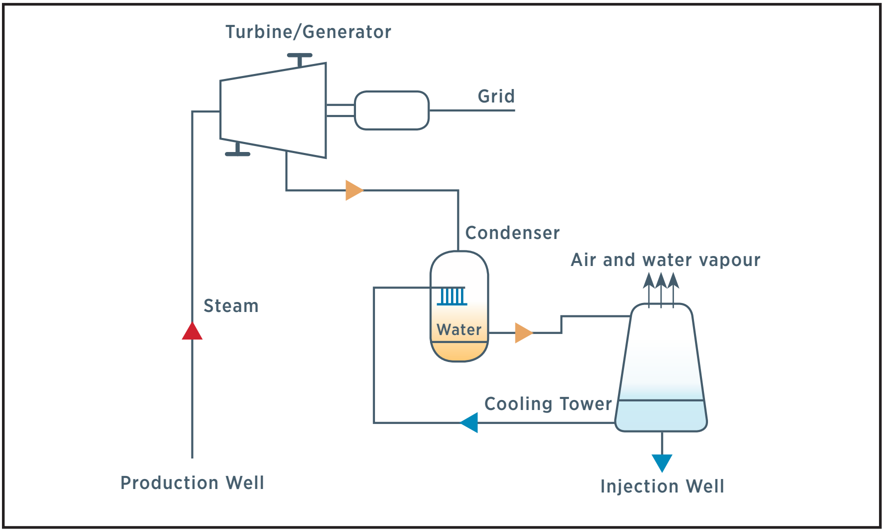
**Flash plants -** These are the most common type of geothermal electricity plants in operation today. They are similar to dry steam plants; however, the steam is obtained from a separation process called flashing. The steam is then directed to the turbines, and the resulting condensate is sent for re-injection or further flashing at lower pressure (IEA-ETSAP, 2010) *(Figure 5)*. The temperature of the fluid drops if the pressure is lowered, so flash power plants work best with well temperatures greater than 180°C. The fluid fraction exiting the separators, as well as the steam condensate (except for condensate evaporated in a wet cooling system), are usually re-injected. Flash plants vary in size depending on whether they are single- (0.2-80 MW), double - (2-110 MW) or triple-flash (60-150 MW) plants (S&P Global Platts, 2016).

**Binary plants -** These plants are usually applied to low- or medium-enthalpy geothermal fields where the resource fluid is used, via heat exchangers, to heat a process fluid in a closed loop (IEA-ETSAP, 2010) (Figure 6). The process fluid (e.g., ammonia/water mixtures used in Kalina cycles or hydrocarbons in organic Rankine cycles (ORC)) have boiling and condensation points that better match the geothermal resource temperature (Köhler and Saadat, 2003). Typically, binary plants are used for resource temperatures between 100°C and 170°C. Although it is possible to work with temperatures lower than 100°C, the efficiency of the electricity output decreases. Binary plants range in size from less than 1 MW to 50 MW (S&P Global Platts, 2016).

**Combined-cycle or hybrid plants -** Some geothermal plants use a combined cycle which adds a traditional Rankine cycle to produce electricity from what otherwise would become waste heat from a binary cycle (IEA-ETSAP, 2010) *(Figure 7)*. Using two cycles provides relatively high electric efficiency (DiPippo, 1999; Thain, 2009). The typical size of combined-cycle plants ranges from a few MW to 10 MWe (Lund, 1999; DiPippo, 1999). Hybrid geothermal power plants use the same basics as a stand-alone geothermal power plant but combine a different heat source into the process; for example, heat from a concentrating solar power (CSP) plant. This heat is added to the geothermal brine, increasing the temperature and power output.

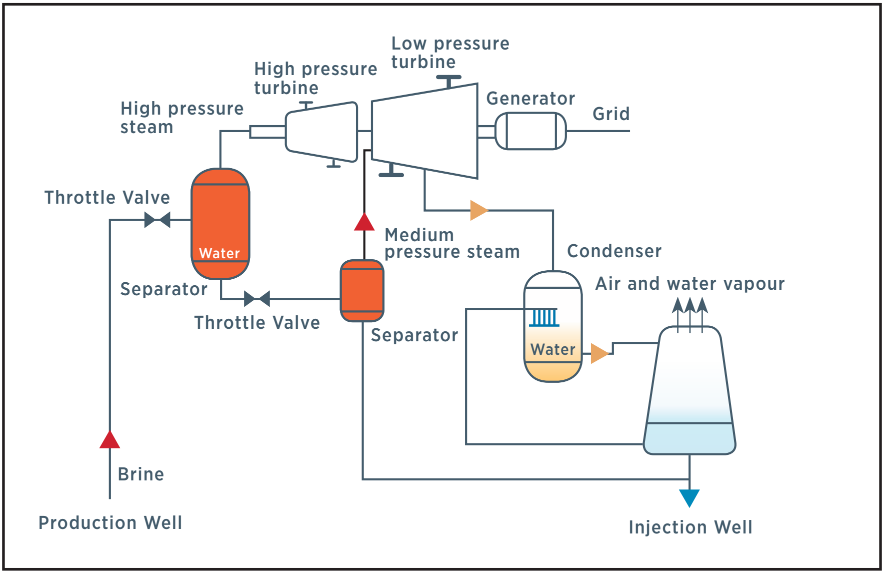
The Stillwater project in the US, operated by ENEL Global Renewable Energies, has launched such a hybrid system; combining CSP and solar photovoltaics with a binary system (DiMarzo et al., 2015). Two other hybrid systems being studied by ENEL include: a hybrid plant with biomass in Italy, which increases the brine temperature, similar to CSP systems (ENEL, 2016a); and a hybrid plant with hydropower in Cove Fort, Utah, which uses the re-injection water flow to generate electricity, providing the additional benefit of increased control of the re-injection, thereby reducing potential damage and thus maintenance costs (ENEL, 2016b).

### *Figure 4: Direct steam plant*



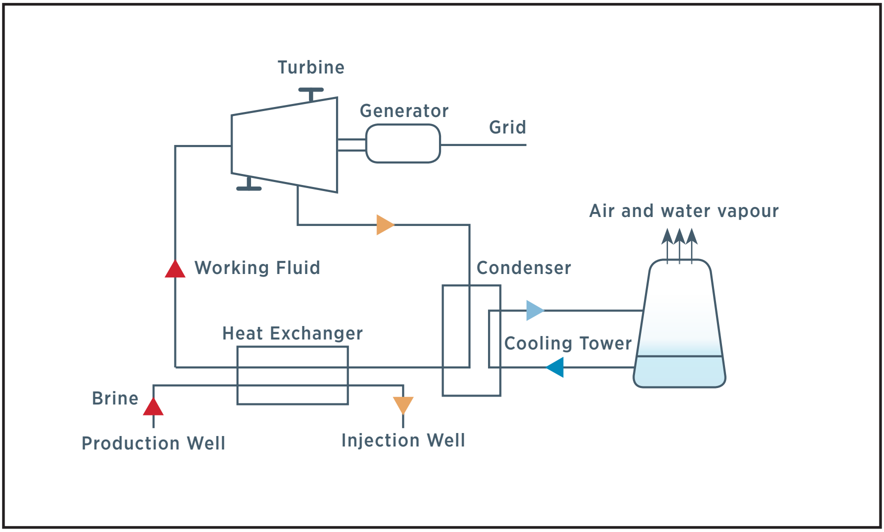

*Source: IRENA, 2017c*

### *Figure 5: Double flash plant*



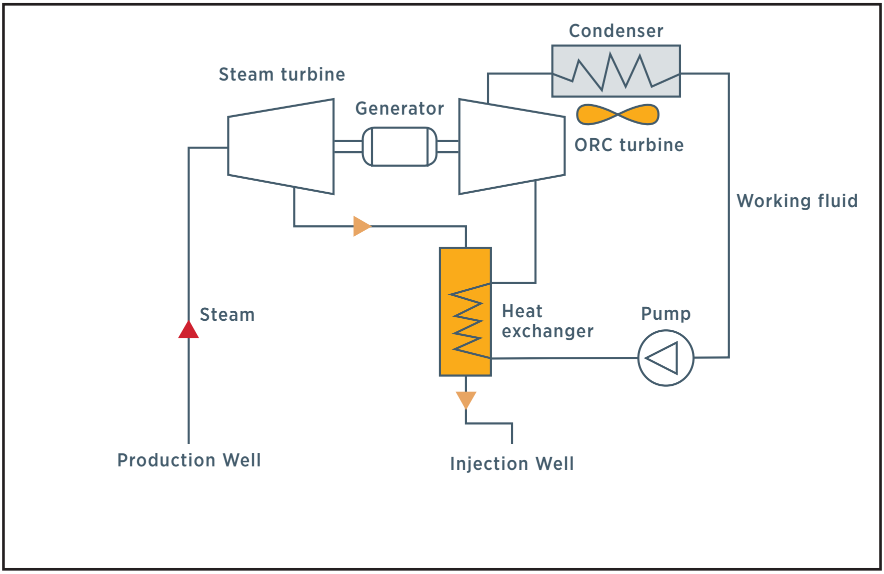

*Source: IRENA, 2017c*

*Figure 6: Binary plant*




*Source: IRENA, 2017c*

*Figure 7: Geothermal combined-cycle plant*



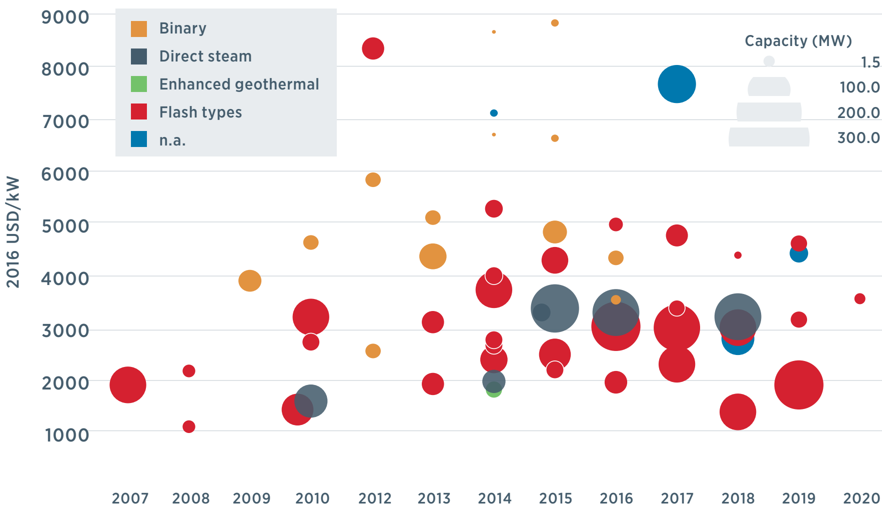

*Adapted from: ORMAT, 2017*

## Costs

Geothermal power projects are capital-intensive; however, they have very low and predictable operating costs. The total installed costs of a geothermal power plant cover the exploration and resource assessment, including: exploration drilling; drilling of production and injection wells; field infrastructure, geothermal fluid collection and disposal systems, and other surface installations; the power plant and its associated costs; project development costs; and grid connection costs. Furthermore, the cost ranges of geothermal power plants will depend largely on power plant type (flash or binary), well productivity (the number of wells) and other geothermal field characteristics.

The global total installed costs for geothermal power plants are typically between USD 1 870 per kW and USD 5 050 per kW (Figure 8); however, costs are highly site-sensitive. For example, installing additional capacity at existing fields can be somewhat less expensive, while costs for projects with more challenging site conditions will be on the higher end of the range (IRENA, 2017b). Generally, costs for binary plants tend to be higher than those for direct steam and flash plants.

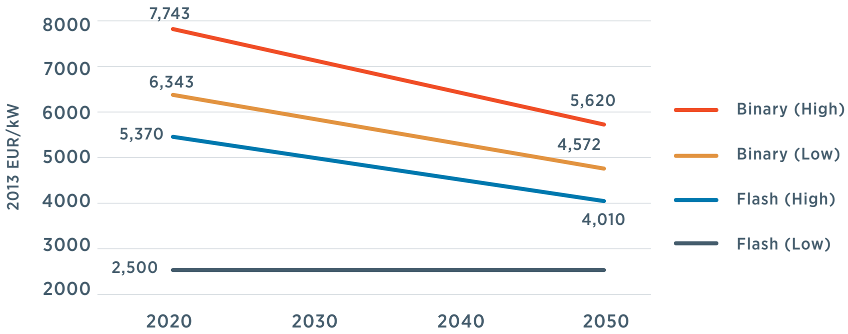
*Figure 8: Geothermal project-level installed costs by technology, 2007-2020*




*Source: IRENA, 2017b*

The European Commission (EC) forecasts the installed costs for both flash and binary plants to decrease through 2050 (Figure 9).

*Figure 9: Forecast of capital expenditures (CAPEX) for geothermal power plant in the European Union*



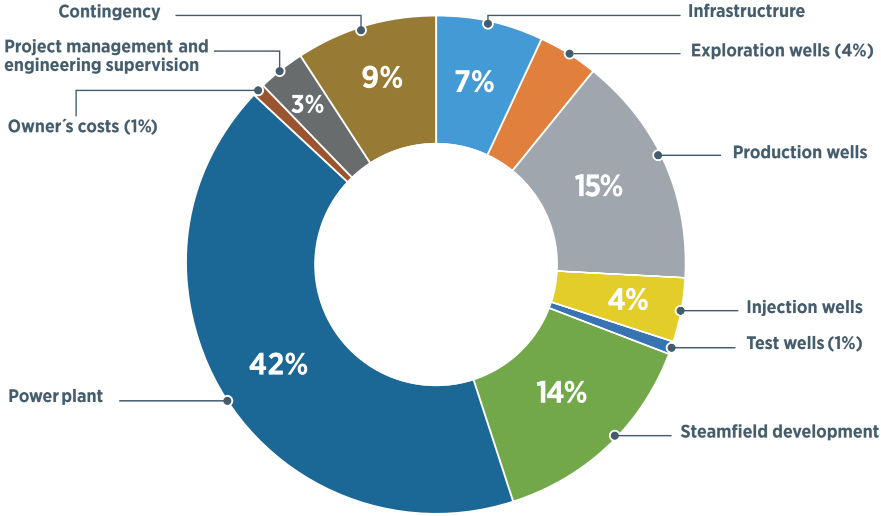

*Source: Sigfusson and Uihlein, 2015*

Figure 10 presents the estimated cost breakdown for the development of two 110 MW flash geothermal power plants in Indonesia, with total installed costs of around USD 3 830 per kW. The power plant and infrastructure costs amount to 49% of the total installed costs; drilling exploration, production and injection wells account for around 24%; while the steam field development accounts for 14% (IRENA, 2014). The EC performed a similar assessment for flash and binary plants and found that roughly 55% of total installed costs corresponds to the power plant and other infrastructure, while exploration, drilling and field development costs amount to 20% for flash plants and 35% for binary plants.

The LCOE from a geothermal power plant is generally calculated by using the installed costs, operations and maintenance (O&M) costs, economic lifetime, and weighted average cost of capital. Figure 11 presents the LCOE for geothermal projects assuming a 25-year economic life, O&M costs of USD 110 per kW per year, capacity factors based on project plans (or national averages if data are not available), two sets of make-up and injection wells over the 25-year life and the capital costs outlined in Figure 8. The observed LCOE of geothermal plants ranged from USD 0.04 per kWh for second-stage development of a field to USD 0.14 per kWh for a first-of-a-kind greenfield development *(Figure 11)*.

The economics of geothermal power plants may be improved by exploiting by-products such as heat, silica or carbon dioxide.

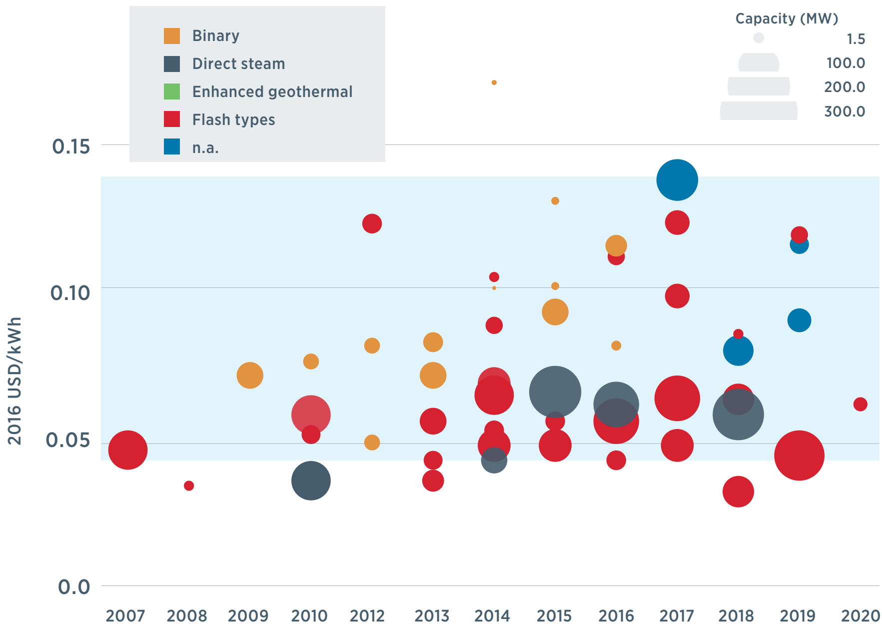
*Figure 10: Total installed cost breakdown for two proposed 110 MW geothermal plants in Indonesia*




*Source: IRENA, 2014*

The LCOE from a geothermal power plant is generally calculated by using the installed costs, operations and maintenance (O&M) costs, economic lifetime, and weighted average cost of capital. Figure 11 presents the LCOE for geothermal projects assuming a 25-year economic life, O&M costs of USD 110 per kW per year, capacity factors based on project plans (or national averages if data are not available), two sets of make-up and injection wells over the 25-year life and the capital costs outlined in Figure 8. The observed LCOE of geothermal plants ranged from USD 0.04 per kWh for second-stage development of a field to USD 0.14 per kWh for a first-of-a-kind greenfield development (Figure 11). The economics of geothermal power plants may be improved by exploiting by-products such as heat, silica or carbon dioxide.

*Figure 11: Geothermal project-level LCOE by technology, 2007-2020*




*Source: IRENA, 2017b*

*Note: The blue band represents the range of costs for fossil fuel power generation.*

# Potential and Barriers

The global technical potential for electricity generation from hydrothermal resources is estimated to be 240 GW (Stefansson, 2005), with a lower limit of 50 GW and an upper limit between 1 000 GW and 2 000 GW, under the assumption that unidentified resources are likely five to ten times larger than currently identified resources. According to the Geothermal Energy Association, the global geothermal industry is expected to reach about 18.4 GW by 2021 (GEA, 2016). Table 2 and Figure 12 show planned capacity additions in the medium term.

*Table 2: Projected geothermal capacity (MW)**

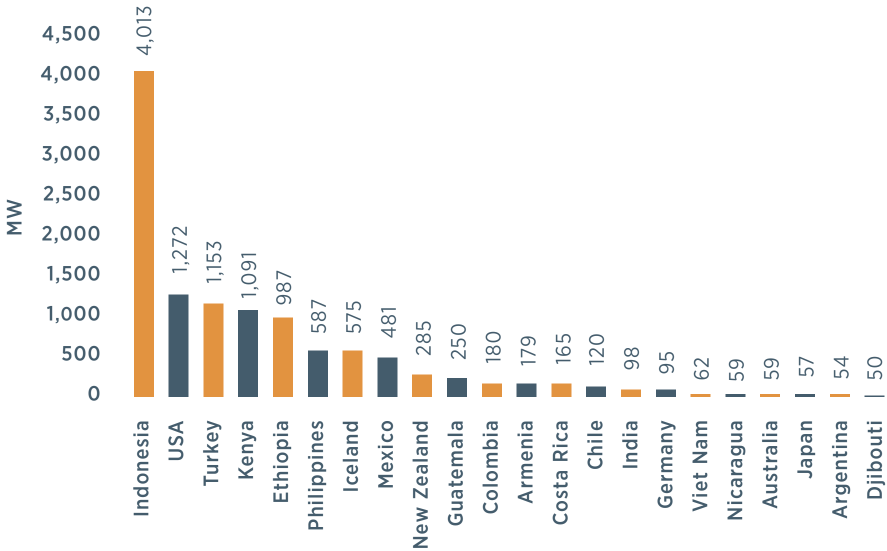
| Country | 2016 | 2025 | >2025** |
|---|---|---|---|
| Australia | 0.8 | 0.8 | 462.5 |
| Chile | - | 98 | 298 |
| China | 28.4 | 28.43 | 98.4 |
| Costa Rica | 213.5 | 368.5 | 368.5 |
| Croatia | - | 16.5 | 36.5 |
| El Salvador | 204.4 | 204.2 | 304.4 |
| Ethiopia | 8.5 | 178.5 | 278.5 |
| Germany | 13.2 | 13.2 | 66.1 |
| Guatemala | 54.2 | 54.2 | 134.2 |
| Iceland | 612.4 | 752.4 | 1 322.4 |
| Indonesia | 1 468.9 | 3 410.7 | 4 270.2 |
| Italy | 946.4 | 946.4 | 1 142.4 |
| Japan | 545.5 | 612.0 | 935.7 |
| Kenya | 617.16 | 932.16 | 1 247.2 |
| Mexico | 882.9 | 957.9 | 1 252.9 |
| New Zealand | 1 058.8 | 1 128.8 | 1 483.8 |
| Nicaragua | 133.2 | 190.2 | 412.2 |
| Papua New Guinea | 56 | 56 | 166 |
| Philippines | 1 943.4 | 2 104.4 | 2 834.4 |
| Portugal | 27.8 | 27.8 | 53.8 |
| Russian Federation | 95.2 | 95.2 | 150.2 |
| Turkey | 409.3 | 721.6 | 997.6 |
| USA | 3 490.3 | 3 874.3 | 5 425.3 |

*Source: S&P Global Platts, 2016*

*Note: *Values presented are nameplate capacity.*

***Capacity additions after 2025 correspond to planned and deferred projects without a completion date.*

*Figure 12: Planned capacity additions for geothermal power by country*

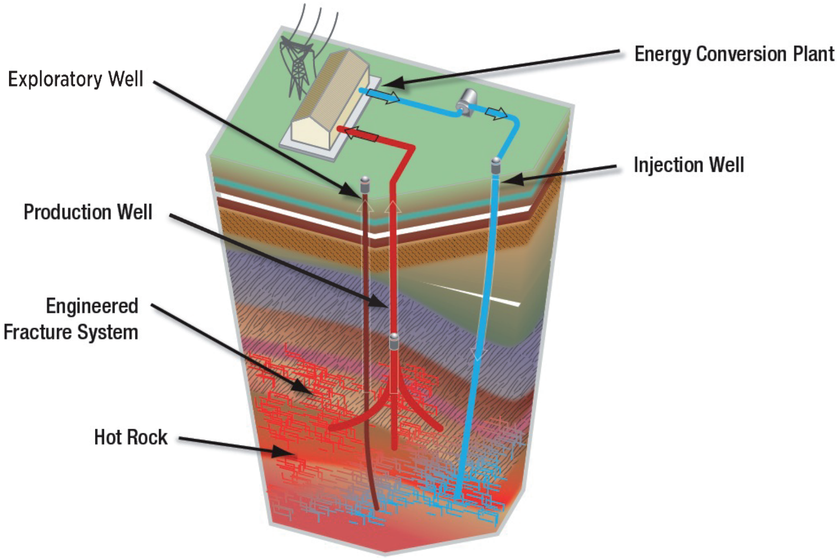



*Source: GEA, 2016*

**Enhanced geothermal systems:** A large part of the geothermal potential is heat stored at depths greater than commonly drilled. Standard hydrothermal technologies depend on permeable aquifers, which allow the flow of water through them, to produce hot water. However, at greater depths the ground becomes less porous and water flow is restricted. Research and demonstration projects are being developed to overcome this limitation. Instead, artificial fractures are created to connect production and injection wells by hydraulic or chemical stimulation. Stimulation is accomplished by injecting water and a small amount of chemicals at high pressure to create or re-open fractures in the deep rock (Figure 13). To prevent these fractures from closing again when the injection pressure is reduced, special materials called proppants are added.

This approach, known as enhanced geothermal (EGS), uses binary plants to produce power from the hot brine. As there is no natural flow of water, all the brine has to be re-injected into the reservoir to keep the pressure and production stable. This helps prevent air emissions during the service life. Several pilot projects were performed in France, at Soultz-sous-Forêts and in Strasbourg (Hébert et al., 2010; Renewable Energy World, 2016), as well as in the US (DOE, n.d.a).

*Figure 13: Enhanced geothermal system*




*Source: GTP, 2008*

Exploiting untapped resources is not the only way to increase the geothermal installed capacity. Additions also can be made through efficiency improvements, such as:

**Low-temperature bottoming cycles:** When dealing with high-enthalpy resources, it is common to use a flash plant configuration to exploit them. In a traditional flash plant, the steam exiting the turbine is re-injected into the ground, leaving it as waste heat. This steam, however, frequently exits the turbine at temperatures that are suitable for power generation through a binary cycle turbine. This would increase the overall efficiency of the plant by increasing the power output.

**Co-generation:** Geothermal energy has many potential uses besides power generation. The water collected after separating the steam for generation is normally re-injected into the ground because the temperature is too low for power generation. However, because it is frequently higher than 100ºC, by exchanging the heat with a different water source before injection, this newly heated water can be used for various direct-use applications such as domestic hot water supply and space heating.

**Co-produced resources:** The use of geothermal fluids that are a by-product of other industrial processes also provides a great opportunity to produce electricity at low cost and with virtually no emissions. Hot geothermal fluids which are a by-product of oil and gas operations usually are considered a nuisance, given that they need to be disposed of at a cost. Power actually can be produced from these co-produced resources, and this already has been successfully tested in the US (NREL, 2016).

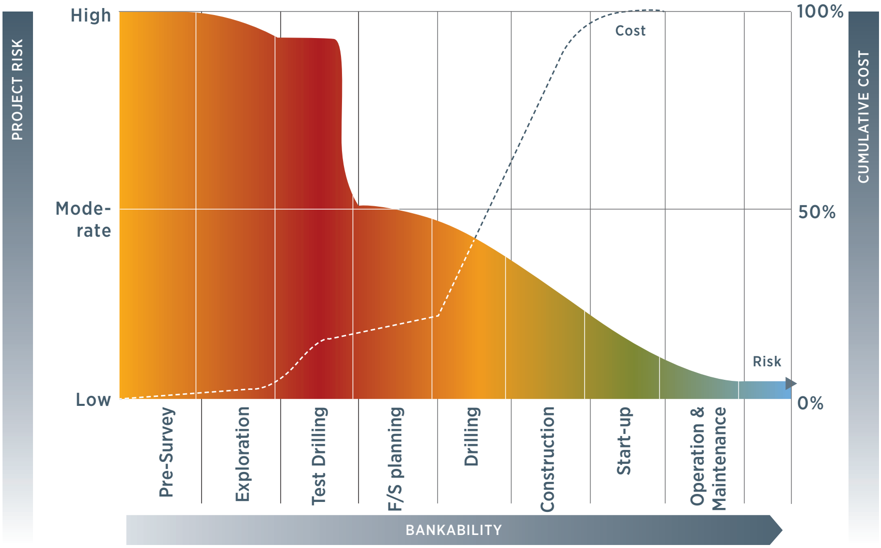
**Supercritical geothermal systems:** These are high-temperature systems located at depths where the reservoir fluid is in supercritical state, e.g., 374ºC and 221 bar for water. These systems are the subject of ongoing research and are not yet commercial; however, they are capable of attaining higher well productivities than conventional systems given their high temperatures (Dobson et al., 2017). In 2009, the IDDP-1 well in Iceland found magma and was capable of producing superheated steam at 450ºC, effectively creating the first magma-EGS system. The well, however, had to be shut down in 2012 due to a valve failure. While such a system could prove to be more economical by exploiting the steam directly from the well, the possibility of applying a reverse procedure also has been explored. This would mean using these types of wells for injection with the objective of enhancing the performance of existing conventional systems (Fridleifsson et al., 2015).

The main barriers to geothermal development can be grouped into three broad categories: financial, environmental and administrative.

**Financial barriers:** Geothermal power plant development involves substantial capital requirements due to exploration drilling costs, for which it can be difficult to obtain bank loans. Since geothermal exploration is considered high risk, developers generally need to obtain some type of public financing. This risk is derived from the fact that capital is required before confirmation of resource presence or exploitability, and therefore before project profitability can be determined *(Figure 14)*.

Governments can reduce this risk and the cost of capital for private developers in a number of ways. For instance, they can create public companies that exploit geothermal resources and provide private companies (that install power plants and supply electricity to their customers) with the steam. Other risk mitigation instruments include cost-sharing for drilling and public-private risk insurance schemes. With sufficient resource information, including seismic events/fractures and deep drilling data (which national or local governments can make available

*Figure 14: Typical uncertainty and expenditure profiles for a geothermal project*




*Source: Gehringer and Loksha, 2012*

to developers), and reliable conceptual models of the underlying geothermal system and groundwater resources, risks could be reduced and financial barriers could be further eased, thereby accelerating geothermal development (Gehringer and Loksha, 2012).

**Environmental and social barriers:** National regulations differ among countries; however, an environmental and social impact assessment of some type is almost always mandatory. Furthermore, apart from the assessment process, sufficient discussion with local groups may be needed before development can commence.

These issues can delay or lead to the cancellation of the geothermal power project; however, if managed in a timely and efficient manner, they do not present an obstacle.

**Administrative barriers:** Administrative issues such as licensing, permitting and environmental assessments are technically not barriers. However, they need to be tackled carefully by project developers, as they might impact a geothermal project by causing unnecessary delays. On the other hand, governments should ensure that their regulations establish a transparent and straightforward process that will foster the deployment of new projects.

## *Summary Table – Key data for geothermal power*

| Technical performance | Typical current international values and ranges |
|---|---|
| Energy input / output | Hydrothermal fluid / Electricity |

| Well drilling technologies | Heat gradient well | Slim well | Full-size well | Injection well |
|---|---|---|---|---|
| Depth, metres (IRENA, 2017c) | <300 | 1 000-1 600 | >1 600 | Varying depth |
| Final diameter of well size, inches (IRENA, 2017c) | <6 | <6 | >6 | Varying size |

| Power plant technologies | Dry steam | Flash steam | Binary cycle |
|---|---|---|---|
| Steam quality | Dry (>99.995%) (DiPippo, 2015) | Wet | Dry/Wet |
| Typical steam temperature, °C (IRENA, 2017c) | >150 | >180 | 100-150 |
| Typical plant size (capacity), MW (IRENA, 2017c) | 0.3-110 | 0.3-110 | 0.1-45 |
| Total cumulative capacity, GW | 12.7 (IRENA, 2017a) | | |
| Capacity factor, % (IRENA, 2017b) | >80 (worldwide), >90 (some individual plants or units) | | |
| $CO_2$ emissions, $gCO_{2eq}$/kWh (IPCC, 2011) | Lifecycle assessments of greenhouse gases: 6-79 | | |
| Forecast for cumulative capacity, GW | 18 (in 2021 – GEA, 2016) | | |
| Technical potential for hydrothermal resources, GW (IPCC, 2011) | >200 | | |

| Costs | Typical current international values and ranges | | |
|---|---|---|---|
| **Typical installed cost breakdown Indonesia/EU** | **Flash steam power plant in Indonesia (110 MW – IRENA, 2014)** | **Flash stem power plant in EU (Sigfusson and Uihlein, 2015)** | **Binary-cycle power plant in EU (Sigfusson and Uihlein, 2015)** |
| Power plant, steam field development/ Power plant and surface installations | 56% | 56% | 55% |
| Drilling wells/ Exploration, drilling, stimulation | 24% | 21% | 34% |
| Infrastructure/ Interconnection, heating process | 7% | 7% | 1% |
| Project management and engineering supervision/ Planning, management, land | 3% | 12% | 5% |
| Others/ Insurance | 10% | 4% | 4% |

| Typical total installed costs | Flash steam power plant | Binary-cycle power plant |
|---|---|---|
| 2016 USD/kW (IRENA, 2017b) | 1 870 - 5 050 | |
| 2014 USD/kW (IPCC, 2011) | 1 900 - 3 800 | 2 250 - 5 500 |
| 2013 USD/kW (EIA, 2016a) | 2 851 (average cost for plants installed in 2013, >1 MW/plant) | |
| 2013 EUR/kW (ETRI, 2014) | 2 500 - 5 930 | 6 470 - 7 470 |
| Forecast in US, 2015 USD/kW (EIA, 2016b) | 2 687 (O&M: USD 116/kW/year; lowest case in US; plant available in 2019) | |
| Forecast in EU, 2013 EUR/kW (Sigfusson and Uihlein, 2015) | 2 500 - 5 370 (in 2020)<br>2 500 - 4 870 (in 2030)<br>2 500 - 4 420 (in 2040)<br>2 500 - 4 010 (in 2050) | 6 300 - 7 743 (in 2020)<br>5 660 - 6 957 (in 2030)<br>5 088 - 6 253 (in 2040)<br>4 572 - 5 620 (in 2050) |

| Levelised cost of electricity | Geothermal power projects |
|---|---|
| Global LCOE, 2016 USD/kWh (IRENA, 2017b) | 0.04 - 0.14 |
| O&M cost, USD/kWh (DOE, n.d.b) | 0.01 - 0.03 |
| Forecast in US, 2015 USD/kWh (EIA, 2016c) | 0.0423 (O&M: 0.0131, capacity factor 91%, in 2022)<br>0.0411 (O&M: 0.0152, capacity factor 93%, in 2040) |

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