# 2021 Annual Report

IEA Geothermal

December 2022

IEA Geothermal

**Disclaimer**

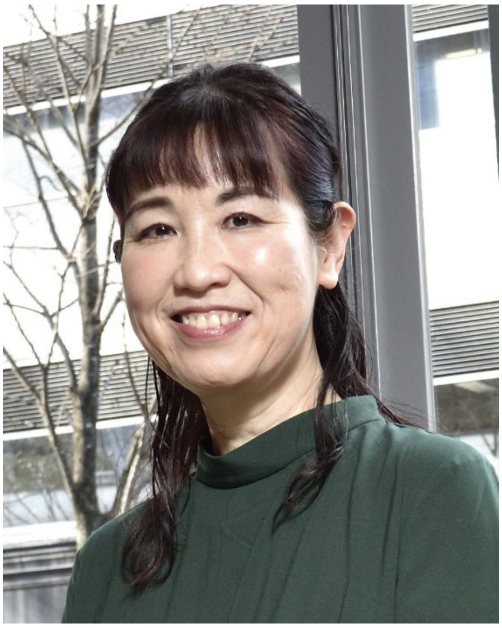


# Contents

# Message from the Chair

Dear Reader,

Welcome to the 2021 IEA Geothermal Annual Report. The document describes the work of IEA Geothermal and our Working Groups, providing you with information about geothermal sector activities in our participating nations, as well as market, technology, research, and statistical information.



It is pleasing to see geothermal energy utilisation continuing to grow along with the interest that nations are showing in this source of renewable low carbon energy.

2021 was the 24th year for the IEA Geothermal Technology Collaboration Programme. The Covid-19 pandemic continued to influence our activity with most activities held virtually.

The second Mine Water Geothermal Energy Symposium was run virtually in March 2021.

The World Geothermal Congress was held virtually and in person through the period April to October 2021. IEA Geothermal participants authored or co-authored 11 papers and the TCP had an exhibition booth in Reykjavik in October.

Virtual activity also included the 45th and 46th Executive Committee and Working Group meetings held on the 27th – 28th April 2021 and 16th – 17th November 2021 respectively.

I would like to thank contributors to our work, those who have provided material and assisted in preparing this report, the Working Groups and the Working Group leaders.

Please enjoy the read.

Dr Kasumi Yasukawa

Chair IEA Geothermal (2022)

# Executive Summary

The work of IEA Geothermal, and highlights from 2021, are presented in this report. IEA Geothermal had 16 participating members; 13 country members; the European Commission; and two industry organization/company sponsors. The group foster the sustainable use of geothermal energy through international collaboration, collating and distributing quality information, supporting the development and uptake of geothermal technologies, and communicating geothermal energy's strategic, economic and environmental benefits. Please visit our website, participate in our Working Groups, join one of our workshops, or become a member of IEA Geothermal.

Geothermal energy is used around the world in direct use applications: space heating and cooling, greenhouse heating, aquaculture, bathing, thermal city networks, and industrial uses. In parts of the world where appropriate conditions are found, geothermal energy is also used to generate electricity.

The interest in geothermal heat is growing rapidly as value from this renewable energy source is being realised. It is not only heat in the traditional sense but also cooling. The interest is right across sectors from residential to city scale. Large integrated smart city energy systems are being developed with the potential for significant reductions in city $CO_2$ emission footprints. Volcanic geothermal systems that are superheated or supercritical are the focus of studies seeking to release usable energy from them. The Enhanced Geothermal System (EGS) environment offers much potential that is yet to be realised and significant investment in EGS technology and development is occurring.

2021 continued to see IEA Geothermal activity impacted by the Covid 19 pandemic. That said activity continued on a number of work fronts and in many of our participant nations. The executive summary identifies achievements of our Working Groups and the geothermal sector highlights in our participating nations.

## Working Group Activities

**Working Group 1 (WG1)**

Working Group 1 works on activities that:

a) encourage the sustainable development of geothermal energy resources;
b) quantify and seek ways to balance any adverse impacts that geothermal energy development may have on the environment; and
c) identify ways of avoiding, remedying or mitigating adverse effects.

Networking and cooperation amongst participating countries' researchers, operators, policy-makers and funding-agencies continued during 2021, albeit with continuing constraints on activity from the COVID pandemic. This resulted in contributions to a number of publications raising awareness internationally of successful mitigation schemes, and beneficial environmental and social outcomes.

Highlights for the year include:

- Presentation of the WG 1 environmental and society collaboration papers to WGC2020+1.

- Continued information compilation in preparation for a book on environmental and social impacts.
- Networking and cooperation amongst researchers, operators, policy-makers and funding-agencies within the participating countries.
- Raising international awareness of successful mitigation schemes and beneficial environmental and social outcomes.
- Supporting relevant presentations and publications by scientists from member countries at international conferences and workshops.

Presentations at workshops and conferences, and publications in conference proceedings, including; the Stanford Geothermal Workshop, the Geothermal Resources Council Annual Meeting, the New Zealand Geothermal Workshop and the World Geothermal Congress WGC2020+1. Please refer to the Reference section at the end of Chapter 2 for more details.

**Working Group 8 (WG8)**

Direct use of geothermal energy is growing worldwide with many applications from heating and cooling buildings, innovative smart district thermal grids, heat pump applications, industrial applications, bathing, agriculture, horticulture, food processing and fish farming. Working Group 8 focuses on providing quality information, communicating and transferring knowledge to reduce barriers to the uptake of geothermal use. In 2021 there was minimal activity not only because of the COVID pandemic but also because the leadership role of the Working Group was vacant through all of 2021.

A very successful Mine Water Geothermal Energy Symposium was held virtually on the 10th and 11th March 2021. The symposium attracted interest from up to 200 people from 73 countries. Presentations can be accessed from this web page (URL to presentations).

Three WG 8 papers were published in the proceedings of the World Geothermal Congress 2020+1. For two of the papers the presentation videos are available – refer to the Reference section in Chapter 3.

The Heat Pump Technology Annex 52 work concluded with the report on Long-term performance monitoring of GSHP systems for commercial, institutional and multifamily buildings released in December 2021 (URL to the report). WG 8 has been aware of the activity by Annex 52 whilst not being actively involved.

**Working Group 10 (WG10)**

Internationally, there is demand for reliable information on renewable energy capacity and energy production. Working Group 10 is seeking to fulfil some of that demand for geothermal data. Data analysis work by IEA Geothermal has been on hold during 2021 pending contract renewal with the Leibniz Institute for Applied Geophysics.

Earlier reports can be accessed from the IEA Geothermal web site.

Two IEA Geothermal papers on data and reporting were published in the proceedings of the World Geothermal Congress 2020+1.

Weber,J., Wissing, L., Ten Years of Geothermal Trend Reporting and Statistics by IEA Geothermal. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)

Song, Y., Link, K., Yasukawa, K., Weber, K., Proposal of New Data Collection Methodology for Geothermal Heat Pumps Statistics - an Outcome of IEA Geothermal Working Group Activities. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)

**Working Group 12 (WG12)**

This WG focuses on the deep roots of volcanic systems and has enthusiastic participation from a number of IEA Geothermal member countries who are working on very high temperature geothermal systems. Amongst a range of necessary advancements energy utilisation from these geothermal conditions requires improved modelling methods, fundamental geochemical characterisation, development of downhole measurement tools, and advancing the understanding of water-rock-gas interaction at high temperatures and pressures.

2021 saw a number of peer reviewed papers prepared, preparations for a supercritical symposium series organised by WG12, Geothermal the Next Generation and the International Partnership for Geothermal Technology, presentations at international conferences including at the WGC2020+1 as part of the virtual and in person sessions from April to October 2021. A comprehensive reference list at the end of the Chapter 5 provides the details.

**Working Group 13 (WG13)**

Working Group 13 covers a broad spectrum of geothermal activity including exploration, drilling, reservoir creation and enhancement, corrosion, scaling, tracers, and the mitigation of induced seismicity. The goal is to provide quality information to facilitate the utilization of geothermal energy worldwide. The development of innovative technologies is being pushed by expert collaboration between countries and the results made available in documents and presentations at conferences and workshops.

Work is carried out in five tasks:

- Exploration (A1), Measurement and Logging (A2),
- Drilling Technology (B),
- Reservoir Creation and Enhancement (C),
- Induced Seismicity (D),
- Surface Technology (E) - Heat and Electricity Production, Corrosion, Scaling, Tracer Technology.

For most Tasks work during 2021 was at a low level.

Task D (Induced Seismicity) was active through 2021 with collaboration amongst researchers sharing the results of the considerable amount of funded research being undertaken by participants in this area.

A paper prepared for the WGC2020+1 meeting was presented during a virtual session of the Congress in April 2021. Papers were also published in the proceedings of several major international geothermal workshops including the; 46th Stanford Geothermal Workshop

(February, California), 43rd New Zealand Geothermal Workshop (virtual presentations February 2022) and the Geothermal Rising Conference, USA (October 2021), and the 9th European Geothermal Workshop, held at KIT Karlsruhe Germany (September, 2021).

## National Activities

The material immediately below is a summary of 2021 activity from each of our member countries. Each participant's geothermal programme provides the basis for IEA Geothermal cooperative activity. The country material is written up in more detail in chapters 7 to 20. Not all participants have been able to complete the 2021 material for this report and where 2020 or earlier material is used it is recorded in the section heading.

**Australia**

The transition of Australia's electricity sector to renewables is proceeding rapidly with renewable generation exceeding 63,000 GWh in 2021, contributing 24% of total electricity generated which is a 15% increase on the previous year. Emissions from the electricity sector in 2020 were 172 $MtCO_{2e}$ with a reduction to 88 $MtCO_{2e}$ projected by 2030.

Commercial factors are driving ongoing investment, with projections of ~30% of grid connected capacity coming from roof top solar (~34GW) by 2030.

The 310 kW ORC geothermal power plant in the remote community of Winton, Queensland operated through 2021 after the plant was commissioned in December 2019.

Interest and investment in Ground Source Heat Pumps (GSHP) and Direct Use geothermal applications continues to grow, particularly in the states of Western Australia, New South Wales and Victoria. The Fairwater development in NSW will have a fully instrumented 14 $MW_{th}$ geothermal heat pump system servicing 800 homes. There has been a substantial technical and social science research effort associated with this development seeking to quantify the costs and benefits. The work is being progressively reported as the work streams are concluded with study work due for completion in 2022. ARENA has funded the performance assessment of the 'deep well direct exchange' (DWDX) ground source heat pumps installed at Fairwater.

In Victoria energy to the St Hilaire community of 5500 homes is supplied from an integrated renewable system with Solar PV, battery storage and geothermal energy in the mix. Morning and evening peak energy demand will be flattened, and reduced greenhouse gas emissions are expected to be achieved from the energy system. The 75,800sqm Melbourne Connect precinct is supported by one of Melbourne's largest rooftop solar PV arrays, a geothermal energy system and on-site rainwater harvesting which has seen the facility accredited to the highest 6-star green sustainable design rating. The geothermal energy system has a 250 kWt capacity, designed to supply heat to 45°C and cooling to 6.5°C with a heating COP of 5.57 and a cooling COP of 5.15.

The geothermal heat supply to the Traralgon Gippsland Regional Aquatic Centre (GRAC) was officially opened in the first quarter of 2021. Geothermal heat is supplied from 65°C water taken from wells drilled into the Traralgon aquifer with the water returned to the aquifer at between 40 and 53 °C depending on the heat load required. Maximum power is 3$MW_{th}$, with annual carbon emissions reductions of 700 tonnes and annual savings of $400K compared to gas heating predicted.

Interest in the Hot Spring and wellness sector is flourishing with a number of projects nationwide under construction or finalising planning and financing. One of these at the Peninsula Hot Springs is an extension project, whilst projects at Talaroo, Alba, Saltwater Springs, and Metung are new developments. A PhD project, at the Victoria University, Melbourne, studying the social, environmental and economic impacts of hot springs on communities across Australia commenced in 2020.

Government funded geothermal research is largely conducted by government research institutions and universities, supported by both State and Commonwealth Government funding including the Australian Research Council (ARC) and the Australian Renewable Energy Agency (ARENA).

No national geothermal conferences were held during 2021.

**European Commission**

The European Commission President aspires for Europe to become the world's first climate-neutral continent by 2050. Geothermal energy is and will contribute to achieving the 2050 climate goals with the European Commission supporting the development of the geothermal sector through an array of activities based on the two major policy initiatives:

- the European Green Deal, and
- the SET-Plan.

The EU Clean Energy Package established a binding target of 32% renewables by 2030 with the EU member states now working to their 10-year integrated national energy and climate plans covering the period 2021 to 2030. The member state plans can be accessed through this URL.

Horizon 2020 concluded in 2020. In Chapter 8 there is a comprehensive listing of geothermal outputs funded from Horizon 2020 with some of the individual funded workstreams running until 2026.

Horizon 2020 was replaced by Horizon Europe, which commenced in the spring of 2021 running through to the end of 2027. The proposed research and innovation budget under the programme is EUR 95.5 billion. Geothermal energy is included under the Climate, Energy and Mobility subprogramme.

The InvestEU Programme is bringing together a multitude of EU financial instruments currently available and expands the successful Juncker Investment Plan. With InvestEU, the Commission will further boost investment in innovation and job creation.

The European Investment Bank together with the European Commission are implementing the InnovFin Energy Demo Projects scheme which provides loan support for first-of-a kind projects. InnovFin aims to facilitate and accelerate access to finance for innovative businesses and projects in unproven markets in Europe. The scheme reduces the financial risk of demonstration projects and offers equity and loans tailored to the needs of a project.

At the end of 2020 there were 139 geothermal power plants with a total capacity of 3.5GWe in operation in Europe. The geothermal electricity production in the EU amounted to some 7 TWh which is ~0.25% of the total EU electricity consumption.

The European district heating market continues to grow and at the end of 2020 there are 350 geothermal district heating plants in operation with a total capacity of 6 $GW_{th}$. An additional 232 projects are under development.

Geothermal Heat Pumps are widely used across Europe with 2.1 million systems installed as of end of 2020, with a corresponding capacity of about 27 $GW_{th}$.

**France**

France has adopted ambitious targets to reach 3 TWh of geothermal heat production by 2023, and 4 to 5.2 TWh by 2028. This in essence doubles the current energy delivery.

The installed capacity for geothermal heating and cooling is ~2800 $MW_{th}$ with about 660 $MW_{th}$ of this being associated with the deeper reservoirs in the Paris area, and the balance being shallow geothermal resource use across France. The number of geothermal installations feeding collective housing and residential blocks, including office buildings, is growing whilst the individual residential geothermal heat pump market is flat.

Total geothermal heat pump capacity is some 2130 MW producing some 13.8 Pj/yr of energy. The residential market has seen about 3000 geothermal heat pump systems installed annually since 2016. This geothermal market continues to face strong competition from air/water and air/air heat pump systems. Individual housing can benefit from a funding programme, "MaPrimeRénov" if energy efficient renovation projects are implemented in the house. The amount increases with the installation of a geothermal heat-pump. There is an income limit and as higher incomes and new builds are not able to access "MaPrimeRénov" funding, the benefits to the shallow geothermal heat pump sector are likely still not enough to revitalize that market.

Geothermal heat pump system locations and data are being entered into graphic tool developed by BRGM and AFGP in 2021. The output is available on the web from https://www.geothermies.fr/viewer/.

Geothermal electricity capacity of ~17.2 $MW_e$ producing some 124 GWh in 2020. Of the two geothermal doublets drilled more recently near Strasbourg, the Illkirch cogeneration project is expected to move to completion in coming years whilst further development at the Vendenheim site will not be undertaken.

Several schemes have been implemented to assist geothermal sector development;

- A geological risk mitigation tool providing for failure in locating geothermal resources, insufficient temperature, insufficient flow rates or highly aggressive fluid chemistry.
- The SAF Environment guarantee for deep aquifer heat production has a proven track record over 40 years.
- Aquapac covers the geological risk for the first well drilled, up to 200m deep for open loop systems, and then the geothermal production during the first 10 years of operation.
- The Renewable Heat Fund (Fonds Chaleur Renouvelable) created in 2009, to subsidise geothermal installations in collective housing, tertiary, industry and agriculture. 678 projects have received support from the fund.

Geothermal energy research and development is supported from funding from ADEME, the National Agency for Research and the Fund for Industrial Clusters. National technology clusters have been established to develop collaborative industry / research institute projects including:

GEODEEP (export focus), Pôle AVENIA (deep applications), and SYNERGILE (renewable energy in offshore territories). Géodénergies, an Institute of Excellence, created in July 2015 supports development of underground activities in: $CO_2$ storage, energy storage, and geothermal energy production (heat and electricity). Géodénergies has launched a number of research projects seeking to bridge gaps in technology.

Lithium is naturally present in some of the geothermal brines, especially in the Rhine Graben and a lithium cluster is being developed to gather together French companies working in different parts of the lithium value chain.

**Germany (2020)**

A shift in emphasis is occurring in Germany with geothermal energy increasing being considered as heat for city and district heating networks rather than for electricity generation. At the beginning of 2020 there were 38 geothermal production operations across Germany with an associated thermal energy delivery capacity of 350 megawatts (thermal). Nine of these facilities generate electricity (capacity of around 47 MWe) either exclusively or supplementary to the heat supply. The feed-in-tariff for geothermal electricity continues to be 25.2 Euro-cents per KWh.

Stadtwerke München (SWM) is working to provide the entire district heating for Munich from renewable energy by 2040, with the majority being geothermal. Project GeoMARE initiated in 2018 continued through 2020 providing both conceptual and comprehensive design of the district heating system with the project overall targeting adaption of citywide heating infrastructure supported from a 400 MW sustainable geothermal heat supply. Heizkraftwerk Süd in Munich is going to become the largest inner-city geothermal plant in Europe with SWM planning to supply around 80,000 residents.

The Market Incentive Programme of the Federal Government promotes renewable energy systems that provide energy for space heating, hot water, cooling and process heat. It covers smaller buildings administered by the Federal Office of Economics and Export Control (BAFA), and larger buildings and commercial uses being a component of the KfW Banking Group renewable energies program. MAP subsidizes the installation of efficient heat pump systems in residential buildings through a repayment bonus, depending on the installation size.

The Federal Government has a strategic approach for technology and innovation transfer using living labs to bring new, promising technological solutions to market through exploring and mastering the challenges under real-life conditions, and then later implementing the tested technologies on a large scale.

For deep geothermal research in 2020, the BMWi approved funding of around 41 million Euros and an additional 14.4 million Euros was invested in 106 ongoing research projects.

The Federal Government supports international collaboration and cooperation through a number of agency activities, including; the implementation of the EU SET-Plan, activities under the IEA and by participation in transnational funding instruments such as GEOTHERMICA.

**Iceland (2020)**

Iceland has developed expertise and experience in harnessing geothermal resources for both space heating and for electricity generation. Over 90% of Icelandic households are heated with geothermal energy and 30% of the nation's electricity is generated from geothermal energy.

The fourth Icelandic Master Plan for Nature Protection and Energy utilization was completed in 2020. The third plan, presented to the Minister for Industry in September 2016 remains unconfirmed. The 10 projects identified in the third plan remain on hold as work cannot commence until the plan is confirmed.

At the end of 2020 the installed geothermal electricity capacity was 757 $MW_e$. In 2020 5960 GWh of geothermal electricity and 33.7 PJ of geothermal heat (2019 data) were produced.

An Energy fund, operated by Orkustofnun, supports geothermal development in areas where geothermal energy is not yet used for heating. The financial support comprises a lump sum of 16 years-worth of subsidies to assist in establishing either geothermal heating or a more efficient heating system, such as using heat pumps. No market incentives apply to geothermal electricity development.

The Reykjavík Energy CarbFix and SulFix projects reinjecting gases extracted from geothermal fluid at Hellisheiði power plant are progressing well with the gases mineralizing in the basalt bedrock in less than two years. Currently 65% of the $H_2S$ and 30% of the $CO_2$ are returned underground.

The main purpose of the IDDP work is to determine if it is economically feasible to extract energy and chemicals from hydrothermal systems at supercritical conditions. Planning for an IDDP-3 well in the Hengill area (near the Hellisheiði power plant) continues.

The 2020 World Geothermal Congress was rescheduled due to Covid 19 into 2021.

A hydrogen pilot plant has been established at Hellisheiði. The concept is that off peak electricity is transformed into hydrogen and stored for later use.

In January 2020 the name of the United Nations University-Geothermal Training Programme, programme changed to the UNESCO GRÓ Geothermal Training Programme with this programme now operating under the auspices of UNESCO.

**Italy (2019)**

At the end of 2018 the Italian Installed geothermal capacity was 915,5 MWe. The gross electricity generation for 2018 was 6,105 GWh.

No new geothermal electricity generation plants were commissioned in 2019.

At the end of 2017 direct geothermal use capacity was more than 1400 MWt, with corresponding total energy use for 2017 of 10.9 Pj/yr. The geothermal energy use is broken down with the main sector use as follows: space heating 42%, thermal balneology 32% and fish farming 18%. Agricultural applications, industrial processes and other minor uses amount to less than 8% of the total annual energy use.

Installed ground-source heat pump (GSHPs) capacity is some 532 $MW_{th}$ delivering ~3.3 Pj/yr of energy. District heating systems with a total installed capacity of ~150MWt annually supply 863 Tj/yr of energy, ~8% of the total geothermal heat. The district heating systems are mainly in the Tuscany Region and District heating is the only sector growing significantly.

Recent official Italian documents forecasting renewable energy production in Italy envisage limited growth in geothermal energy applications. The 2017 Italian Energy Strategy (MISE, 2017) predicts a rather limited increase in geothermal electricity production whilst proposing to establish a support scheme for innovative geothermal technologies demonstrating power production with zero emissions. In July 2019 geothermal power was excluded from participating in the incentive schemes offered for electrical energy produced from renewables. At the end of 2019 the support scheme for zero emission or other innovative geothermal technologies had not been established.

Recent Italian research projects focussing on sustainable development, and reducing and mitigating environmental impacts have achieved good results:

- In 2019 the EU H2020 program Matching concluded. The Matching project achieved the target of an up to 15% reduction in evaporative losses from geothermal cooling towers, through the replacement of wet cooling towers with hybrid towers.
- The Spirulina cultivation project successfully demonstrated use of geothermal $CO_2$ and heat to grow spirulina algae. This integrated geothermal and algae production process reduces $CO_2$ emissions from a geothermal facility.

The H2020 Geoenvi project was established in 2019. Scheduled for completion by April 2021 the project aims to define Guidelines for Life Cycle Analysis (LCA) and environmental impact assessments of geothermal energy facilities.

**Japan**

Japanese geothermal electricity capacity was ~537 $MW_e$ at the end of 2021. Geothermal energy production was some 2300 GWh over the 12 month period ending March 2020.

Direct geothermal use capacity is ~2400 $MW_{th}$ producing ~30 PJ/year of energy.

The installation of GSHP systems has been increasing in recent years, with a total of 2,994 geothermal heat pump installations recorded in the 2020 census data, with a capacity of ~160 MWth delivering about 770 TJ/year of energy (older 2018 data). Of the GSHP installations about 84% are closed loop systems.

Changes in the legal framework applicable to geothermal drilling were made in 2021 where the regulations were changed from prohibited in natural parks, to encouraged providing that special care of the environment is part of the proposed activity.

Promotional measures in play since 2011 to intensify deployment of Renewable Energy have brought renewed interest in geothermal energy development. A feed in tariff (FIT) was introduced in 2012 payable in advance to renewable electricity generation projects certified in a given year. The FIT for geothermal projects has been maintained over the years whilst for solar and wind the tariff has been reducing year on year. A Feed in Premium arrangement is expected to be mandated in 2022 which will see a reduction in the application of the FIT.

METI has been supporting geothermal through other funding mechanisms and at the end of 2021 about 6 billion JPY in total grant subsidy had been paid to 20 projects. Loan guarantees have been provided to 6 projects, four of which have commenced operation and two are under construction.

A number of the older geothermal power plants are undergoing major refit and upgrading.

Social acceptance of geothermal development remains difficult, especially amongst hot spring resort owners. METI began a program in 2013 to improve social acceptance of geothermal power generation. It is a subsidy scheme for general public educational activities undertaken by local governments and/or the private sector. In 2021 seven projects were adopted. 2021 saw the annual JOGMEC Geothermal Symposium run both in-person and virtually with attendance of more than 1600 people.

Since 2013 JOGMEC has been undertaking airborne helicopter geophysical surveys, land based geological and geophysical surveys augmented with some drilling in some areas. By the end of 2021 nineteen areas in Hokkaido, Honshu and Kyushu had been airborne surveyed.

JOGMEC has 7 geothermal technology projects active in four development theme areas;

- Technology for Exploration of Geothermal Reservoirs
- Drilling Technology
- EGS (Enhanced Geothermal Systems) technology
- Innovative Geothermal Technology

NEDO began research in 2017 on subduction-origin supercritical geothermal resources, which have potential for 10’s of giga-watts of power generation for Japan, with a pilot plant targeted to be in place by 2040. Fundamental studies are being conducted by the National Institute of Advanced Industrial Science and Technology (AIST) and Kyoto University looking to utilise 500°C super critical fluids at up to 5km depths.

**Mexico**

The installed geothermal electricity capacity in 2021 was unchanged from 2019, being ~1002 MW installed and 959 MW operational. This operational capacity represents ~1.1% of the country’s total installed electricity generating capacity. During 2020, 4511.5 GWh of electricity was produced from geothermal energy (1.4% of Mexico’s electricity).

In 2020 30.5% of the total electricity generated in Mexico was from clean energy sources. The Energy Transition Law has set a national target to produce 35% of the total electrical energy from clean sources by 2024.

Direct use of geothermal energy in Mexico remains largely undeveloped from what has been estimated to a very large potential (40,000$MW_{th}$). Some geothermal direct use demonstration projects have been sponsored by CeMIEGeo in the period 2014-2019. Several geothermal heat pump installations have been installed following on from the successful CeMIEGeo heat pump demonstration project.

No changes or new policies regulating geothermal energy use were introduced in Mexico during 2021.

As of December 2021, six exploitation concessions and 24 exploration permits had been awarded by the Energy Ministry. The Covid pandemic has held back 2020 and 2021 exploration activity because the SENER permitting office was closed and not processing geothermal applications.

The Inter-American Development Bank (IDB) and the Mexican development bank Nafin have developed a financing and risk transfer program for geothermal projects, Geothermal Financing Mexican Program (PGM), structured to finance up to 300 MW of geothermal capacity over ten years. It includes risk mitigation, financing support for exploration and execution, and technical assistance to support execution. The total amount is US$108.6 million. The goal is to leverage other public and private funds to contribute to Mexico's geothermal sector.

The Geothermal Development Facility for Latin America (GDF-Latam) was opened to Mexican geothermal projects during 2021. Previously the facility had been open to Latin American geothermal projects other than in Mexico.

The GEMex bilateral initiative between Mexico (SENER-CONACyT Energetic Sustainability Fund) and the European Community under Horizon 2020 is investigating an EGS system in Acoculco, Pue., and a superhot system at Los Humeros concluded in December 2021. The outputs are recorded in specialist journals and in the proceedings of the World Geothermal Congress 2020+1, Reykjavik, Iceland. Information is also available from http://www.gemex-h2020.eu including the proceedings of the final European conference.

The CeMIE-Geo project successfully requested an extension for 2021 and 2022 for five new projects. Four projects are direct use projects being undertaken by the National University of Mexico and the fifth is a specialised laboratory project being undertaken by CICESE.

CeMIEGeo's digital collection contains technical papers and thesis generated by CeMIEGeo's projects in the period 2014 to 2019. The digital collection includes papers in refereed international journals, thesis, and conference posters, accessible through https://colecciondigital.cemiegeo.org/xmlui/?locale-attribute=en.

The 2021 Mexican Geothermal Association's Annual Congress was postponed due to the Covid pandemic. The Mexican Geophysical Union) annual meeting took place on October 31st through November 5th 2021 in Guadalajara, with a hybrid virtual and on-site format. Some papers from the GEMex project were presented.

**New Zealand**

In 2021 electricity generated from geothermal energy contributed ~18% to national electricity production from an operational geothermal capacity of ~1040 MWe.

Construction activity continued on the 168 Mwe steam turbine facility as the next stage of the Tauhara II project which is scheduled to be operational by the end of 2023.

Taheke drilling and well testing commenced for a planned 25 MWe development. Eastland Generation (85%) and local iwi partners (Taheke 8C, 15%) received a NZ$11.9 million New Zealand Government funding contribution for the 1st stage.

The New Zealand Government announced a strategic target of 100% renewable electricity generation by 2035, in a normal hydro-generation year. This is in addition to the previous target of 90% renewable by 2025

There is interest from policy makers and investors in direct geothermal heat use in New Zealand. The Bay of Plenty Region and the Taupō District are actively promoting the development of geothermal business. Implementation continues through a nation-wide geothermal direct use strategy initiative through the New Zealand Geothermal Association (NZGA, 2022). The Geoheat Strategy for Aotearoa NZ, 2017 – 2030 has goals of increasing the direct use of geothermal energy by 7.5 PJ per annum (primary energy) and fostering an additional 500 jobs in those enterprises that use it. Operators and investors are working on commercial projects that would benefit economically from a supply of geothermal fluid. The development of an Innovation hub is under consideration in the industrial area east of Taupō.

In 2021, the weighted average $CO_2$ equivalent atmospheric emissions factor from New Zealand Geothermal power stations was 64 g/KWh. The New Zealand carbon price has risen significantly from about NZ$25/tonne $CO_2$ during 2019 to NZ$70/tonne in December 2021. This has provided geothermal power plant operators with increasing incentive to further reduce gas emissions through selective well operation strategies or trial NCG reinjection schemes. Capture and reinjection of $CO_2$ gas emissions and modelling long-term net emissions was initiated in several projects by Mercury Energy, Contact Energy and Ngawha Generation.

Tissue maker Essity announced investment approval for its Kawerau geothermal steam-drying project moving further to reduce its use of natural gas at its Kawerau plant. ECCA contributed a $1.65 million Government Investment in Decarbonising Industry (GIDI) fund grant to this NZ $16 million investment that will reduce carbon emissions by 136,610 tonnes over the project life (~6500 tonnes per annunm). This is first paper mill in the world to have geothermal energy used in the drum dryer and hood.

Halcyon Power (Tuaropaki Trust & Obayashi Corp JV) completed a geothermal powered, green hydrogen project at Mokai in December 2021. This consists of a pilot plant with a design capacity of 250 $Nm^3$ per hour. It uses up to 1.25 MWe from the Mokai power station and is expected to produce 180 tonnes of $H_2$ per year for the New Zealand market (mostly for transport).

Geo40 has developed a small-scale process to extract lithium from silica depleted geothermal fluid. At laboratory scale, samples of geothermal brine types from across Europe, the Americas and New Zealand have been successfully processed. A pilot plant for lithium extraction is scheduled for 2022 to fit into the operational Geo40 silica extraction plant at Ohaaki.

Through 2020 GNS Science used core science funding to fund NZ$2.5M in geothermal research through the "New Zealand's Geothermal Future" programme, under four themes:

- Shallow resources and direct use,
- Taupō Volcanic Zone - Structure and Dynamics,
- Taupō Volcanic Zone – Source models; and
- Reservoir Chemistry.

The "Endeavour Fund" has supported research into "Empowering Geothermal Energy; Increased Utilisation of Geothermal Energy Through New Integrated Geoscience Methods". This project addresses geoscientific uncertainties of accessing underground resources. The project is funded at NZ$1.3M / yr until 2022.

A 5-year Endeavour fund research program (2019-2024), Geothermal the Next Generation, funded at a level of about NZ$2M / yr, continued through 2021. The programme is studying supercritical fluid resources that are likely to occur in the deep roots of volcanic-hosted geothermal systems in the Taupō Volcanic Zone in New Zealand. The research involves geochemical experiments, geophysical surveys, simulation modelling and community engagement. The research includes international collaboration and advisors from IEA-Geothermal member countries (Switzerland, Iceland and USA).

A "Marsden" research project (2019-2021) addressing the topic of improved understanding of natural $CO_2$ flux passing through Taupō Volcanic Zone geothermal systems concluded in 2021.

The University of Auckland PGCert geothermal diploma course had just 6 students enrolled in 2021 because of COVID19 travel restrictions for overseas students. In "normal" years government-sponsored scholarships (up to 25 students) target the training needs of countries such as Indonesia, Philippines, Mexico, Kenya and the Caribbean. Masters and PhD activity in geothermal topics continued through 2021 and the University of Canterbury continued to run geothermal graduate programs: a Geothermal Energy Systems Engineering Group within the College of Engineering, and a Geothermal Resource Research Group within the Department of Geological Sciences.

The New Zealand Geothermal Association 2021 seminar themed "Geothermal in a low carbon future" was held on the 29th July 2021 in Taupō.

The 43rd New Zealand Geothermal Workshop organised by the Geothermal Institute, University of Auckland, was rescheduled from November 2021 to a virtual event on the 2nd and 3rd February 2022.

**Norway**

Geothermal energy use in Norway is dominated by the widespread deployment of geothermal heat pumps. Statistics from the Norwegian heat pump organization (NOVAP) identifies a peak of 3979 GHP installations in 2018. During 2020 about 2400 units were installed. Total GHP capacity is some 1862 MWth (2020 data) in 50,600 installations.

There is no electricity production from geothermal resources in Norway and no geothermal energy installations from wells deeper than 1500m in operation. In 2018 a geothermal de-icing system was installed at Oslo Gardermoen airport with heat extracted from two 1500 m deep bore hole heat exchangers.

Increasing the use of geothermal energy in Norway is aligned with the country´s energy policy of increasing the use of renewable energy resources. Norway has already decarbonised energy in buildings and 45% of new cars sold are now electric. Ferries and boats are converting to electric.

The Research Council of Norway supports geothermal research projects through its ENERGIX programme. Funding from national agencies "Enova" and "Innovation Norway" is also possible for larger industrial projects such as deep well drilling. Norway is contributing to the EU funded Horizon 2020 programme with several Norwegian organisations involved in geothermal projects.

Norwegian industrial and academic expertise in off-shore technologies is anticipated to be readily utilised in an emerging geothermal industry with an emphasis on deep drilling, well technology, reservoir management, corrosion and scaling mitigation, and tracer technology.

The GeoEnergy 21 conference was organized by the Norwegian Centre for Geothermal Energy Research and was held virtually on the 1st and 2nd September 2021.

An update paper on Geothermal Energy in Norway was presented at the World Geothermal Congress April-October 2021 (URL to paper).

**Republic of Korea**

The total installed capacity of geothermal heat pumps in Korea at the end of 2021 was estimated to be ~1.6$GW_{th}$. Since 2012 capacity has been growing at a rate of about 100 $MW_{th}$ per year, albeit declining a little over the last few years, with an estimated 74 $MW_{th}$ installed in 2021.

The government is keen to foster renewable energy deployment with a target of 30-35% renewable power generation by 2040. However, the deep geothermal investment outlook is poor as all deep geothermal exploration activity ceased and has remained in hiatus since the 2017 Mw 5.4 Pohang earthquake that occurred close to the EGS site. Government funds allocated for geothermal research and development are currently reducing year on year.

Korea has been active in Working Group 8 and has led the development of a data collection spreadsheet for GHP statistics. Data for the scheme is entered into the Excel spreadsheet, gross and nett energy consumption are computed, heating and cooling is accounted for separately, and free cooling can be computed if the data is available. The work was reported in a paper and presentation to the 2020+1 World Geothermal Congress, April – October 2021.

**Spain**

The Spanish Government commenced activity on implementation of the Integrated National Energy and Climate Plan (INECP) 2021-2030 lodged with the European Commission in 2020. The plan is focused on achieving carbon neutrality by 2050. Over the ten years from 2020 a 30% reduction in greenhouse gas emissions relative to current emission levels is targeted, which is expected to see a doubling in the utilization of renewable energy.

For five years GEOPLAT has worked with the National Institute of Qualifications of the Spanish Ministry of Education to develop material to qualify professionals in managing the installation and maintenance of geothermal heat exchange systems. In June 2021, the first professional training qualifications on geothermal heating and cooling systems were published in the State Agency for the Official State Gazette (BOE). In September of 2021, ENAE06 the ‘Installations, commissioning and maintenance of closed-loop geothermal exchange facilities’ (level 2) was included in the Catalogue of Formative Specialities of the Spanish Public Service state employment. This enables a Spanish accredited training center to teach this geo-exchange program.

In March 2021, the geothermal district heating network at Fondón, Langreo, Asturias, Northern Spain, was completed. The heat network supplies heating and domestic hot water in buildings located in the city of Langreo (public health center, residential buildings, the Juan Carlos Beiro sports center, the Nuestra Señora del Fresno elderly residence, and the Langreo hotel) through the use of pumped mine water. This, the first of three phases sees geothermal plant supplying 1.5 MW of heat.

In 2021, a deep geothermal direct use project in in Campo de Níjar, Almeria, Southeast Spain saw the first well completed to a depth of 2,000 meters reaching a temperature in its lower zone of 105 ºC. This well provides evidence of the geothermal potential underground with the next wells, expected to reach depths of 2,500 meters. The resulting borehole network is proposed to supply thermal energy to greenhouses. This 8 MW heat supply project could be the forerunner of greater geothermal energy use in the agriculture sector and is a decisive step in the implementation of deep geothermal energy in Spain.

In 2020 the Spanish Association of Heating and Cooling Networks (ADHAC) identified 9 geothermal district heating and cooling systems in operation, with 2 GeoDH systems planned.

GEOPLAT fostered the 'geothermal decade' of activity as the backbone to the Spanish geothermal sector. The decade of activity was inaugurated at the GEOPLAT 2020 Annual Assembly. There were:

- Workshop(s) on geothermal energy in giving coal mines a second life using the heat in the flooded mine workings whilst helping to achieve environmental objectives, decarbonisation and fair energy transition in a number of regions in Spain.
- Working with the Government of the Canary Islands on the Canary Islands Energy Transition Plan and the Geothermal Energy Strategy and Roadmap which identifies necessary actions to increase the use of low and high enthalpy geothermal energy in the Archipelago.
- Participating in several EU funded projects including,
  - GEO-URBAN – The project includes the county of Vallès, Catalonia which is the subject of feasibility study on the utilisation of geothermal resources.
  - GEO-ENERGY EUROPE focused on the transnational European cluster dedicated to the development and improving competitiveness of small and medium sized geothermal enterprises. In the second phase GEO-ENERGY EUROPE 2 which seeks to assist the European SME member companies to win business and export to third-country markets is underway.
  - CROWDTHERMAL. The project released a video explaining the objectives and presents several case studies.
- GEOPLAT was involved in nine workshop / conference events during 2021 including the online GEOPLAT Annual Assembly held on the 12th July 2021.

**Switzerland**

Geothermal use in Switzerland is dominated by shallow lower temperature use with ~2335 $MW_{th}$ of geothermal heat pump capacity installed. The use of geothermal and heat pump technology will continue to grow as the push for renewable heat intensifies over coming years.

Large infrastructure projects, such as rail and road tunnels, are being used as sources of geothermal energy (~11 $MW_{th}$).

Direct geothermal use is dominated by Spa use, with an estimated capacity of ~23 MWth.

There are no geothermal power facilities operational in Switzerland.

The implementation of Switzerland's Energy Strategy 2050 sees financial support measures in place supporting installations using geothermal energy for heating and cooling, and the development geothermal power generation.

During 2021 financial measures supporting geothermal energy available were:

- Financial support for geothermal power generation projects including prospecting and exploration to a maximum of 60% of the eligible cost. Up to CHF 50 million (1 CHF ~ 1 US$) per year available. The scheme runs until the end of 2030.
- Financial support for direct use geothermal energy projects, maximum 60% of the eligible costs, capped at CHF 30 million per year.
- Feed-in tariffs for a 15 year period, for power production from hydrothermal and EGS projects are available up until 1 January 2023.
- For projects subsidised with financial support are required to lodge all data and analyses to the Swiss Geological Survey, Swisstopo. Swisstopo can make full use of the material whilst only some of the material will be published in the public domain.

Switzerland's geothermal research expenditure for 2021 was some USD 20million.

The Swiss Competence Centers for Energy Research (SCCER) concluded at the end of 2020. A synthesis report (Giardini et al, 2021) was published in September 2021 highlighting the major achievements of the SCCER-SoE. (URL to report)

The SWissEnergy research for the Energy Transition (SWEET) funding programme to 2032 is the follow up to the SCCER programme. The goal of SWEET is to accelerate innovations crucial to implementation of Switzerland's Energy Strategy 2050 and the country's climate policy ambitions. The first call on integration of renewables was released under this program in 2020.

Fours areas of Swiss activity in geothermal research are highlighted in the Swiss Chapter (19):

- The hydraulic stimulation work in the underground laboratories. The Bedretto Underground Laboratory for Geoenergy and Geosciences has been functioning since 2019.
- Innovation in Engineered Geothermal Systems (EGS),
- Heat storage, including the two Swiss project sites in Geneva and Bern ( Forsthaus), and
- Drilling technology innovation.

Geothermal conferences or conferences with significant geothermal content in 2020 and 2021:

- Journées romandes de la géothermie 2020, Montreux (VD), 5 February 2020
- Gurten Symposium Geothermie, Quo Vadis, Bern, 4 November 2020
- Geothermie Forum 2021, Fribourg (FR), 21 September 2021.

**United Kingdom**

The most significant use of geothermal energy in the United Kingdom is through geothermal heat pump installations with a forecast capacity of ~780 $MW_{th}$ (2021). Total capacity from deep geothermal energy is ~8.1 $MW_{th}$. Two geothermal power schemes are under development.

The United Downs Deep Geothermal Power project (UDDGPP) project is led by Geothermal Engineering Ltd. and is the first commercial project in the UK to develop deep geothermal for power generation. The production well (UD1) and reinjection well (UD2) were completed in 2019. Successful testing was undertaken during 2021 and the combined heat and power scheme is expected to be completed in 2022.

The Eden project, a second, deep geothermal project in Cornwall situated on the St Austell granite is being developed by Eden Geothermal Ltd. The project has targeted a deep crustal fracture and an initial well to a vertical depth of 4.8 km was completed in November 2021. The target structure was intersected with high temperatures and good permeability reported. The heat will be used in Eden's Biomes, offices and greenhouses. A well for power generation is scheduled for drilling in 2022.

There is growing interest in utilising the waters within disused mine systems for their geothermal potential. Although in many cases the temperature of the water will be at normal ground water temperatures, the high abstraction rates possible make these ideal for large capacity open loop ground source heat pump systems. Additionally at some former colliery sites pumping of the mine waters is already undertaken for environmental reasons. The Coal Authority are developing geothermal heating schemes at a number of their pumped sites.

The Glasgow Geothermal Energy Research Field Site (GGERFS) is operational with 12 wells equipped with high resolution monitoring equipment now open to the UK science community and international researchers. A second research site UKGEOS Chesire is being developed and will include infrastructure for research on GSHP systems, thermal storage in the Triassic Sherwood Sandstone and investigation of environmental aspects.

UK geothermal research is broadening out, with an increasing number of funding calls supporting geothermal research. A number of projects have started in 2021 including under the following;

- NetZero Geothermal Research for District Infrastructure Engineering (NetZero GeoRDIE)
- NERC / EPSRC Programme to Decarbonise Heating and Cooling
- UK Unconventional Hydrocarbons (UKUH) research programme

In Northern Ireland a partnership between academia and Industry focussing on using geothermal energy is being funded through Invest Northern Ireland's Competence Centre Programme and the Centre for Advanced Sustainable Energy.

**United States of America**

The United States of America (U.S.A.) remains the global leader of installed geothermal electricity capacity (~3.7 GWe). Ninety-five percent of this is in California and Nevada.

The 2019 GeoVision analysis, published by the U.S. Department of Energy's Geothermal Technologies Office (GTO), continues to guide geothermal R&D planning.

Drilling activity in 2021 at the Milford EGS Frontier Observatory for Research in Geothermal Energy (FORGE) site in Utah saw the successful completion of the first highly deviated deep well. The well drilled to a total vertical depth of 8,559 ft (~2610 m), and at 6,000 ft (~1830 m) was deviated at 65° from vertical. The well will be used to determine stress conditions and monitor microseismicity to interpret the orientation and distribution of existing and induced fractures in crystalline basement granite lying beneath ~4,700 ft (~1430 m) of sediments.

FORGE also announced up to $46 million of funding for projects on new and innovative enhanced geothermal systems (EGS) tools and techniques. Seventeen projects were selected under five research topics:

- Topic 1: Devices suitable for zonal isolation along cased and open-hole wellbores under geothermal conditions
- Topic 2: Estimation of stress parameters
- Topic 3: Field-scale characterization of reservoir stimulation and evolution over time, including thermal, hydrological mechanical, and chemical (THMC) effects
- Topic 4: Stimulation and configuration of the well at Utah FORGE
- Topic 5: Integrated laboratory and modeling studies of the interactions among THMC processes.

The EGS Collab work launched in 2017 continued through 2021. The team worked on Experiment 2: design, execution, and monitoring of hydraulic shearing of fractures and associated predictive modelling. The Experiment 2 location was moved in 2020 to a location at the 4,100-ft (~1219 m) depth level. Working with the Sanford Underground Research Facility (South Dakota), the Collab team refurbished and modified this location.

The GTO released an up to $14.5 million new Funding Opportunity Announcement (FOA) to support active field testing of EGS technologies and techniques within existing wells. The Wells of Opportunity 2021 FOA, solicited the partnership of well owners or operators to develop geothermal power from existing wells. GTO awarded projects that improve zonal isolation continued to develop prototypes and prepare for field testing, with aims to reduce risk to wellbore integrity and fracture conductivity and to develop tools that can operate extensively at high temperatures and in varying pressures and corrosive, hard rock environments.

GTO projects continue to accelerate explorations and discovery of new, commercially viable hidden geothermal systems, particularly in the Great Basin Region of the western U.S. Projects include INnovative Geothermal Exploration through Novel Investigations Of Undiscovered Systems (INGENIOUS) and Basin & Range Investigations for Developing Geothermal Energy (BRIDGE).

Building on the 2020 GeoDAWN initiative, in 2021 GTO initiated GeoFlight—a partnership with the U.S. Geological Survey for an airborne survey of the Salton Sea region, California. This is to identify new geothermal prospects and potential areas for mineral recovery (e.g., lithium).

The National Renewable Energy Laboratory completed a retrospective report on the studies on deep direct-use (DDU) systems completed in 2020. Work on two study sites continue: Cornell University is proceeding with drilling and stimulation to directly test the concepts from their DDU study; and West Virginia University plans to drill an exploratory well to develop the low-temperature resource beneath their campus and evaluate for energy storage.

Regarding future research priorities, GTO has established key priorities for the next 8-10 yrs. These are to demonstrate geothermal energy's value as the baseload renewable source of the future with three objectives: unlock the potential of EGS; increase geothermal energy on the U.S. electricity grid; and expand geothermal energy opportunities throughout the U.S.

GTO's 2021 Geothermal Collegiate Competition (GCC) focused on community geothermal, specifically addressing the question on how direct-use geothermal can benefit the local community. The competition entries directly support geothermal R&D and are valuable in gauging and developing future R&D initiatives.

GTO continues to expand outreach and stakeholder engagement by presenting R&D overviews or participating in various workshops, conferences and symposiums. GTO provided a keynote plenary and led or participated in multiple technical sessions at the Geothermal Rising 2021 Conference. GTO-funded principal investigators participated in Stanford University's 46th geothermal workshop.

# 1. Introduction

Progress reducing and mitigating greenhouse gas emissions along with the increasing use of renewable energy sources is occurring in many nations with geothermal energy utilisation providing an invaluable contribution.

Geothermal energy is renewable energy, available 24/7 independent of the time of day or the weather. Heat energy can also be stored in the ground for later retrieval and use, such as in borehole energy storage or aquifer energy storage systems. Geothermal resource use and investigations continued to grow through 2021 with a number of nations making significant investments in the direct use of geothermal energy and in geothermal heat pump technology. Growth rates in these sectors are globally running at 10% or more per annum. Globally direct geothermal energy use uptake rates are out pacing the growth rates in geothermal electricity generation.

To develop non-traditional (ultra-high temperature, supercritical and EGS) geothermal resources, technology development is vital. Research in EGS is needed to release the vast geothermal energy potential contained within the earth. Ultr-hot / supercritical research is being undertaken in Japan, Iceland, Italy and New Zealand. EGS research is a particular focus in countries in Europe and the USA. Reliable technology needs to be developed to be able to release the energy potential from these earth energy sources.

## 1.1 IEA Geothermal

The International Energy Agency (IEA) Technology Collaboration Programmes look for solutions to long-term energy challenges through government and industry collaboration. IEA Geothermal seeks to: Promote the sustainable use of geothermal energy through collaboration, facilitating knowledge transfer, providing high quality information, and communicating strategic, economic and environmental value of geothermal energy.

IEA Geothermal has 16 members, 13 countries (Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, Norway, the Republic of Korea, Switzerland, the United Kingdom and the United States of America), Ormat Technologies Ltd (industrial company), the Spanish Geothermal Technology Platform (GEOPLAT) and the European Commission.

IEA Geothermal members focus activities into the Working Groups. Working Group activity is further subdivided into tasks. Task Involvement is determined by members' current interests and their research and development programmes.

IEA Geothermal collects and collates geothermal energy data annually as part of Working Group 10. The data is assembled into annual trend and power statistics reports. These can be found under Working Group Publications tab on the IEA Geothermal website.

The activities of IEA Geothermal are managed by an Executive Committee. Because of the Covid pandemic the two Committee meetings held in 2021 were hosted on virtual platform.

This report provides details on the activities carried out by the Working Groups along with the geothermal activities in member countries. The status, activities and 2021 achievements of the Working Groups are described in Chapters 2 to 6. Information on member activity is found in

Chapters 7 to 21. There are many references to up-to-date information contained within the report which can be found at the end of each chapter.

Appendix 1 details the IEA Geothermal Executive Officers at the end of December 2021, and Appendix 2 the IEA Geothermal Executive Committee Members and Alternates.

For more information on IEA Geothermal please visit our website iea-gia.org or email iea-giasec@gns.cri.nz.

# 2. Working Group 1 – Environmental Impacts

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## 2.1 Introduction

Working Group 1 (Environmental Impacts) has the following goals:

a) encourage the sustainable development of geothermal energy resources in an economic and environmentally responsible manner;
b) quantify and seek ways to balance any adverse impacts that geothermal energy development may have on the environment; and
c) identify ways of avoiding, remedying or mitigating adverse effects.

The Working Group 1 (WG 1) web page on the IEA Geothermal web site can be accessed through this hyperlink.

Collaboration activity commenced in 1997. At that time the activity was referred to as Annex 1. The tasks have changed over time, as different environmental and social issues have been identified and discussed by participants at meetings and workshops. Outputs have consisted of published papers (including three Geothermics Journal Special Issues), recommended protocols, environmental workshops and conference sessions.

In 2021, many activities and new initiatives were again constrained by the COVID pandemic. Topics that were in focus for the working group are briefly described below:

A) Impacts on natural features: monitoring surface thermal feature and ecosystem changes, and devising techniques to avoid or mitigate adverse impacts, while encouraging beneficial effects.

B) Discharge and reinjection: gas emissions ($CO_2$ & $H_2S$); chemical contamination of water, subsidence, scaling and corrosion, and treatment options (e.g. injection).

C) Methods of impact mitigation and environmental procedures: analysis of issues, procedures, efficient policies, protocols, effective compliance, and successful mitigation strategies to address social and environmental effects.

D) Sustainable utilisation strategies: long-term reservoir simulation, optimized operational strategies, recharge factors, recovery times, improved reservoir performance, and sustainability protocol indicators.

The countries officially participating in the WG 1 are Australia, Iceland, Italy, Japan, New Zealand, Norway, Switzerland and the United States.

## 2.2 Highlights

Highlights for the year include:

- Preparation of videos and presentation of environmental and society collaboration papers for WGC2020+1 (presented in April 2021).
- Compilation of further information in preparation for a book on environmental and social impacts.
- Networking and cooperation amongst researchers, operators, policy-makers and funding-agencies within the participating countries.
- Raising international awareness of successful mitigation schemes and beneficial environmental or social outcomes.
- Supporting relevant presentations and publications by scientists from member countries at international conferences and workshops.

## 2.3 Task Progress and Outputs

### 2.3.1 Progress in 2021

WG1 focusses on networking and connecting researchers, policy makers and operators from different countries to increase awareness of environmental improvement opportunities and successful strategies mitigating adverse effects.

Cooperation between WG1 participating countries continues, and members are involved in a range of national and international research projects.

Progress reports on WG 1 activities were presented at the virtual (online) Executive Committee meetings held in 2021.

WG 1 participants were encouraged to address the following issues:

a) Gas emissions, reinjection of non-condensable gases ($CO_2$);
b) $H_2S$ abatement technology;
c) shallow thermal groundwater changes (heating or cooling);
d) insurance industry outreach (communication of risks & solutions);
e) power-plant visibility (acceptable design for a given landscape environment);
f) casing integrity (monitoring corrosion rates);
g) sustainability protocols in practical applications;
h) Improvements in shallow/surface feature and ecosystem monitoring using drones;
i) thermal imaging and satellite imagery for monitoring;
j) subsidence monitoring and improved modelling of reservoir deformation processes;
k) policy initiatives and sustainability modelling scenarios

Selected publications during 2021 by geothermal environmental researchers from participating countries are listed below. A number of these papers were presented and discussed at the following conferences: World Geothermal Congress (WGC) , Stanford Geothermal Workshop (Palo Alto, USA), Geothermal Resources Council Annual Meeting (virtual) and New Zealand Geothermal Workshop (virtual). Papers can be downloaded through the www.geothermal-energy.org conference database.

### 2.3.2 Outputs

The 2021 environmental outputs are linked with task activities, through member country participation or cooperation. These include presentations at several workshops and publications in conference proceedings, including Stanford, GRC and NZGW (Refer the References section).

Joint WG1 papers on Environmental and Social Impacts were presented at WGC2020(+1). Refer to a list of collaborative articles in the References section and https://iea-gia.org/workshop-presentations/2021-world-geothermal-congress/ for links to WG1 papers and video presentations.

During the following WGC Sessions (April to October 2021), 1B, 2B, 3B, 4B, 5B, 5D, 6D, 7B, 7D, 8B, 9B, 9D, 37D, 49A, 49A, 51B, and 55A on 'Environmental', 'Societal', 'Cultural', Sustainability', 'Life-cycle emissions', 'Climate-change', 'Well-being', and 'Regulatory' aspects, a total of 85 papers were presented orally, of which many were prepared by members of countries who take part in IEA Geothermal WG 1 (see Introduction for the list of these countries).

### 2.3.3 Future Activities

Future work includes continuing efforts on the existing tasks.

a) Preparation of a book describing international geothermal environmental codes-of-practice, and effective protocols and policies for environmental management of geothermal projects.

> Sub topics include: construction and drilling environmental effects; induced seismicity; production & injection effects (noise, effluents, emissions); social impacts; promotion of beneficial effects and mitigation of adverse effects; methods of drilling/producing/injecting deep beneath protected areas with negligible surface impact; subsidence mitigation by injection; avoiding groundwater contamination; Biochemical remediation/treatment of condensates; Monitoring of casing integrity to protect groundwater; Appropriately allocating geothermal systems for protection or development using categories and criteria; Streamlining Environmental Impact Assessments (EIA) by standardising common issues and good practice procedures; cooling, stimulation and make-up water issues; tools to monitor, model and manage sustainable reservoir performance and long term reinjection; communication with local and indigenous stakeholders.

b) Planning and organising workshops or special sessions on, for example, sustainability and surface feature monitoring.

c) Collating results of trials; using targeted shallow reinjection of hot fluids to remedy adverse effects; on $CO_2$ gas injection; and on water treatment to remove potentially harmful chemicals.

## 2.4 References


**Journal papers:**

Astu Sam Pratiwi, Evelina Trutnevyte, "Life cycle assessment of shallow to medium-depth geothermal heating and cooling networks in the State of Geneva" Geothermics, 90, 101988, (2021)

Balzan-Alzate, D., López-Sánchez, J., Blessent, D. "An online survey to explore the awareness and acceptance of geothermal energy among an educated segment of the population in five European and American countries", Geothermal Energy, 9, 9 (2021).

Kathrin Menberg, Florian Heberle, Christoph Bott, Dieter Brüggemann, Peter Bayer "Environmental performance of a geothermal power plant using a hydrothermal resource in the Southern German Molasse Basin", Renewable Energy, 167, p20-31, April 2021.

Andrea Paulillo, Aleksandra Kim, Christopher Mutel, Alberto Striolo, Christian Bauer, Paola Lettier "Influential parameters for estimating the environmental impacts of geothermal power: A global sensitivity analysis study", Cleaner Environmental Systems,3, 100054, (2021)

**Conference papers (accessible through www.geothermal-energy.org/cpdb/search.php)**

**WGC2020: (video presentations in 2021), Reykjavik, Iceland**

Chris BROMLEY, Lauren BOYD, Adele MANZELLA, Kasumi YASUKAWA : Review of Environmental & Social Aspects and Best-Practice Mitigation Measures from an IEA-Geothermal Perspective. Paper #02007. [Video] and {Paper]

Jonas KETILSSON, Chris BROMLEY : Adaptive Leadership Roles and Tools of Government to Assist Geothermal Developers in Overcoming Barriers. Paper #03037. [Video] and [Paper]

**46th Stanford Geothermal Workshop, February 2021**

M. CAVUR, J. MORAGA, H.S. DUZGUN, H. SOYDAN and G. JIN "The DInSAR Analysis with Machine Learning for Delineating Geothermal Sites at the Brady Geothermal Field"

C.TEODORIU, W.BROWN, D.EDWARDS, J.HEATLY, A. OAKES, R. SANDMANN "Reducing Emissions in Hydraulic Fracturing for Geothermal Application with the Technology Revolution"

**Transactions Geothermal Resources Council Annual Meeting October 2021**

Robins, J. C. "The Impacts of Geothermal Operations on Groundwater"

**43nd New Zealand Geothermal Workshop (virtual, postponed), New Zealand:**

K. McLean, I. Richardson "GEOTHERMAL GREENHOUSE GAS EMISSIONS IN NEW ZEALAND IN 2020: LIFECYCLE AND OPERATIONAL EMISSIONS"

I. Galeczka, I. Chambefort "THE POTENTIAL OF GEOTHERMAL EMISSIONS STORAGE IN THE TAUPŌVOLCANIC ZONE, NEW ZEALAND"

N.C. Ruiz, K. McLean, I. Richardson, T. Misa, A. Ferguson, D.E. Altar, and E. Kaya "PASSIVE NCG REINJECTION AT TE HUKA GEOTHERMAL BINARY POWER PLANT"

A. Dean, G. Ussher, W. Gerardi, L. Schwartz, A. Batten, A. Hochwimmer, and S. Henderson "GEOTHERMAL AND HYDROGEN: COULD HYDROGEN MAKE SOME GEOTHERMAL PROJECTS VIABLE?"

K.A. Titus, D. Dempsey, R. Peer "CARBON NEGATIVE GEOTHERMAL: THEORETICAL COMBINED GEOTHERMAL BECCS INJECTION CYCLE"

A. Choudhary, J. Burnell, R. Rayudu and J. Hinkley "ANALYSIS OF THE IMPACT OF THE REINJECTION OF GASES ON THE MASS FLOW RATE FROM PRODUCTION WELLS AT VARYING RESERVOIR CONDITIONS"

M.J. Gravatt, J.P. O'Sullivan, J. Popineau and M.J. O'Sullivan "NUMERICAL MODELLING FOR CARBON ACCOUNTING FROM GEOTHERMAL POWER PLANTS"

P. Doorman, J.L. Lebe, K. Luketina, J. McLeod, and P. Parson "A REVIEW OF GEOTHERMAL RESOURCE MANAGEMENT UNDER THE RMA 1991 WITH A VIEW TO THE FUTURE"

K. Dekkers, M. Gravatt, O.J. Maclaren, R. Nicholson, J. O'Sullivan, M. O'Sullivan "DATA-WORTH ANALYSIS: DESIGNING A MONITORING PLAN FOR ROTORUA THAT REDUCES UNCERTAINTY"

# 3. Working Group 8 – Direct Use of Geothermal Energy

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## 3.1 Introduction

During recent decades the direct use of geothermal energy has become more important with steadily increasing uptake worldwide. Applications include: facilities heating, area/district heating schemes, greenhouse heating, crop drying, aquaculture, snow melting, spas and bathing, therapeutic applications, industrial process heat, and small and large heat pump applications. The heat pump applications include "smart thermal" low-temperature grids combined with underground thermal storage. Additionally, cooling using geothermal energy is becoming important.

The Working Group (WG) gathers and disseminates quality information seeking to mitigate barriers and enhance direct geothermal utilisation. The main objectives are to collaborate, cooperate, share knowledge, and boost awareness, fostering the uptake of direct geothermal use technologies.

In 2013, WG 8 was restructured to include five tasks, with one task (E) continuing from earlier work and four tasks initiated:

A. New and Innovative Geothermal Direct Use Applications,
B. Communication,
C. Guidelines on Geothermal Energy Statistics,
D. Guidelines on Statistics for Geothermal Heat Pump Applications and
E. Design Configuration and Engineering Standards (continued).

In 2018, Task F was launched, Costs of Geothermal Heat Pump Systems.

In 2019, Task G was launched, Monitoring Systems. This was to capture interaction associated with the IEA HPT Annex 52 and IEA ECES Technology Collaboration Programmes.

More details on the scope of each of the tasks is provided in the Task Statements in Section 4.

Task C was completed in 2017 following GEOSTAT activity funded through the Geothermal ERA-NET which developed from the Ketilsson et al (2015) publication 'International Collection of Geothermal Energy Statistics – Towards reducing fragmentation and improving consistency'.

Task D was completed in 2021 with the publication of Song et al (2021) in the proceedings of World Geothermal Congress in 2020+1.

Task G concluded with the conclusion of IEA HPT Annex 52 in December 2021.

Current participants of WG 8 are France, Germany, Iceland, Japan, Mexico, New Zealand, Republic of Korea, Switzerland, United Kingdom, and United States of America. Observing guests are Australia, Norway, and the European Commission.

Geothermie-Schweiz, the Swiss Geothermal Association (https://geothermie-schweiz.ch/) led WG 8 from September 2012 until the end of July 2020. The WG lead role remained vacant through 2021.

## 3.2 2021 Highlights

The Mine Water Geothermal Energy Symposium organised by the British Geological Survey (BGS), the Department for Business, Energy and Industrial Strategy (BEIS) and IEA Geothermal was held virtually on the 10th and 11th March 2021. The symposium attracted interest from up to 200 people on line at peak times, from 73 countries. Presentations can be accessed from this web page (URL to presentations).

Three WG 8 publications were published in the proceedings of the World Geothermal Congress 2020+1. For two of the papers the presentation videos are also available with a URL to access the video included at the end of the paper reference:

> Link, K., Carey, B., Geothermal Direct Use - International Energy Agency Geothermal TCP. (pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/28029.pdf) [Video]
>
> Song, Y., Link, K., Yasukawa, K., Weber, J., Proposal of New Data Collecting Spreadsheet for Geothermal Heat Pumps Statistics: An Outcome of IEA Geothermal Working Group Activities. (pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/29009.pdf) [Video]
>
> Farr, G., Busby, J., The Thermal Resource of Mine Waters in Abandoned Coalfields; Opportunities and Challenges for the United Kingdom. (pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/41021.pdf)

## 3.3 Task Activity

### 3.3.1 Task A – New and Innovative Geothermal Direct Use Applications

The Mine Water Geothermal Energy Symposium organised by BGS/BEIS/IEA Geothermal was held virtually on the 10th and 11th March 2021. Presentations can be accessed from this web page (URL to presentations).

A number of innovative geothermal heat pump projects are being assembled as two-page case studies to be uploaded to the IEA Geothermal website (URL to web page).

### 3.3.2 Task B – Communication

No activity in 2021.

### 3.3.3 Task C – Guidelines for Geothermal Energy Statistics

Task completed and closed in 2017.

### 3.3.4 Task D – Statistics for Geothermal Heat Pump Applications

Publication of the paper (Song et al 2021) in the proceedings of World Geothermal Congress in 2020+1 completed Task D. The Task closed at the end of 2021.

### 3.3.5 Task E – Design Configuration and Engineering Standards

No activity.

### 3.3.6 Task F – Costs of Geothermal Heat Pump Applications

No activity.

### 3.3.7 Task G – Monitoring Systems

Annex 52 concluded in December 2021 and the work reported in the final report. The report (Davis et al 2021) can be accessed through the URL link (URL to report).

## 3.4 Task Statements

The task statements for each of the tasks are below.

### 3.4.1 Task A- New and Innovative Geothermal Direct Use Applications

Task Leader: Brian Carey, GNS Science, New Zealand

Geothermal direct use technologies are mature and in general competitive in a number of established markets. Innovative applications to open up new possibilities for utilization, to enhance efficiency, and to reduce costs are being explored. These include projects such as "smart city thermal networks" and geothermal energy in combination with other energy sources, such as solar energy. In the agricultural sector there is significant potential for new and innovative direct use applications. In many countries in the world, cooling from geothermal energy is as important as heating

### 3.4.2 Task B – Communication

Task Leader: Vacant

Although the worldwide technical and economic potential of geothermal direct use applications is enormous, knowledge amongst the general public, politicians and decision-makers is generally lacking. The level of awareness varies widely. In some countries, like many in Europe, the potential of GSHP systems for heating residential houses is well known, but the fact that there are many other applications much less so. Even in a country like New Zealand, which has obvious potential, the many direct uses for geothermal energy are poorly known compared to geothermal power generation. To boost geothermal direct use and to enhance deployment, communication is essential. Activities are concentrated on collecting available information from member countries and cooperating organizations, exchanging experiences, identifying barriers and opportunities, and communication.

### 3.4.3 Task C – Guidelines for Geothermal Energy Statistics

Task Leader: Jonas Ketilsson, Orkustofnun, Iceland

Geothermal energy statistics, especially geothermal direct use statistics, have been a major point for discussion. The aim of the Task is to give an overview of the international collection of geothermal energy statistics by various international agencies, offices, organizations and associations. The goal is to enable the successful exchange and interpretation of shared energy statistics, to increase reliability, to decrease fragmentation, and to increase coherence.

This work is conducted within the scope of the Geothermal ERA NET supported by the European Commission seeking to develop guidelines to improve geothermal energy statistics.

### 3.4.4 Task D – Statistics for Geothermal Heat Pump Applications

Task Leader: Yoonho Song, Korean Institute of Geoscience and Mineral Resources (KIGAM), Republic of Korea.

The main objective of Task D is to develop data recording in a consistent manner widely adopted across the globe for computing national and world statistics. The data recording methodology will include all types of GHP installations and consider cooling as well as heating.

Different load factors are applicable to various types of direct utilization, such as heating a residential house, an office building, or a green house, but different load factors are not usually considered when estimating capacity factors of the different applications. In smaller applications, as opposed to large-scale district or other heating systems, flow rate monitoring is not often undertaken and the thermal loads for GSHPs are not determined. There is therefore significant uncertainty in the statistics for geothermal energy use in GSHPs, at both a national and global level. In addition, many countries do not separate the statistics for cooling with GSHPs from heating, which causes further uncertainty in the statistics. Consequently, Task D was initiated in 2013 to determine a method for estimating geothermal energy utilization with GSHPs as accurately as possible.

If the statistics and the standard load pattern of each application type could be determined, it might be possible to establish a recommended method, or develop a reference table for calculating GSHP statistics.

### 3.4.5 Task E – Design Configuration and Engineering Standards

Task Leader: Kasumi Yasukawa, JOGMEC, Japan

The Scope of this Task is to collect, characterize and exchange standard design and practice information for applications, with the goal of minimizing the engineering related input. The main issues are quality, reliability of operation, long term efficiency, sustainability, and cost reduction achievable through standardized procedures. Examples of successful cooperation are the dissemination of experience using quality certificated ground source heat pump installers, and the results from long-term monitoring of installations. Task E also includes documentation assembling listings of national and international standards (norms), engineering practices and other relevant documents.

### 3.4.6 Task F – Costs of Geothermal Heat Pump Applications

Task Leader: Vacant

Costs are the key issue in most countries worldwide, especially in emerging economies and developing countries. Knowledge about the costs of geothermal heat pump applications and the influencing factors are crucial for boosting deployment of such systems. Cost data from the WG member countries and some further selected countries, especially in Europe, will be collected and analysed and the influencing factors deduced. The results will allow conclusions to be drawn on how costs can be minimized efficiently and sustainably while maintaining high quality standards.

### 3.4.7 Task G – Monitoring Systems

Task G was set up to work with Annex 52 in the IEA HPT Technical Collaboration Programme as was appropriate.

## 3.5 Concluding Remarks

Funding is being worked through to enable a new leader for Working Group 8 to be appointed.

## 3.6 References

Davis, M., Martinkauppi, I., Witte, H., Berglöf, K., Guidelines for Instrumentation and Data. IEA HPT Annex 52 Final Report. December 2021. (2021) Report: https://heatpumpingtechnologies.org/annex52/wp-content/uploads/sites/60/2021/12/instrumentationguidelinefinal.pdf

Farr, G., Busby, J., The Thermal Resource of Mine Waters in Abandoned Coalfields; Opportunities and Challenges for the United Kingdom. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)
Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/41021.pdf

Ketilsson, J., Sigurðsson, T., Bragadóttir, E.R., International Collection of Geothermal Energy Statistics – Towards reducing fragmentation and improving consistency, Orkustofnun, February 2015 (2015) ISBN: 978-9979-68-351-3. (URL for document)

Link, K., Carey, B., Geothermal Direct Use - International Energy Agency Geothermal TCP. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)
Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/28029.pdf

Song, Y., Link, K., Yasukawa, K., Weber, K., Proposal of New Data Collection Methodology for Geothermal Heat Pumps Statistics - an Outcome of IEA Geothermal Working Group Activities. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021)
Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/29009.pdf

# 4. Working Group 10 – Data Collection and Information

Brian Carey

Executive Secretary, IEA Geothermal, email: iea-giasec@gns.cri.nz

## 4.1 Introduction

Working Group (WG) 10 activity focuses on collecting geothermal energy use data, analyzing statistical trends and tracking geothermal developments in IEA Geothermal member countries. This material is published in IEA Geothermal Trend Reports (iea-gia.org/publications-2/working-group-publications). All Contracting Parties participate in this Working Group and sponsors also contribute.

The Operating Agent for the Working Group is the Leibniz Institute for Applied Geophysics (LIAG), Germany led by Josef Weber. The contract funding for this work stream has been interrupted since the beginning of 2020, with funding anticipated to be accessible again from later in 2021. This has resulted in the data analysis task not being completed during 2021.

The task of data collection and information is important in terms of the demand for reliable renewable geothermal energy use data. Data collection activities commenced in 2011 with data collated for the 2010 year. Additional data from nations that are not IEA Geothermal participants but have significant geothermal energy developments are also compiled and analyzed, seeking to provide more complete comparative analysis on global trends.

The Geothermal Trend Report provides a brief overview of key data on geothermal energy use and shows the national progress in the development of geothermal energy activities.

Data on geothermal power utilization is easier to obtain than heat utilization data, and since 2016 IEA Geothermal have produced a separate Geothermal Power Statistics Report earlier in the year than the Trend Report. This short report includes tables and figures on the development of geothermal power in IEA Geothermal member countries along with an overview of the latest geothermal power plants commissioned.

Work is in progress to collaborate with other institutions and organizations operating internationally in the field of geothermal energy data in an effort to expand the database to include geothermal energy use data from an increasing number of non-member countries as geothermal development increases worldwide.

## 4.2 Highlights

Two IEA Geothermal papers on data and reporting were published in the proceedings of the World Geothermal Congress 2020+1 (2021).

Weber,J., Wissing, L., Ten Years of Geothermal Trend Reporting and Statistics by IEA Geothermal. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021) Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/40000.pdf

Song, Y., Link, K., Yasukawa, K., Weber, K., Proposal of New Data Collection Methodology for Geothermal Heat Pumps Statistics - an Outcome of IEA Geothermal Working Group Activities. Proceedings World Geothermal Congress 2020+1. Reykjavik, Iceland, April - October 2021 (2021) Paper: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/29009.pdf and [Video]

## 4.3 Progress in 2021

Data analysis work has been on hold during 2021 pending contract renewal with the Leibniz Institute for Applied Geophysics.

## 4.4 Outputs

See highlights section above.

## 4.5 Future Activities

- Preparation and publication of the IEA Geothermal Trend and Power Reports, including analysis of data from 2018 and the preparation of the 2020 and 2021 reports.
- Continuing collaboration with other organizations and institutions to expand data collection and to extend the countries involved.

# 5. Working Group 12 – Deep Roots of Volcanic Systems

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## 5.1 Introduction

The deep roots of volcanic geothermal systems involve various heat transfer processes including the flow of magma, flow of single-phase, two-phase or supercritical fluids (water and gas), and water-rock interactions involving gases and salts. These processes are difficult to monitor and challenging to simulate using geothermal simulation modelling methods and laboratory experiments. Developing a strategy for deep roots energy utilisation therefore requires improved modelling methods, innovation of measurement tools and better understanding of high temperature water-rock-gas-salt interaction. Advances are being accelerated by collaborative research, cooperation, and coordination across international research groups, including those that are represented by IEA-Geothermal participants in Working Group 12 (WG 12).

WG 12 strategies to address these challenges, are:

Task A: Compilation of conceptual models of the roots of volcanic geothermal systems and associated research methods, using open-source information from participating countries to provide background material for deep-roots research, including information on exploration, modelling methods and tools.

Task B: Advancement of methods for deep geothermal exploration to disseminate information on advances in exploration methods, facilitate cooperation amongst research-groups, and enhance the depth resolution of available methods by using the power of joint data-set interpretation.

Task C: Methods for modelling conditions and processes in deep geothermal resources, by advancement of methods applied in the modelling of physical processes, revealing the overall process of upwards heat transfer, improving geothermal reservoir modelling, and enhancing synergy by avoiding duplication of effort through improved sharing of open-source software and information.

## 5.2 Highlights

Key highlights for WG12 in 2021 are:

- Presentation of a joint paper for WGC2020+1 in July 2021 (see the References section) and participation in sessions addressing supercritical geothermal research.
- Presentations by scientists from member countries at international conferences and workshops (GRC meeting and NZGW workshop);
- Peer reviewed papers by scientists from member countries;
- Strengthening of internal cooperation between WG12 participating countries; along with expanded involvement in various national and international research projects. An example is a series of joint seminars on supercritical topics organised between JOGMEC (Japan) and GNS Science (New Zealand) under a collaboration MOU proposed by IEA-

Geothermal members. Another example is the DEEPEN project established between collaborating European and US partners.

- Planning and preparation of a 3-day seminar on supercritical resources, organised jointly between IEA-Geothermal WG12, IPGT modelling group and 'Geothermal: the Next Generation' (hosted by New Zealand), that was delayed and eventually held virtually in February 2022.

## 5.3 Progress and Outputs

### 5.3.1 Progress in 2021

WG12 activities to date have been jointly coordinated by Chris Bromley (New Zealand) and Gudni Axelsson (Iceland). Keen participation from other country representatives (especially Japan, USA, Switzerland and Italy) continues.

A compilation of references from relevant conferences and participating countries are listed in the References section.

Below is a review of the most significant 2021 activities. As in 2020, some constraints on activities were caused by the COVID pandemic.

Internal cooperation between WG 12 participating countries continued to be strengthened. The list below identifies WG 12 participant involvement in recent and current national and international research projects on deep roots, supercritical and super-hot resources:

- Supercritical Geothermal Resources research in Japan (AIST and JOGMEC)
- Supercritical ("Geothermal the Next Generation") and super-hot fluids research (funded by New Zealand government) which includes collaboration with Swiss, USA Japanese and Icelandic researchers www.geothermalnextgeneration.com/
- DEEPEGS, H2020 EU funded (deep stimulation in Iceland) www.deepegs.eu
- IDDP, Iceland deep drilling project (4-5 km) – Two wells completed and IDDP-3 in planning. https://iddp.is/
- GEORG SU-DG-IWG, Deep roots exploration and utilization in Iceland and Europe https://georg.cluster.is/su-dg-iwg/
- Krafla Magma Testbed (KMT), Iceland https://www.kmt.is/
- IPGT- cooperation in supercritical modelling https://ipgtgeothermal.org/
- Hot Rock Energy Research Organisation (HERO), Clean Air Task Force (CATF), USA www.catf.us/work/superhot-rock/
- DEEPEN – 'derisking exploration plays in magmatic environments' (including supercritical and super-hot), is a Geothermica project, 2021-2024, involving consortium members from Iceland, USA, Norway, Germany, Switzerland and France; and includes a 2021 data catalogue for US magmatic geothermal systems set up as open source training sites https://gdr.openei.org/submissions/1332

### 5.3.2 Outputs

The 2021 outputs that are linked with WG12, directly or indirectly through participation by member countries, are listed in the References section. These include various presentations at workshops, as well as papers published in conference proceedings (accessible through https://www.geothermal-energy.org/cpdb/search.php) and peer-reviewed journals. Planning was undertaken for a joint 3-day seminar (IEA-Geothermal, IPGT and Geothermal- The Next Generation) on the themes of 'modelling', 'geochemistry' and 'other' (smorgasbord).

The latest published results from a Geothermics Virtual Special Issue titled 'Supercritical Geothermal' are listed in the link below. The titles and first authors of the papers are also provided in the references section.

https://www.sciencedirect.com/journal/geothermics/special-issue/10Z8R36V2X6

This special issue involves the results of targeted Japanese research (with assistance from international reviewers) into geological, geophysical, geochemical and modelling studies to simulate super-hot energy extraction and to explore potential utilisation strategies.

### 5.3.3 Future Activities

An important planned activity will be the presentations at the 3-day joint seminar on Supercritical Resources in February 2022. Other future activities will build on the achievements to date, by communicating and sharing research results amongst participating countries and organisations. The objective is a reduction of duplication of effort and acceleration of deployment opportunities for supercritical (deep roots) geothermal resource utilisation. Participation of research collaborators is anticipated in a call for papers for a new "Geothermal Energy" journal special issue "On the future development of superhot and supercritical geothermal systems" : https://geothermal-energy-journal.springeropen.com/shgs2

Planning for other future activities includes :

a) Begin planning of a follow-up international seminars to discuss the results of recent research into supercritical resource utilisation and assessment methodologies;
b) Completion during 2022 of the virtual special issue of Geothermics Journal titled 'Supercritical Geothermal', led by Japan, with support from international reviewers;
c) Match up projects such as Swiss (ETH), New Zealand, USA, Italian and Japanese supercritical resource capacity and assessment methods, Norwegian high temperature tracers to assess permeability, modelling advances, and Iceland's planned IPPD3 drilling project.

## 5.4 References - 2021

**Geothermics Virtual Special Issue on 'Supercritical Geothermal' 1st author & paper titles:**


1. Norio Yanagisawa Estimation of Casing Material Corrosion Rates in Supercritical Geothermal Development

2. Jun-ichiro Ishibashi Gas geochemistry of geothermal fluids from the Hatchobaru geothermal field, Japan

3. Takatoshi Ito Experimental and Numerical Study on a Two-stage Coring Method for Stress Measurement: Application to Deep and High-Temperature Geothermal Wells

4. Eko Pramudyo $CO_2$ injection-induced complex cloud-fracture networks in granite at conventional and superhot geothermal conditions

5. Ryota Goto		Wellbore stability in high-temperature granite under true triaxial stress
6. Norihiro Watanabe		Electrical conductivity of H2O-NaCl fluids under supercritical geothermal conditions and implications for deep conductors observed by the magnetotelluric method
7. Keiichi Ishizu		Ability of the magnetotelluric method to image a deep conductor: Exploration of a supercritical geothermal system
8. Yusuke Yamaya		3-D resistivity imaging of the supercritical geothermal system in Sengan geothermal region, NE Japan
9. Kazuya Ishitsuka		Constraining temperature at depth of the Kakkonda geothermal field, Japan, using Bayesian rock-physics modelling of resistivity: implications to the deep hydrothermal system
10. Kyosuke Okamoto		Structures and fluid flows inferred from the microseismic events around a low-resistivity anomaly in the Kakkonda geothermal field, Northeast Japan
11. Kentaro Aoyama		Magnetotelluric Study on a Vapor-dominated Geothermal Reservoir in the Matsukawa area, Japan

**Workshops/meetings:**

**WGC2020 presentations**

Chris BROMLEY, Gudni AXELSSON, Hiroshi ASANUMA, Adele MANZELLA, Patrick DOBSON: Supercritical Fluids - Learning about the Deep Roots of Geothermal Systems from IEA Geothermal Collaboration. Paper # 37011, July 2021, Session 42C. [Paper] and [Video]

Other WGC2020+1 papers from WG12 participating countries on supercritical fluids research include 13 general papers, 9 geophysics papers, 14 IDDP2 and Krafla (Iceland) papers, and 7 geochemistry and modelling papers, mainly in sessions 8C, 42C, 43C, 44B, and 44C. Refer to https://wgc2020.com/programme/

**Transactions Geothermal Resources Council, Vol. 45, (October 2021)**:

MacDonald, W. D.; Gram, M. “Titanium Casing for High Temperature Wells”

Robisson, A. “Materials For Swellable Annular Seals In High Temperature Wells”

Sakuma, S.; Naganawa, S.; Sato, T.; Ito, T.; Yoshida, Y. “Evaluation of High-Temperature Well Cement for Supercritical Geothermal Drilling”

Hoshino, A.; Naganawa, S.; Sato, T.; Ito, T.; Yoshida, Y. “Numerical Study on Downhole Temperature Distribution During Cementing Operation for Supercritical Geothermal Wells”

Houde, M.; Woskov, P.; Lee, J.; Oglesby, K.; Bigelow, T.; Garrison, G.; Uddenberg, M.; Araque, C. “Unlocking Deep SuperHot Rock Resources Through Millimeter Wave Drilling Technology”

Uddenberg, M. “Superhot Rock Economics: An Exploration of the Parameters Controlling the Cost of Superhot Rock Resources”

Johnston, J.; Scruggs, J.; Taylor, C. D.; Hoyer, D.; Kovacs, W. “An Ultra-High Temperature Logging Tool Enabled by Additive Manufacturing”

**Proc. 43rd New Zealand Geothermal Workshop, New Zealand (2021, postponed to January 2022):**

B. Carey, M. Climo, I. Chambefort, C. Miller, A. Rae, D. Kissick, P. Bixley, R. Winmill "NEW ZEALAND'S PATHWAY TO SUPERCRITICAL GEOTHERMAL ENERGY USE: MOVING FORWARD TO EXPLORATION DRILLING" [Video} and [Paper]

P.M. Rendel, B.W. Mountain, L. Sajkowski, and I. Chambefort "EXPERIMENTAL STUDIES OF SUPERCRITICAL FLUID-ROCK INTERACTIONS - GEOTHERMAL: THE NEXT GENERATION" [Paper]

N. Yanagisawa, M. Sato, K. Osato, Y. Yamamoto, K. Lichti, B. Mountain, and L. Sajkowski "CORROSION RATE ESTIMATION OF Cr CASING STEELS AT HIGH TEMPERATURE ACID CONDITIONS" [Paper]

D. Dempsey, C. McConnochie "THEORETICAL MODELS OF MAGMA ASCENT THROUGH A GEOTHERMAL BOREHOLE" [Paper]

# 6. Working Group 13 – Emerging Geothermal Technologies

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## 6.1 Introduction

Working Group (WG) 13, Emerging Geothermal Technologies, was established on 21st April 2015 and commenced work subsequent to a meeting in Hanover, Germany, in September 2015. The working group covers a broad spectrum of geothermal activity including: exploration, drilling, reservoir creation and enhancement, corrosion and scaling in surface facilities, the use of tracers, and the mitigation of induced seismicity.

Work in WG 13 is currently carried out in five tasks:

- A: A1. Exploration (Geothermal Play Types)
  - A2. Measurement and Logging
- B: Drilling Technology
- C: Reservoir Creation and Enhancement
- D: Induced Seismicity
- E: Surface Technology (Heat and Electricity Production, Corrosion, Scaling, Tracer Technology)

The goal of WG 13 is to provide quality information to facilitate and promote the utilization of geothermal energy worldwide. The development of innovative technologies is being pushed by expert collaboration between countries with the results made available in documents and presentations at conferences and workshops.

Participants are Germany, Switzerland (with Christian Minnig as WG co-leader), Norway (IFE), Korea (KIGAM), New Zealand (GNS Science), Japan, Australia, France, the United States and the European Commission.

### 6.1.1 Highlights

2021 saw little activity of the entire working group due to the ongoing Covid-19 pandemic which made collaboration difficult and so there are no highlights to report.

## 6.2 Task A – Exploration, Measurement and Logging

Task A is targeting sharing information on new and emerging technologies in exploration, measurement, geophysical and well logging, and sharing experiences from case studies in geothermal fields in different countries.

In 2017 Task A was subdivided into two subtasks: Task A1 Exploration (Geothermal Play Types) is led by Prof. Dr. Inga Moeck from the Leibniz Institute for Applied Geophysics (LIAG), Germany, and Task A2 Measurement and Logging is led by Dr. Tae Jong Lee from the Korea Institute of Geoscience and Mineral Resources (KIGAM).

### 6.2.1 Progress in 2021

#### Subtask A1: Exploration

No activity to report in 2021

#### Subtask A2: Measurements and logging

Subtask A2 continued collecting and sharing Information on high temperature and high pressure (HTHP) logging tools and services. Articles presented from WGC2020+1 were added to the archives.

An innovative idea developing a geothermal logging tool utilizing a cryoflask to achieve stable and lower payload component temperatures during logging operations leading to longer in well operational times was published in the proceedings of the World Geothermal Congress 2020+1 (Hjelstuen et al., 2021).

### 6.2.2 Outputs

#### Task A: Exploration, Measurements and logging

No output to report in 2021

### 6.2.3 Future Activities

#### Subtask A1: Exploration

Future activities not planned yet

#### Subtask A2: Measurements and logging

It is planned to keep updating the list of organizations who can provide downhole measurements and logging services for geothermal applications and on the research projects developing HTHP tools. Several articles about borehole seismic systems utilizing optical fibre cables were published in the WGC2020+1 proceedings.

## 6.3 Task B – Drilling Technology

Drilling can account for up to 50% of the total costs of a geothermal project. Task B seeks to address the question of reducing drilling costs and innovative drilling alternatives to rotary methods that are predominantly used. For this purpose, Task B includes the compilation of geothermal well drilling performance and cost information. The aim is to identify problem areas identifying possible improvements.

### 6.3.1 Progress in 2021

The task leader is currently on leave, hence no activity to report in 2021 and so for organizational reasons it was necessary to suspend the task until end of 2022.

### 6.3.2 Outputs

No output to report in 2021.

### 6.3.3 Future Activities

Activities will be planned for 2023 including contact being made with a Swiss drilling expert to discuss the strategy of the task.

## 6.4 Task C – Reservoir Creation and Enhancement

Reservoir creation and enhancement technologies are of the utmost importance to exploit the enormous worldwide untapped geothermal energy potential. In most countries, there are no naturally occurring hydrothermal reservoirs which can be used for energy production. Even in countries like New Zealand, Iceland and the Philippines such technologies are crucial, as the favourable hydrothermal conditions providing sufficient natural fluid flow for economic geothermal utilisation are limited to a few spatially restricted areas.

As a consequence, in most countries deeper geothermal energy remains undeveloped. To utilize the vast quantity of energy stored in the earth, new and innovative technologies to create or enhance artificial reservoirs have to be developed and improved.

The objectives of Task C are to:

- establish a platform for international knowledge and information exchange,
- collate quality information with the overall goal of accelerating the development of these technologies, and
- mitigate the technical and non-technical barriers.

### 6.4.1 Progress in 2021

No activity to report in 2021

### 6.4.2 Outputs

No output to report in 2021

### 6.4.3 Future Activities

Future activities are not planned yet

## 6.5 Task D – Induced Seismicity

### 6.5.1 Progress in 2021

Induced seismicity can potentially provide both a benefit (in terms of enhanced fracture permeability for heat extraction) and a risk for geothermal projects, particularly those involving deep EGS stimulations, and those located in densely populated regions, near quake-prone buildings, or regions where people are not familiar with the felt effects of natural earthquakes. Collaborative research into this topic commenced in 2004 as a task in Annex 1 which moved to Annex 11, and in 2015 this transferred to Task D under WG 13. The initial work focus was on developing a protocol to assist developers and regulators, as well as providing a forum for research collaboration and information exchange. Collaboration with IPGT continued between individuals researching various aspects of geothermal induced seismicity. In 2021, opportunities for joint work between researchers and geothermal field operators were further pursued.

### 6.5.2 Outputs

In 2021, the primary effort of this task was to continue the activities of previous years (where-ever practical, given COVID-19 travel constraints) and further encourage researchers to share the results of their funded research. Countries with a strong interest in this topic include: Germany, France, Switzerland, Iceland, Japan, USA and New Zealand.

Geothermal participants from IEA Geothermal countries continued to work on topics such as: consistent earthquake data protocols, understanding mechanisms, and improving advanced forecasting methods using a modified “traffic-light” approach. Mitigation of larger events using ‘softer’ reservoir stimulation options is anticipated. An adaptive response to observed levels of seismicity based on modifying injection and stimulation parameters is expected. Research is also focused on better understanding the key mechanisms behind induced seismicity that can accompany both long term injection and production of fluids.

A paper prepared for the WGC2020+1 meeting was presented in April 2021 (see reference section below, which includes a selection of papers presented during various WGC sessions by groups of induced seismicity researchers from participating countries). Papers by similar groups were also published in other geoscientific journals. These are also listed in the reference section.

Papers on the topic of geothermal induced seismicity were presented and published in the proceedings of several other major international geothermal workshops. They included: 46th Stanford Geothermal Workshop (16-18 February 2021, Virtual, California), the 43rd New Zealand Geothermal Workshop, Auckland, New Zealand, (presentations were postponed to a virtual meeting in February 2022), the Geothermal Rising Conference, USA (2-6 October 2021), and the 9th European Geothermal Workshop, held at KIT Karlsruhe on the 23th of September, 2021. These papers can be accessed from the IGA papers database.

The list of key induced seismicity publications was again updated for future reference and review purposes. The main topics that were of interest to collaborating researchers during 2021 were: seismicity observations, novel equipment, improved forecasting methods, risk governance, social impacts, robust policy, mechanisms and models, ground motion simulation, deviatoric stress triggers, aseismic slip processes and passive seismic tomography. Case studies and research teams from the following IEA-Geothermal countries were mostly involved: Iceland, USA, New Zealand, Switzerland, United Kingdom, France, and Germany.

### 6.5.3 Future Activities

All interested parties will be kept up to date on the latest research results and technology developments. Further efforts to strengthen international collaboration will continue. Lessons learnt will be summarised to assist developers, policy makers and the general public to make informed opinions about the risks involved. Outcomes will include improved and informed decisions about protocols and recommended monitoring schemes required for new or expanded geothermal projects. Follow-up on induced seismicity papers presented and published in 2021 and participation at the Beijing WGC2023 conference is being planned.

## 6.6 Task E – Surface Technology (Heat and Electricity Production, Corrosion, Scaling, Tracer Technology)

### 6.6.1 Progress in 2021

No activity in 2021 due to COVID-19 pandemic. All planned activities were postponed by 1-2 years.

### 6.6.2 Outputs

No output to report in 2021

### 6.6.3 Future Activities

We expect to collect and collate available information from technical presentations at international forums, increasing awareness of the work of IEA Geothermal, sharing knowledge with the international community, collaborating, initiating joint actions and research projects with international bodies dealing with similar aspects and issues, and attracting interested new members.

## 6.7 References

### 6.7.1 Task A

Hjelstuen, M.B., Hovik, T., Andersen, G., Volland, K., Roed, M. H., 2021, Cryogenic cooling enabling increased performance of logging tools utilizing vacuum flasks, Proceedings World Geothermal Congress 2020+1, Reykjavik, Iceland, April-September 2021.

### 6.7.2 Task D

**WGC2020: Reykjavik, Iceland (2020+1) (selected papers)**

C. BROMLEY and IEA-Geothermal WG13 Task D participants: “Induced Seismicity - a Perspective on Monitoring, Mechanisms and Public Acceptability for Hydrothermal Systems”. Paper #13117, and video presented in session 14C, 11th May, 2021.

A. BARBOUR: “Induced Seismicity and Deformation at Geothermal Fields in California, USA”

D. KARVOUNIS, S. WIEMER: “Forecasting Induced Seismicity and Maximizing Production of Electricity in EGS”

E. GAUCHER, V. MAURER, M. GRUNBERG, R. KOEPKE, R. PESTOURIE, N. CUENOT: “Seismicity Observed During the Development of the Rittershoffen Deep Geothermal Field (France)”

V. Hjörleifsdóttir, S. Snæbjörnsdóttir, G. Gunnarsson, B. Kristjánsson: “Induced Earthquakes in the Hellisheidi Geothermal Field, Iceland”

J. M. RIVERA, D. DEMPSEY: “Reservoir Microearthquake Modeling Analysis: a Proof-of-concept Study and Its Application to Injection Fluid-Induced Seismicity”

**2021 Selected Journal articles**

E Keilegavlen, L Duboeuf, AM Dichiarante et al: "Hydro-mechanical simulation and analysis of induced seismicity for a hydraulic stimulation test at the Reykjanes geothermal field, Iceland" Geothermics, 97, https://doi.org/10.1016/j.geothermics.2021.102223

M. Cacace, H. Hofmann, S. A. Shapiro: "Projecting seismicity induced by complex alterations of underground stresses with applications to geothermal systems" Scientific Reports 11 , 23560, https://doi.org/10.1038/s41598-021-02857-0

Q. Gan, Z. Feng, L. Zhou, H. Li, J. Liu, D. Elsworth: "Down-dip circulation at the United Downs deep geothermal power project maximizes heat recovery and minimizes seismicity" Geothermics, 96, https://doi.org/10.1016/j.geothermics.2021.102204

**Proc. 46th Stanford Geothermal Workshop, February 2021**

D. TEMPLETON, C. MORENCY, E. MATZEL, E. MAHER, and J. AJO-FRANKLIN "Seismic Monitoring of the Sacramento Basin Using Dark Fiber and Distributed Acoustic Sensing (DAS)"

**Proc. 43rd New Zealand Geothermal Workshop, 2021+1, Auckland, New Zealand:**

S. Sewell, M. Savage, J. Townend, C. Hopp, S. Mroczek and K. Graham: "IMAGING THE ALTERATION AND DEFORMATION HALO ABOVE THE DIORITE TONALITE INTRUSIVE AT THE NGATAMARIKI GEOTHERMAL FIELD"

P. Yu, D. Dempsey, A. Calibugan, R. Archer: "MACHINE LEARNING INVESTIGATION OF INJECTION-SEISMICITY IN ROTOKAWA GEOTHERMAL FIELD"

**Transactions of the Geothermal Rising Conference, October 2021:**

Smith, J.T.; Sonnenthal, E. L.; Majer, E. L. "Modelling Pohang, South Korea, Geothermal Well Stimulations and Seismicity"

Bolisetti, C.; Pankow, K.; Kim, K. T.; Podgorney, R.t "Deterministic Simulation of Ground Motion from Induced Seismicity at the FORGE Site"

Rutledge, J.; Pankow, K.; Dyer, B.; Wannamaker, P.; Meier, P.; Bethmann, F.; Moore, J. "Seismic Monitoring at the Utah FORGE EGS Site"

Ye, Z.; Zhou, X.; Ghassemi, A. "Injection-induced Shear Slip and Seismicity in Rough and Saw-cut Gabbro Fractures"

Gao, K.; Huang, L. "High-Resolution Elastic-Wave Imaging at the Utah FORGE Site"

Moradi, P.; Angus, D. "Learning from EGS microseismic response at FORGE"

Snyder, H. L. "An Additive Manufactured Nano-Thick-Film Wide Bandwidth 3-Axis Accelerometer and Vibration Sensor"

**Proc. 9th European Geothermal Workshop, KIT Karlsruhe, 23th September 2021**

Fiori, Rémi "Induced micro-seismicity monitoring in urban context using seismic arrays"

Azzola, Jérôme "The INSIDE project: Investigating the impact of geothermal exploitation in the Munich area – The induced seismicity perspective"

# 7. Australia

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## 7.1 Introduction

Activity in geothermal electricity generation in Australia peaked in the 2009 to 2015 period with a focus on the development of Engineered Geothermal (EGS) and Hot Sedimentary Aquifer (HSA) Systems. At this time about 10 unconventional geothermal projects were under development and significant technical successes were achieved including the creation of EGS reservoirs by Geodynamics Ltd at the Habanero field in the Cooper Basin, South Australia and by Petratherm Ltd at Paralana, South Australia

The technical achievements made during this period were tempered by a lack of commercial success, largely influenced by a combination of high drilling costs, poor market conditions leading to the retraction of private venture capital for speculative investments, and an uncertain policy environment for renewable technologies. Succinct discussions of these issues and the current climate faced by the generation sector in Australia are provided by Budd and Gerner (2015) and a report by the Australian Geothermal Association (Ballesteros et al, 2019).

A number of companies continue to hold geothermal exploration licences across Australia (*Figure 7.1*) and recently there has been renewed interest in developing small-scale geothermal generation in remote regional centres using waste heat from bore water infrastructure, such as the recently commissioned ORC plant at Winton, Queensland.

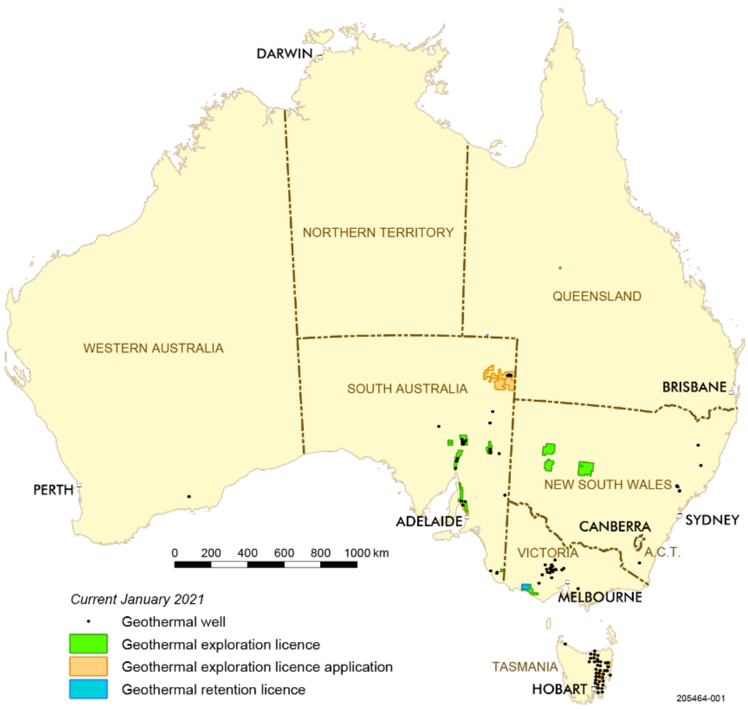


*Figure 7.1: Geothermal licences, applications and gazettal areas as at 15 January 2021.*

A census of geothermal energy installations in Australia undertaken by the Australian Geothermal Association (AGA, 2019) has highlighted the increasing interest and investment in Ground Source Heat Pumps (GSHP) and Direct Use geothermal applications (Figure 7.2, Figure 7.3). The census results have exposed the previously underestimated deployment of GSHPs, particularly in New South Wales, and drawn attention to the upswing in new developments of geothermal aquatic centres and hot spring spa resorts. These developments are largely concentrated in the states of Western Australia and Victoria (Beardsmore et al, 2021) with aquatic centre projects generally funded from local government infrastructure budgets, whereas the current surge in hot spring developments is being driven by private industry investment.

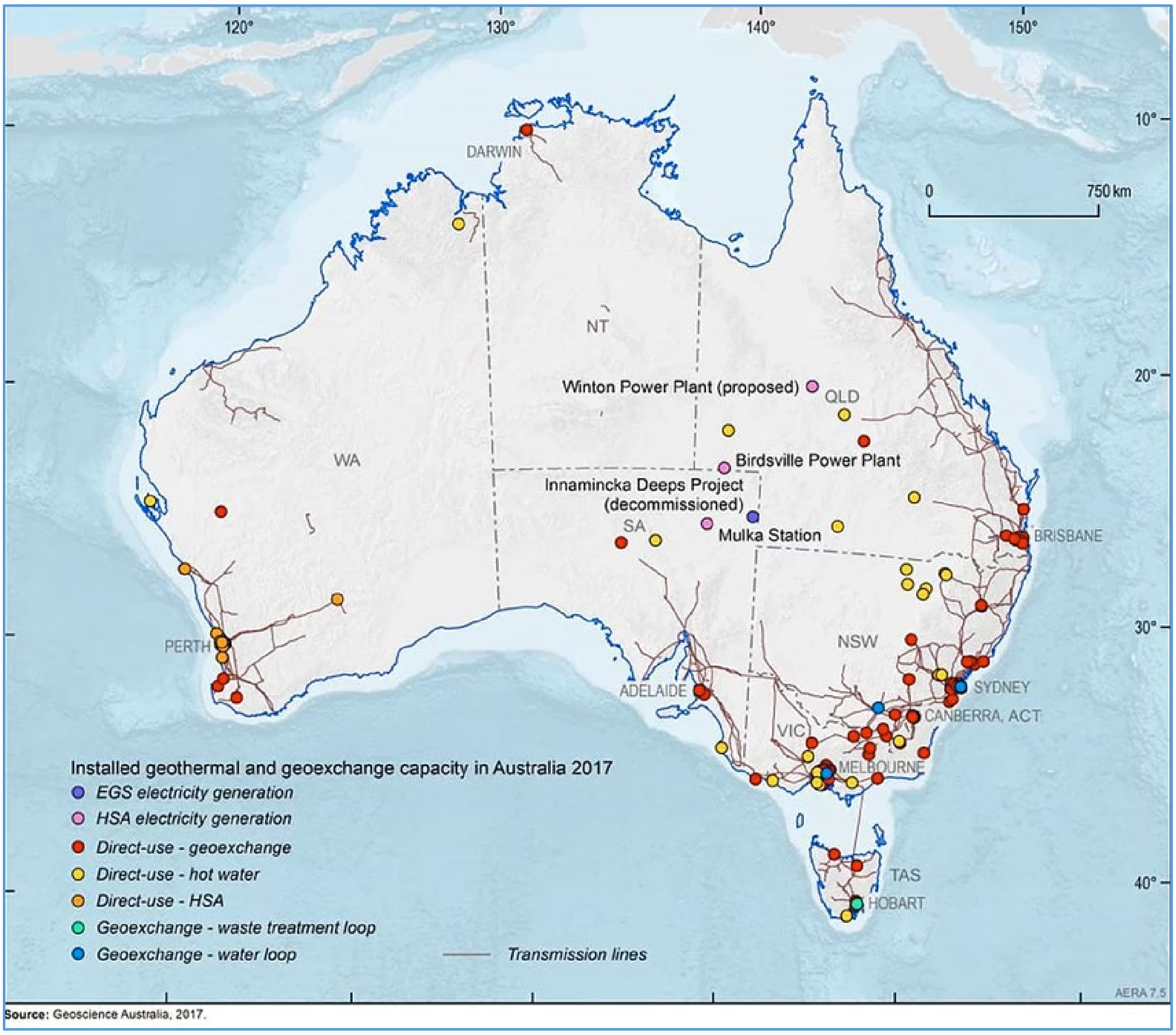


Figure 7.2 ***Installed geothermal and geoexchange capacity in Australia circa 2017 (after AGA, 2019).***

These developments occur largely in the absence of supporting policy incentives since Direct Use geothermal technologies, including GSHPs, remain ineligible under the Australian Commonwealth Government's Small-Scale Renewable Energy Target program. Lack of supporting policy mechanisms and low community awareness of the potential of GSHP and direct use geothermal continue to be major impediments to the wider deployment of these technologies.

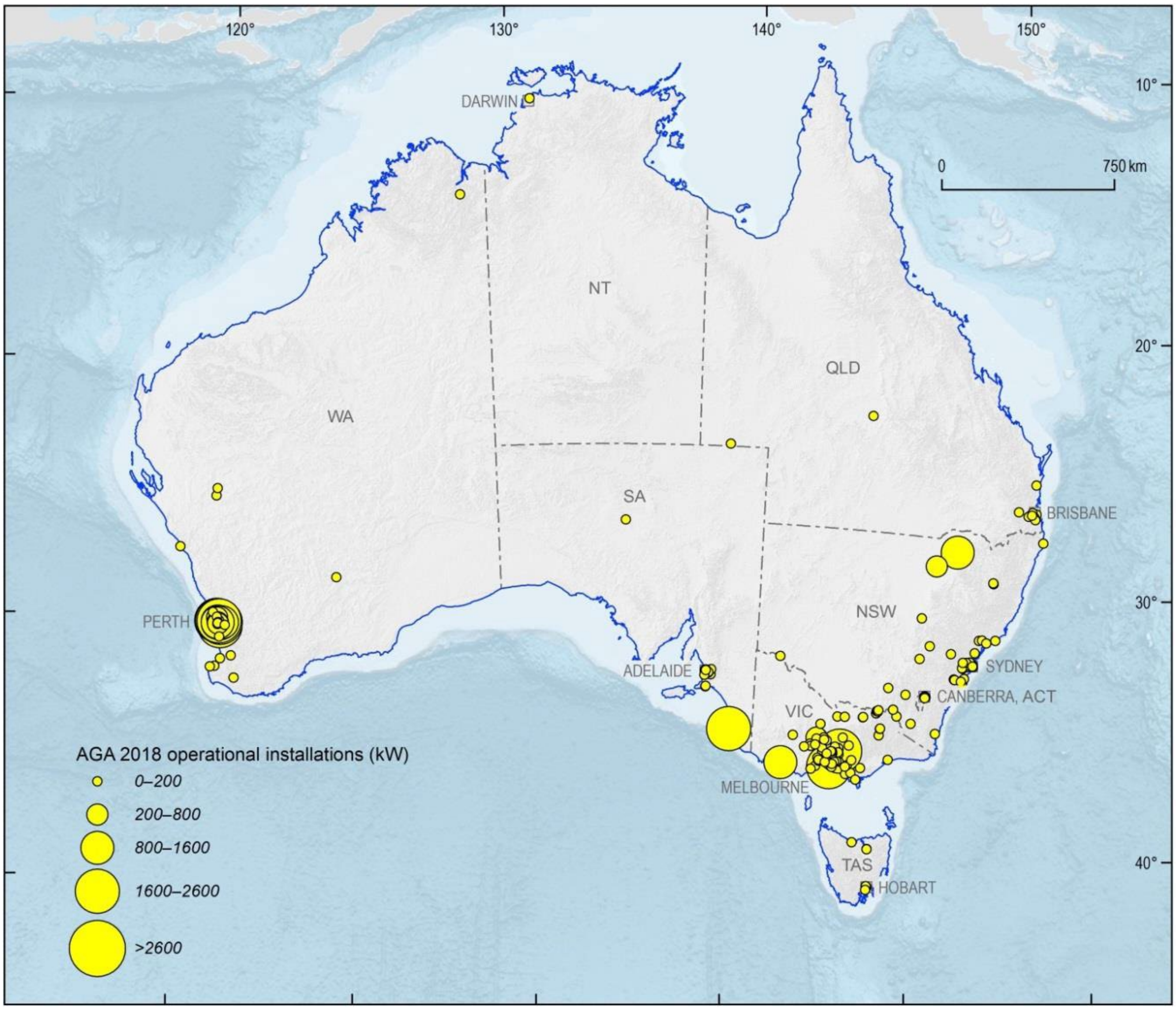


Figure 7.3 ***Operational geothermal and geoexchange capacity in Australia circa 2017 (after AGA, 2019).***

Table 7.1 Geothermal energy usage in Australia for the calendar year 2020.

| Electricity | | Direct Use | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | 0.3 | Total Installed Capacity ($MW_{th}$) | 71.2 |
| New Installed Capacity ($MW_e$) | 0 | New Installed Capacity ($MW_{th}$) | 1.4 |
| Total Running Capacity ($MW_e$) | N/A | Total Heat Used (PJ/yr) [GWh/yr] | 310.4 |
| Contribution to National Capacity (%) | N/A | Total Installed Capacity Heat Pumps ($MW_{th}$) | 78.9 |
| Total Generation (GWh) | N/A | Total Net Heat Pump Use [GWh/yr] | 30.9* |
| Contribution to National Generation (%) | 0 | Target (PJ/yr) | N/A |

(N/A = data not available)

(* indicates estimated values from 2019)

## 7.2 Changes to Policy Supporting Geothermal Development

At the international level, Australia's commitment under the 2015 Paris Agreement is to reduce emissions by 26–28% below 2005 levels by 2030. A revised Renewable Energy Target (RET) scheme in operation since 2011 has been the main incentive for delivering this target through the deployment target of 33,000 GWh of renewable generation by 2020 (Clean Energy Regulator, 2020; DISER, 2020b; Li et al, 2020). This target was achieved in 2019 with a total of 6.3 GW of additional renewable generation capacity being delivered, an increase of 24% above 2018 levels, taking the total share of renewables to 25% of the total National Electricity Market. This new capacity overachieves on the 20% by 2020 target leaving no further legislated incentive for growth in new renewables, however at the close of 2019 a future 37 GW of new renewable generation had received development approval, driven primarily by favourable commercial factors (Clean Energy Regulator, 2020; DISER, 2020a).

No new policies have been developed by the current Commonwealth Government and in the absence of additional national level policy directives, many Australian states and territories have introduced their own renewable energy and emission reduction targets (Table 7.2). South Australia, Tasmania and Queensland are developing significant renewable generation and storage capabilities. Tasmania already regularly achieves over 100% renewable generation and exports the excess to the mainland states. South Australia also regularly generates over 50% of their supply from renewables. The Australian Energy Market Operator (AEMO), foresees renewables offering the least-cost solution to replace aging fossil fuel fired generators as they are retired in the coming decades (Clean Energy Regulator, 2020; DISER, 2020a; Li et al, 2020).

Table 7.2 ***2020 State level Renewable Energy and Emissions Targets.***

| State | Renewables | Net Emissions |
|---|---|---|
| Tasmania | 100% by 2022 | Zero by 2050 |
| Australian Capital Territory | 100% by 2020 | Zero by 2045 |
| South Australia | 100% by 2030 | Zero by 2050 |
| Victoria | 40% by 2025 | Zero by 2050 |
| Queensland | 50% by 2030 | Zero by 2050 |
| New South Wales | | Zero by 2050 |
| Northern Territory | 50% by 2030 | |
| Western Australia | | Zero by 2050 |

In the fiscal year 2018-19, total electricity generation in Australia rose by about 1% to 264,000 GWh. Renewable generation across all technologies increased by 17% contributing 20% of total generation, led by a 50% increase in solar and 17% increase in wind generation (DISER, 2020a). The steady increase in renewable generation continues to drive significant reductions in greenhouse gas emissions from the electricity generation sector. Emissions from the sector in 2020 were 172 MtCO2e and are projected to decline to 111 MtCO2e by 2030 (DISER, 2020b). The latest cumulative emissions projections from all sectors suggest that Australia's abatement task to reach the 2030 target is between 56 – 123 MtCO2e. If the 2020 target overachievement is included in projections, Australia will overachieve on the 2030 target by an estimated 336 to 403 MtCO2e. These 2020 emissions projections include savings attributed to over 24GW of deployed small scale (rooftop) PV and the impact of the COVID 19 pandemic which has restricted transport activity and increased uptake of digital (teleworking) technologies (DISER 2020b). By 2030 small scale (rooftop) PV is projected to be the largest electricity generation type comprising ~30% of grid connected capacity.

In Australia, jurisdiction for the legislation, permitting and regulation of geothermal exploration and development is a State and Territory government responsibility. Currently there are no national policies or grant structures which specifically target geothermal technologies. There has been some support for individual projects however by State and local Governments under general funding mechanisms for renewable technologies and infrastructure.

## 7.3 Geothermal Project Development

### 7.3.1 Projects Commissioned

Construction is nearing completion on the AU$57 million Gippsland Regional Aquatic Centre (GRAC) in Traralgon, a regional centre located in south-eastern Victoria, with the centre expected to open in early 2021. The project involves the construction of a large aquatic centre including 5 pools, splash park, 2 large water slides, gym, fitness rooms, and wellness suites. A geothermal heating system provides heating for the pool water along with the air in the pool hall. After the successful completion of a 24hr flow test, the geothermal system was commissioned in November 2020. The production bore provides water at approximately 68°C from the Traralgon aquifer and the rejected water pumped back to aquifer via the injection bore is between 40 - 53°C depending on the heat load required. The geothermal system is designed to maintain sealed conditions and avoid geochemical precipitation by avoiding exposure of the geothermal water supply to atmospheric conditions, pumping and injecting within the same aquifer and maintaining positive operation pressures. Maximum power is 3000kWt with about <350ML/year of groundwater circulation required to produce <2800kW of geothermal energy. It is anticipated that the use of geothermal energy in this project will save around $400k per year in gas costs and offset about 700 tonnes of carbon emissions annually.

Interest in the Australian Hot Springs and wellness sector is flourishing with seven projects nationwide either under construction or finalising planning and finance. This includes the Burketown, Talaroo Station and Cunnamulla projects in Queensland, the Alba, Metunga and Saltwater Hot Springs projects all under construction in Victoria, and the Tawarri Hot Springs project in Perth, Western Australia.

Commenced in 2018, a $13 m (total) expansion to the existing Peninsula Hot Spring facility at Mornington Peninsula Victoria has progressed to the third development phase. Early development stages saw the construction of a new wing of hot pools, saunas, an ice cave and an outdoor amphitheatre. The second and latest stage involving the construction of luxury on site glamping accommodation is complete and opened in December 2020.

Figure 7.4 ***Geothermal heating system plant room at the Gippsland Aquatic Centre, Victoria, Australia.***

### 7.3.2 Projects Operational

Construction and commissioning of a 310 kW ORC geothermal power plant in the remote community of Winton, Queensland was completed in 2019, and the plant began operation in December 2019. Production statistics for the Winton plant are not yet available.

Winton township is located in central western Queensland with a population of about 900 people. It is situated toward the end of the existing regional transmission grid and suffers from poor security of supply, relying on diesel backup generators when common brown outs and power interruptions occur. The town's water supply is sourced from the Great Artesian Basin. Water emerges from a networked bore system drilled to 1330m depth at 86°C with a flow rate of 77 l/s which was originally cooled in ponds before being reticulated throughout the town for use. The small modular ORC plant is comprised of two 155kW modules which generate electricity using the heat from the town water supply. Generation from the plant is automatically modulated to match water consumption.

Figure 7.5 *Winton Shire ORC geothermal plant.*

## 7.4 Research Highlights

Government funded geothermal research is largely conducted by government research institutions and universities, supported by both State and Commonwealth Government funding including the Australian Research Council (ARC) and the Australian Renewable Energy Agency (ARENA). As the principal agency for the funding and support of renewable energy technologies in Australia, ARENA's objectives are to increase the supply and competitiveness of renewable energy in Australia. ARENA is currently funding a three-year study, due for completion in 2022, on the performance of 'deep well direct exchange' (DWDX) ground source heat pumps installed at the Fairwater Living Lab, a residential community in Western Sydney (ARENA, 2019).

A PhD project to study and review the social, environmental and economic impacts of hot springs on communities across Australia commenced in 2020 at the Victoria University, Melbourne. This study is jointly funded and supervised by 10 hot springs industry tourism operators, the Australian Geothermal Association (AGA) and the Victoria University School for the Visitor Economy.

## 7.5 Other National Activities

### 7.5.1 Geothermal Education

No new educational programmes commenced in 2020.

### 7.5.2 Conferences

No national geothermal conference program was held in 2020.

### 7.5.3 Publications

Aditya, G.R, and Narsilio, G.A., (2020). Environmental assessment of hybrid ground source heat pump systems. Geothermics, v87, https://doi.org/10.1016/j.geothermics.2020.101868.

Aditya, G.R, Mikhaylova, O., Narsilio, G.A.,and Johnston, I.W. (2020). Comparative costs of ground source heat pumps against other forms of heating and cooling for different climatic conditions. Sustainable Energy Technologies and Assessments, v42, https://doi.org/10.1016/j.seta.2020.100824.

Avanthi Isaka, B.L. and Ranjith, P.G., (2020). Investigation of temperature- and pressure-dependant flow characteristics of supercritical carbon dioxide - induced fractures in Harcourt granite: Application to CO2-based enhanced geothermal systems. International Heat and Mass Transfer v158, https://doi.org/10.1016/j.ijheatmasstransfer.2020.119931

Ballesteros, M, Pujol, M., Aymard, D. and Marshall, R., 2020, Hot Sedimentary Aquifer Geothermal Resource Potential of the early Permian Kingia Sandstone, North Perth Basin, Western Australia, GRC Transactions, Vol 44.

Heidari, A., Esmaeel Nezhad, A.E., Tavakoli, A., Rezaei, N., Gandoman, F.H. Reza Miveh, M., Ahmadi, A., and MAlekpur, M.m (2020) . A comprehensive review of renewable energy resources for electricity generation in Australia. Front. Energy, v14, Pages 510–529. https://doi.org/10.1007/s11708-020-0671-6

Li, H.X., Edwards, D.J., Reza Hosseini, M., and Costin, G.P., (2020).
A review on renewable energy transition in Australia: An updated depiction. Journal of Cleaner Production, January 2020, https://doi.org/10.1016/j.jclepro.2019.118475

### 7.5.4 Useful Websites

https://www.australiangeothermal.org.au/

http://www.ga.gov.au/scientific-topics/energy/resources/geothermal-energy-resources

http://www.wearepeak.com.au/wintongeothermal

https://www.youtube.com/watch?v=ArML2QVbH08

https://www.uts.edu.au/sites/default/files/LNCLET_Winton_Fact_sheet_finalV3.pdf

https://www.bing.com/videos/search?q=winton+geothermal&docid=608050502521259273&mid=9138C7D7AD9E3E7D60E19138C7D7AD9E3E7D60E1&view=detail&FORM=VIRE

https://www.facebook.com/watch/?v=416280545936162

http://www.latrobe.vic.gov.au/Building_and_Planning/Major_Projects/Latrobe_Valley_Sports_and_Community_Initiative/Gippsland_Regional_Aquatic_Centre

## 7.6 Future Activity

Key activities scheduled for 2021 include completion of the Gippsland Aquatic Centre in Victoria and commencement of construction of a number of hot springs developments in Victoria and Western Australia.

## 7.7 References


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Ballesteros, M., Pujol, M., Walsh, F., and Teubner, J., (2019). Geothermal energy electricity generation in Australia: recent developments and future potential. Report prepared for the Australian Geothermal Association. https://0f7740a0-ff70-4bb8-9bda-923c19113c61.filesusr.com/ugd/75fc4e_cb45515bc7444756adfde8ea5c6a3206.pdf

Beardsmore, G., Davidson, C., Ricard, L., Pujol, M., Larking, A., and Bendall, B., 2021—Current directions for geothermal energy development in Australia. *Proceedings of World Geothermal Congress 2020+1, Reykjavik, Iceland, April – October 2021*. 7pp.

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Department of Industry, Science, Energy and Resources, (2020a). Australian Energy Update 2020. Available online at: https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202020%20Energy%20Update%20Report_0.pdf

Department of Industry, Science, Energy and Resources, (2020b). Australia's emissions projections 2020. Available online at: https://www.industry.gov.au/sites/default/files/2020-12/australias-emissions-projections-2020.pdf

Department of Agriculture, Water and the Environment (DAWE), (2019). Climate Solutions. Available online at: https://www.environment.gov.au/climate-change/publications/climate-solutions-package

Li, H.X., Edwards, D.J., Reza Hosseini, M., and Costin, G.P., (2020). A review on renewable energy transition in Australia: An updated depiction. Journal of Cleaner Production 242; 118475.

# 8. European Union

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## 8.1 Introduction

The European Commission supports the development of the geothermal sector through an array of activities based on two major policy initiatives: the European Green Deal and the SET-Plan.

In November 2019, the President of the European Commission Ursula von der Leyen said that she wants Europe to become the world's first climate-neutral continent by 2050 and presented the European Green Deal. It will be the most ambitious package of measures that should enable European citizens and businesses to benefit from sustainable green transition. The long-term goal of net zero greenhouse gas (GHG) emissions by 2050 as well as the intermediate target of their reduction by 55% by 2030, compared to the 1990 levels, received the approval of the Council and of the Parliament in 2021 as part of the new European Climate Law. In order to initiate the necessary changes in the EU legislation to achieve the new targets, including a much higher share of renewable energy sources in the EU energy mix, the European Commission proposed the 'Fit for 55' package. Under this package, the revision of several directives has been initiated, such as the Renewable Energy Directive.

The European Commission cooperates closely with its Member States to increase support for geothermal energy. The SET-Plan steering group has adopted the Deep Geothermal Implementation Plan (DG-IP) and a Deep Geothermal Implementation Working Group (DG-IWG) is being established to advance the DG-IP.

The European Commission continued to support geothermal energy research and development via their funding programs like Horizon 2020, its successor Horizon Europe, and the European Regional Development Fund.

## 8.2 Changes to Policy Supporting Geothermal Development

The European Commission is supporting the development of the geothermal sector through an array of activities based on two major policy initiatives: the European Green Deal and the SET-Plan. Geothermal energy is promoted by the Climate and Energy objectives of the European Union (EU). The regulatory and policy framework for geothermal energy is complex, and national and regional frameworks vary significantly from the European level, by applying more regionally specific policies. The European Climate and Energy Framework is structured around two main areas:

- Climate and energy targets (on renewable energy, energy efficiency, and carbon emission reduction) and the related legislative texts, such as the Renewable Energy Directive or the Energy Efficiency Directive;
- The Emission Trading System (ETS), the largest existing carbon market and associated mechanisms.

The Renewable Energy Directive has introduced key provisions for the development of innovative energy technologies. The directive requires a binding target for the share of renewables by 2030, hence countries are obliged to specify sources of renewable energies to develop. Under the directive, priority of dispatch and priority access is given to geothermal electricity, which provides investors with certainty when supporting demonstration projects. Feed-in tariffs or premiums that incentivise investments in new deep geothermal projects were also established. In November 2018, the European Parliament adopted the revision of the Renewable Energy Directive, the Energy Efficiency Directive and the Governance of the Energy Union Regulation, which lay out the European climate and energy regulatory framework from 2020. The EU Clean Energy Package sets a 32% binding target for renewables in 2030. Because of the increased ambition of -55% GHG emissions by 2030, compared to the 1990 levels, set in 2021 by the European Climate Law, various directives needed to be realigned. For this purpose, the European Commission presented the 'Fit for 55' package, which includes the revision of the Renewable Energy Directive, with a higher binding target of 40% in the share of renewable energy sources in European final energy consumption by 2030. Based on the same rationale, the package also contains a legislative proposal for the revision of the EU ETS.

To meet the EU's energy and climate targets for 2030, EU Member States have established a 10-year integrated national energy and climate plan (NECP) from 2021 to 2030. The NECPs were introduced by the Regulation on the governance of the energy union and climate action (EU/2018/1999)[1]. The national plans outline how the EU Member States intend to address energy efficiency, renewables, emissions reductions, and research and innovation. This approach requires a coordination of purpose across all governmental departments. It also provides a level of planning that will ease public and private investment. The fact that all EU Member States are using a similar template means that they can work together to make efficiency gains across borders. All the EU Member States were asked to submit their plans before the end of 2019. EU countries have submitted their national long-term strategies and they must ensure consistency between long-term-strategies and the NECPs. The NECPs are published on the website of the European Commission[2]. Member States will submit their progress reports every two years.

The President of the European Commission Ursula von der Leyen said that she wants Europe to become the world's first climate-neutral continent by 2050. It will be the greatest challenge and opportunity of our times. To achieve this, the European Commission presented the European Green Deal3. It will be the most ambitious package of measures that should enable European citizens and businesses to benefit from sustainable green transition. Measures accompanied with an initial roadmap of key policies range from ambitiously cutting emissions, to investing in cutting-edge research and innovation, to preserving Europe's natural environment.

Supported by investments in green technologies, sustainable solutions and new businesses, the Green Deal can be a new EU growth strategy. Involvement and commitment of the public and of all stakeholders is crucial to its success. The European Green Deal sets a path for a transition that is just and socially fair. It is designed in such a way as to leave no individual or region behind in the great transformation ahead.

[1] https://ec.europa.eu/energy/topics/energy-strategy/energy-union_en?redir=1#content-heading-2
[2] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/national-energy-climate-plans
[3] https://ec.europa.eu/info/publications/communication-european-green-deal_en

Geothermal developments have been shown to benefit from government support. Several Member States of the EU have implemented support policy instruments that have resulted in an acceleration of geothermal development [Sanyal et al. 2016]. Policy support instruments for geothermal energy include both push and pull mechanisms. These differ between Member States and depend on the technology in question, i.e. power production, direct use, ground source heat pumps (GSHP). For geothermal power, support schemes at EU or national level include feed-in tariffs, feed-in premiums, subsidies, loans, tenders, quota systems, net-metering and tax regulation. For geothermal heating and cooling (including GSHP), subsidies, loans, quota systems, tax regulation and price-based mechanisms are available. A report of the Joint Research Centre (JRC) shows all policy instruments available for geothermal electricity, and heating and cooling [Shortall et al. 2019].

The geothermal energy sector is also supported at a European level through the Cohesion Fund, the European Regional Development Fund, the European Social Fund and the European Agricultural Fund for Rural Development [ETIP-DG 2018a]. Financial instruments provide technical assistance, soft loans schemes or revolving funding.

Horizon 2020 (H2020) was the main EU R&I programme with nearly EUR 80 billion of funding available over seven years (2014 to 2020), which provided funding to geothermal R&D projects since its inception.

Horizon Europe is the successor of Horizon 2020 and the budget proposal for Research and Innovation is EUR 95.5 billion for the period 2021-2027. The programme commenced in June 2021 and includes topics on geothermal energy development under the Climate, Energy and Mobility subprogramme, in the context of providing tools to accelerate the green and digital transition of European economy, industry and society with a view to achieving the climate neutrality of Europe in 2050.

The European Investment Bank (EIB) is owned by the Member States and works closely with other EU institutions to implement EU policy focusing on specific priorities such as climate action and strategic infrastructure. It supports projects through loans, technical assistance, guarantees or venture capital [ETIP-DG 2018a]. The EIB together with the European Commission is implementing the InnovFin Energy Demo Projects (EDP) scheme which provides support in the form of loans for first-of-a kind projects. InnovFin aims to facilitate and accelerate access to finance for innovative businesses and projects in unproven markets in Europe. The scheme helps by reducing the financial risk of demonstration projects and offering equity and loans tailored to the need of the project.

Since 2021, the InvestEU Programme has brought together under one roof the multitude of EU financial instruments currently available and expanded the successful model of the Investment Plan for Europe, the Juncker Plan. With InvestEU, the Commission will further boost investment, innovation and job creation.

## 8.3 Geothermal Project Development

### 8.3.1 Geothermal power

As of end 2020, there are 139 geothermal power plants in operation in Europe, corresponding to 3.5 $GW_{el}$ of installed capacity. The increase through 2019 is 0.2 $GW_{el}$, all concentrated in Turkey. Most of the installed capacity is located in two non-EU countries, namely Turkey (1.7 $GW_{el}$) and Iceland (0.8 $GW_{el}$). Hence, only 1 $GW_{el}$ is installed in the EU, almost entirely in Italy (0.9 $GW_{el}$) [EGEC 2020] [EGEC 2021]. In order to put this value in perspective, the economic potential of geothermal power in the EU is estimated at 522 $GW_{el}$ by 2050 [Limberger et al. 2014].

Due to the disruptive impact of the Covid-19 pandemic, but also to the lack of dedicated policy support frameworks, other than Turkey no country commissioned a geothermal power plant in 2020 [EGEC 2021]. [EGEC 2020]. 36 projects were under development and 124 projects were in the planning phase in Europe (notably in Italy, France, Greece, and Germany), which suggested that the number of operational plants could double over the following 5-8 years. However, in 2020 several projects were stopped or delayed, which will likely impact the next years' trends [EGEC 2021].

In 2020, the yearly electricity generation from geothermal sources in the EU amounted to 7 $TWh_{el}$ (6 $TWh_{el}$ in Italy), corresponding to 0.25% of the total electricity generation [EGEC 2021] [IEA 2021].

Most geothermal energy in Europe is produced from hydrothermal resources. Only three Enhanced Geothermal Systems (EGS) plants are operational, two in Germany and one in France. Additionally four projects are under development (three in France and one in Switzerland), while several others are under investigation in the Czech Republic, France, Germany, Romania, Switzerland, and the United Kingdom [EGEC 2021].

### 8.3.2 Geothermal direct use

Geothermal heat can be used for a variety of applications, including district heating and cooling, industry, services and agriculture. District heating for households remains the main application. As of end 2020, a total of 350 geothermal district heating systems are installed in Europe, corresponding to a capacity of 6 $GW_{th}$, and an additional 232 projects are under development [EGEC 2021].

As with geothermal power, Iceland and Turkey are the main markets. Installed capacities are 2.6 $GW_{th}$ and 1.0 $GW_{th}$, respectively. An additional 0.2 $GW_{th}$ are distributed outside the EU, while the EU accounts for 2.2 $GW_{th}$, notably in France (0.66 $GW_{th}$), Germany (0.34 $GW_{th}$), the Netherlands (0.30 $GW_{th}$), and Hungary (0.26 $GW_{th}$) [EGEC 2021]. The main capacity additions with respect to 2019 took place in Iceland (+0.4 $GW_{th}$) and the Netherlands (+0.1 $GW_{th}$) [EGEC 2020] [EGEC 2021].

Similar to the power sector, in 2020 the Covid-19 pandemic impacted on the deployment of projects in the heating and cooling sector. However, these impacts are expected to be temporary and not affect the general growing trend in the sector, which should benefit from the stimulus from the European Green Deal [EGEC 2021].

### 8.3.3 Geothermal heat pumps

GSHPs represent the most common and widespread form of geothermal energy use in Europe: 2.1 million systems are installed as of end 2020 (+0.1 million with respect to 2019), with a corresponding capacity of about 27 $GW_{th}$ [EGEC 2021].

Different from the geothermal power and direct use sectors, EU countries have the lion's share of this sector in Europe. Sweden is a mature market with an average of 12 GSHPs per 100 households, resulting in an overall amount of 0.66 million systems. Other significant countries are Germany (0.42 million), France (0.22 million), and Finland (0.16 million). The most relevant non-EU European countries are Switzerland (0.11 million GSHPs) and Norway (0.06 million) [EGEC 2021].

## 8.4 Research Highlights

The H2020 energy Work Programme for 2018-2020 [European Commission 2017] included six R&D topics specifically targeting geothermal energy covering the whole range of technology development, from TRL 3 (experimental proof of concept) to TRL 8 (system complete and qualified)[4]. All projects which started up until 2021 were under the H2020 programme. The first Horizon Europe calls opened in mid-2021 with the first projects starting in 2022.

Figure 8.1 shows the EU contribution to co-funded projects from 2004 to 2021. The chart reports funds from H2020 and from the Framework Programmes which preceded H2020, i.e. FP6 (2002-2006) and FP7 (2007-2013), as well as from two other funding schemes called Intelligent Energy Europe (IEE) and NER300. Projects are aggregated according to their start date.

The total amount of funds granted by the EU to geothermal energy in the considered period is EUR 430 million, shared among 119 projects. Figure 8.1 shows that more R&D funding was allocated during H2020 (EUR 268 million in 67 projects) than in any other previous funding programme, although with a marked variability across the years. In particular, after a yearly average of EUR 47 million distributed among 11 projects between 2015 and 2019, a considerable drop in funding was observed in 2020 (EUR 11 million in 5 projects), only partially recovered by the increase which took place in 2021 (EUR 22 million in 7 projects).

The most recent H2020 projects are listed in the following sections. Projects are sorted by those:

- completed in 2021
- ongoing in 2021
- started in 2021

Each section lists projects in descending order of EU funding. A link to the relevant webpage in the CORDIS project database is provided for each project.

[4] TRL = Technology Readiness Level

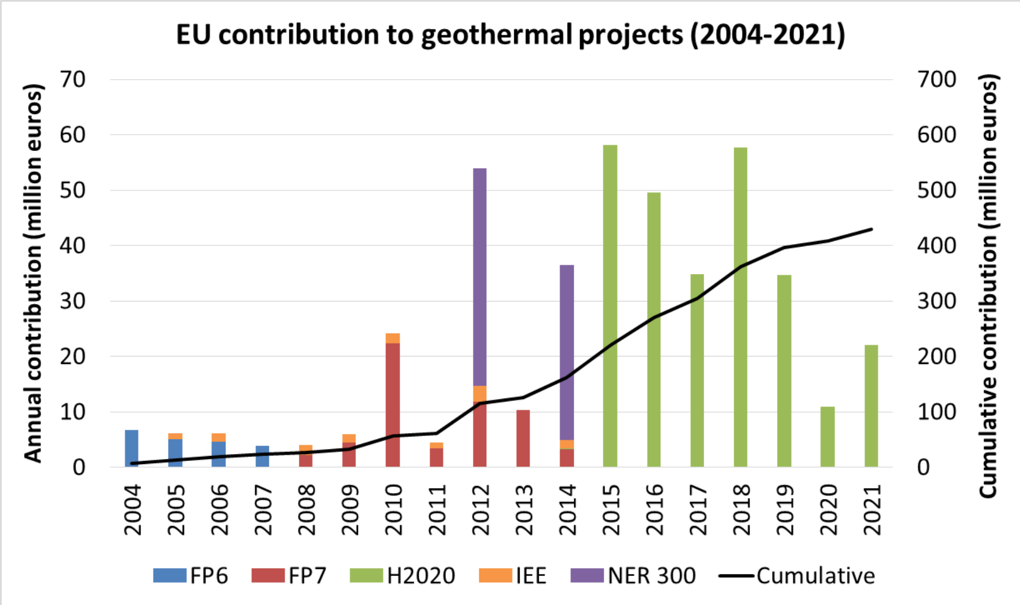


Figure 8.1 EU contribution to co-funded projects from 2004 to 2021. Source: JRC elaboration based on CORDIS

### 8.4.1 H2020 projects completed in 2021

**DESTRESS – Demonstration of soft stimulation treatments of geothermal reservoirs**[5] (March 2016 – May 2021, EUR 10.7 million EU funding, topic: Demonstration of renewable electricity and heating/cooling technologies)

The project was aimed at creating EGS reservoirs with sufficient permeability, fracture orientation and spacing for economic use of underground heat. The concepts were based on experience in previous projects, on scientific progress and developments in other fields, mainly the oil & gas sector. Recently developed stimulation methods were adapted to geothermal needs, applied to new geothermal sites, and prepared for market uptake. Understanding of risks in each area (whether technological, in business processes, for particular business cases, or otherwise), risk ownership, and possible risk mitigation were the scope of specific work packages.

**EUROVOLC – European Network of Observatories and Research Infrastructures for Volcanology**[6] (February 2018 – November 2021, EUR 5.0 million EU funding, topic: Integrating Activities for Starting Communities)

The project aimed at constructing an integrated and harmonised European volcanological community able to fully support, exploit and build-upon existing and emerging national and pan-European research infrastructures, including e-Infrastructures of the European Supersite volcanoes. Among other outcomes, the project also aimed at opening pathways for enterprise to better exploit geo-resources in volcanic areas such as using geothermal energy.

[5] https://cordis.europa.eu/project/id/691728
[6] https://cordis.europa.eu/project/id/731070

**Geo-Coat – Development of novel and cost effective corrosion resistant coatings for high temperature geothermal applications**[7] (February 2018 – May 2021, EUR 4.7 million EU funding, topic: Developing the next generation technologies of renewable electricity and heating/cooling)

The project aimed at developing new resistant materials in the form of high performance coatings of novel targeted "High Entropy Alloys" and Cermets, thermally applied to the key specified vulnerable process stages (components in turbines, valves, pumps, heat exchangers and pipe bends) in response to the specific corrosion and erosion forces that are found at each point. It also captured the underlying principles of the material resistance, to proactively design the equipment for performance while minimising overall capex costs from these expensive materials.

**MPC-. GT – Model Predictive Control and Innovative System Integration of GEOTABS in Hybrid Low Grade Thermal Energy Systems**[8] (September 2016 – February 2021, EUR 4.0 million EU funding, topic: New heating and cooling solutions using low grade sources of thermal energy)

The project brought together a transdisciplinary team of small and medium enterprises, large industry, and research institutes, experienced in research and application of design and control systems in the combined building and energy world. Based on prior research, supported by (joint) EU and national projects and practical experience, the bottlenecks were identified that currently prevent a real breakthrough of geothermal heat pumps combined with thermally activated building systems. The innovative concepts aimed at increasing the share of low valued (low-grade) energy sources by means of using low exergy systems on the one hand and at upgrading low/moderate temperature resources on the other hand.

**GEOCOND – Advanced materials and processes to improve performance and cost-efficiency of Shallow Geothermal systems and Underground Thermal Storage**[9] (May 2017 – February 2021, EUR 4.0 million EU funding, topic: Developing the next generation technologies of renewable electricity and heating/cooling)

By a combination of different material solutions under the umbrella of sophisticated engineering, optimisation, testing, and on-site validation, the project aimed at developing solutions to increase the thermal performance of different subsystems, configuring a Shallow Geothermal Energy System (SGES) and an Underground Thermal Energy Storage (UTES).

**GEOENVI – Tackling the environmental concerns for deploying geothermal energy in Europe**[10] (November 2018 – April 2021, EUR 2.5 million EU funding, topic: Market Uptake support)

The first objective of the project was to make sure that deep geothermal energy can play its role in Europe’s future energy supply in a sustainable way. The project aimed at creating a robust strategy to respond to environmental concerns: (i) by assessing the environmental impacts and risks of geothermal projects operational or in development in Europe; (ii) by providing a robust framework to propose recommendations on environmental regulations to the decision-makers, an adapted methodology for assessing environment impact to the project developers; and finally (iii) by communicating properly on environmental concerns with the general public. The project

[7] https://cordis.europa.eu/project/id/764086
[8] https://cordis.europa.eu/project/id/723649
[9] https://cordis.europa.eu/project/id/727583
[10] https://cordis.europa.eu/project/id/818242

also aimed at engaging with both decision-makers and geothermal market actors, to have the recommendations on regulations adopted and to see the Life Cycle Assessment (LCA) methodology implemented by geothermal stakeholders.

**CarbFix2 – Upscaling and optimizing subsurface, in situ carbon mineralization as an economically viable industrial option**[11] (August 2017 – January 2021, EUR 2.2 million EU funding, topic: Geological storage pilots)

The project built upon the previous FP7 CarbFix project. CarbFix developed a novel, safe, and efficient geologic carbon storage method – applied at the Hellisheidi geothermal power plant (Iceland) – which successfully converted injected $CO_2$ into stable carbonate rocks within two years. CarbFix2 was designed to make the CarbFix geological storage method economically viable with a complete Carbon Capture and Storage (CCS) chain and to make the technology transportable throughout Europe. This is done through a comprehensive project consisting of i) the co-injection of impure $CO_2$ and other water-soluble polluting gases into the subsurface, ii) developing the technology to perform the CarbFix geological carbon storage method using seawater injection into submarine basalts, and iii) integrating the CarbFix method with novel air-capture technology.

**GEORISK – Developing geothermal and renewable energy projects by mitigating their risks**[12] (October 2018 – September 2021, EUR 2.2 million EU funding, topic: Market Uptake support)

A geothermal project development has several risky components, the most important one being the resource risk. This concerns mainly deep geothermal projects, but some shallow geothermal open systems could also be included in this category of projects. Beyond exploration, the bankability of a geothermal project is threatened by this geological risk. The project worked to establish such risk insurance all over Europe (and, in some key target, third countries) to cover the exploration phase and the first drilling (test).

**NERUDA – Numerical and ERT stUdies for Diffusive and Advective high-enthalpy systems**[13] (November 2018 – April 2021, EUR 0.2 million EU funding, topic: Individual Fellowships)

The project proposed an innovative and multidisciplinary approach to predict the role of faults on fluid flow, combining numerical simulations of fluid flow with deep Electric Resistivity Tomography (ERT). The project aimed at constraining the tectonic control on fluid flow in hydrothermal systems.

### 8.4.2 H2020 projects ongoing in 2021

**GECO – Geothermal Emission Gas Control**[14] (October 2018 – September 2022, EUR 15.6 million EU funding, topic: Demonstrate solutions that significantly reduce the cost of renewable power generation)

The project applies an innovative technology, recently developed and proved successfully at pilot scale in the context of the FP7 CarbFix project in Iceland, which can limit the production of emissions from geothermal plants by condensing and re-injecting gases or turning the emissions

[11] https://cordis.europa.eu/project/id/764760
[12] https://cordis.europa.eu/project/id/818232
[13] https://cordis.europa.eu/project/id/793662
[14] https://cordis.europa.eu/project/id/818169

into commercial products. To both increase public acceptance and to generalise this approach, it is being applied in four distinct geothermal systems in four different European countries.

**GeoSmart – Technologies for geothermal to enhance competitiveness in smart and flexible operation**[15] (June 2019 – September 2024, EUR 15.0 million EU funding, topic: Demonstrate highly performant renewable technologies for combined heat and power (CHP) generation and their integration in the EU's energy system)

The project works on methods to store heat energy when demand is low so as to release it when demand is high. It also plans to create a hybrid cooling system for the organic Rankine cycle plant that will prevent efficiency degradation due to seasonal changes. The aim is to allow geothermal plants to cost-effectively respond to different heat and power demands.

**MEET – Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potentials**[16] (May 2018 – January 2022, EUR 10.0 million EU funding, topic: EGS in different geological conditions)

The project aims at demonstrating the viability and sustainability of EGS with electric and thermal power generation in all kinds of geological settings with four main types of rocks: granitic (igneous intrusive), volcanic, sedimentary, and metamorphic with various degrees of tectonic overprint by faulting and folding.

**GeoFit – Deployment of novel GEOthermal systems, technologies and tools for energy efficient building retroFITting**[17] (May 2018 – April 2022, EUR 7.9 million EU funding, topic: Easier to install and more efficient geothermal systems for retrofitting buildings)

The project is an integrated industry-driven effort aimed at deployment of cost effective EGS for energy-efficient building retrofitting. This entails the technical development of innovative EGS and its components, namely, non-standard heat exchanger configurations, novel hybrid heat pumps, and electrically driven compression heat pump systems. It also includes developing a suite of heating and cooling components to be integrated with the novel GSHP concepts, all specially designed to be applied in energy-efficient retrofitting projects.

**GEOTHERMICA – ERA NET Cofund Geothermal**[18] (January 2017 – June 2022, EUR 7.0 million EU funding, topic: Joint Actions towards the demonstration and validation of innovative energy solutions)

The objective of the project is to combine the financial resources and know-how of 16 geothermal energy research and innovation programme owners and managers from 13 countries, to launch joint actions that demonstrate and validate novel concepts of geothermal energy utilisation within the energy system, and that identify paths to commerciality. Joint actions comprise joint calls and coordination activities, which will strengthen Europe’s geothermal energy sector by building a tightly interconnected and well-coordinated network of European funding agents.

[15] https://cordis.europa.eu/project/id/818576
[16] https://cordis.europa.eu/project/id/792037
[17] https://cordis.europa.eu/project/id/792210
[18] https://cordis.europa.eu/project/id/731117

**GEO4CIVHIC – Most Easy, Efficient and Low Cost Geothermal Systems for Retrofitting Civil and Historical Buildings**[19] (April 2018 – March 2022, EUR 6.8 million EU funding, topic: Easier to install and more efficient geothermal systems for retrofitting buildings)

The project identifies and, where missing, develops building block solutions in drilling (machines and methods), ground source heat exchanger types, heat pumps and other renewable energy/storage technologies, heating and cooling terminals with the focus on every type of built environment, civil and historical. It will also generate and demonstrate the easiest to install and most cost-effective geothermal energy solutions using and improving existing and new tools.

**Geo-Drill – Development of novel and cost-effective drilling technology for Geothermal Systems**[20] (April 2019 – September 2022, EUR 5.0 million EU funding, topic: Developing solutions to reduce the cost and increase performance of renewable technologies)

The project aims to reduce drilling cost for geothermal systems with increased penetration rate and reduced tripping due to improved tool durability. It proposes drilling technology incorporating a bi-stable fluidic amplifier driven mud hammer, low cost 3D printed sensors & cables, a drill monitoring system, and graphene-based materials and coatings.

**REFLECT – Redefining geothermal fluid properties at extreme conditions to optimize future geothermal energy extraction**[21] (January 2020 – December 2022, EUR 5.0 million EU funding, topic: Optimising manufacturing and system operation)

The efficiency of geothermal utilisation depends on the behaviour of fluids that transfer heat between the geosphere and the engineered components of a power plant. The project aims to avoid problems related to fluid chemistry rather than treat them. The physical and chemical fluid properties are often poorly defined, as in situ sampling and measurements at extreme conditions are difficult to date. Therefore, large uncertainties in current model predictions prevail, which will be tackled by collecting new, high-quality data in critical areas. These data will be implemented in a European geothermal fluid atlas and in predictive models for providing recommendations on how to best operate geothermal systems for sustainable use.

**GeoHex – Advanced material for cost-efficient and enhanced heat exchange performance for geothermal application**[22] (November 2019 – October 2022, EUR 5.0 million EU funding, topic: Developing the next generation of renewable energy technologies)

The project relies on the use of low-cost carbon steel as the base material for heat exchangers for geothermal power plants. Through modifying the surface with nano porous coating and controlling the surface chemistry (along with the surface structure), the project will significantly improve the heat transfer performance of single phase and phase change heat transfer processes, respectively.

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[19] https://cordis.europa.eu/project/id/792355
[20] https://cordis.europa.eu/project/id/815319
[21] https://cordis.europa.eu/project/id/850626
[22] https://cordis.europa.eu/project/id/851917

**GEOPRO – Accurate Geofluid Properties as key to Geothermal Process Optimisation**[23] (November 2019 – October 2022, EUR 4.9 million EU funding, topic: Optimising manufacturing and system operation)

The project aims at producing experimental data on heat and mass transfer behaviour of high-concentration fluids in very high temperatures. Data serve as input in a set of new design and operation tools that should allow the geothermal power plants to design and operate systems more effectively, reducing the levelised cost of energy to competitive levels.

**EASYGO – Efficiency and Safety in Geothermal Operations**[24] (November 2020 – October 2024, EUR 3.4 million EU funding, topic: Innovative Training Networks)

The project develops system components, monitoring concepts and operational paradigms to enhance the safety and efficiency of geothermal systems. By connecting academia and industry with real-scale research infrastructure, the project is preparing young researchers with both experimental and practical knowledge.

**TEMPO – TEMPerature Optimisation for Low Temperature District Heating across Europe**[25] (October 2017 – March 2022, EUR 3.1 million EU funding, topic: New heating and cooling solutions using low grade sources of thermal energy)

The technical and economic viability of today's district heating networks are undermined by transitions to highly efficient building stocks and ineffective business models which fail to benefit all stakeholders. The project tackles this by (i) innovations to create low temperature networks for increased network efficiency and integration options for renewable and residual heat sources, and (ii) new business models to boost network competitiveness and attractiveness for stakeholder investment.

**CROWDTHERMAL – Community-based development schemes for geothermal energy**[26] (September 2019 – August 2022, EUR 2.3 million EU funding, topic: Market Uptake support)

The project aims to empower the European public to directly participate in the development of geothermal projects with the help of alternative financing schemes (crowdfunding) and social engagement tools. In order to reach this goal, the project first increases the transparency of geothermal projects and technologies by creating one to one links between geothermal actors and the public so that a Social Licence to Operate (SLO) could be obtained. The project is creating a social acceptance model for geothermal energy that will be used as a baseline in subsequent actions for inspiring public support for geothermal energy. Parallel and synergetic with this, the project is working out details of alternative financing and risk mitigation options covering the different types of geothermal resources and various socio-geographical settings.

**BigMac – Microfluidic Approaches mimicking BIoGeological conditions to investigate subsurface $CO_2$ recyclings**[27] (November 2017 – July 2023, EUR 2.0 million EU funding, topic: ERC Consolidator Grants)

[23] https://cordis.europa.eu/project/id/851816
[24] https://cordis.europa.eu/project/id/956965
[25] https://cordis.europa.eu/project/id/768936
[26] https://cordis.europa.eu/project/id/857830
[27] https://cordis.europa.eu/project/id/725100

The objective of this project is to develop and use “Biological Geological Laboratories on a Chip - BioGLoCs” mimicking reservoir conditions in order to gain greater understanding in the mechanisms associated with the biogeological conversion process of $CO_2$ to methane at pore scale. New generic lab scale tools are also being made available for investigating geological-related topics (enhanced oil recovery, deep geothermal energy, bioremediation of groundwater, shale gas recovery).

**PRD-Trigger – Precipitation triggered rock dynamics: the missing mesoscopic link**[28] (February 2020 – January 2025, EUR 1.5 million EU funding, topic: ERC Starting Grants)

Cyclic changes during rock weathering or at geothermal or $CO_2$-sequestration sites lead to precipitation-dissolution cycles of salts, natural constituents of brines inside rocks, which might degrade rocks' structure. What triggers rock dynamics into fracturing during salt precipitation? Can we ultimately control this trigger? The project advocates that the answer lies at the mesoscale, the scale of the pore network. It will combine 4D X-ray imaging with a mesoscopic numerical simulator integrated into the image analysis workflow to identify key factors in precipitation-induced damage. Damage control and crack healing will then be demonstrated on core-scale rocks.

**GEoREST – predictinG EaRthquakES induced by fluid injecTion**[29] (February 2019 – January 2024, EUR 1.4 million EU funding, topic: ERC Starting Grants)

Forecasting injection-induced earthquakes is a big challenge that must be overcome to deploy geo-energies. The objective of this project is to develop a novel methodology to predict and mitigate induced seismicity. The project proposes an interdisciplinary approach that integrates the thermo-hydro-mechanical-seismic (THMS) processes that occur in the subsurface as a result of fluid injection.

**ENeRAG – Excellency Network Building for Comprehensive Research and Assessment of Geofluids**[30] (October 2018 – March 2022, EUR 1.0 million EU funding, topic: Twinning)

The project significantly strengthens research and innovation capacities in geofluids' research and aligns geological resource assessment of groundwater, geothermal energy and hydrothermal mineral resources at Eötvös Loránd University (ELTE, Hungary) by capacity enhancement through cooperation with Geological Survey of Finland (GTK) and University of Milan (UMIL, Italy), with seven supporting stakeholders.

**GeoTwinn – Strengthening research in the Croatian Geological Survey: Geoscience-Twinning to develop state-of-the-art subsurface modelling capability and scientific impact**[31] (October 2018 – January 2022, EUR 1.0 million EU funding, topic: Twinning)

This project addresses the need to spread excellence and widen participation across the European Union by the twinning of research institutions. It proposes to twin the Croatian Geological Survey (HGI-CGS) with the Geological Survey of Denmark and Greenland and the British Geological Survey of the United Kingdom Research and Innovation, to significantly

[28] https://cordis.europa.eu/project/id/850853
[29] https://cordis.europa.eu/project/id/801809
[30] https://cordis.europa.eu/project/id/810980
[31] https://cordis.europa.eu/project/id/809943

strengthen HGI-CGS's research, and transform its capability in a number of areas, such as (i) 3D geological surveying and modelling; (ii) groundwater flow and contaminant transport modelling; (iii) geological hazards; (iv) geothermal energy.

**GeoUS – Geothermal Energy in Special Underground Structures**[32] (January 2020 – December 2022, EUR 0.8 million EU funding, topic: Twinning)

The project will enable the VSB - Technical University of Ostrava (VSB-TUO) in the Czech Republic to enhance the scientific excellence of its personnel and collaborate with leading international research institutions in the field. Young researchers will have the chance to study fundamental and practical aspects of developing geothermal energy sustainably. Research results will be shared with local and national authorities.

**MATHROCKS – Multiscale Inversion of Porous Rock Physics using High-Performance Simulators: Bridging the Gap between Mathematics and Geophysics**[33] (April 2018 – March 2023, EUR 0.8 million EU funding, topic: Research and Innovation Staff Exchange)

The project develops and exchanges knowledge on applied mathematics, high-performance computing, and geophysics to better characterise the Earth's subsurface. The aim is to better understand porous rocks physics in the context of elasto-acoustic wave propagation phenomena. To verify and validate the developed tools and methods, results are applied to: characterise hydrocarbon reservoirs, determine optimal locations for geothermal energy production, analyse earthquake propagation, and jointly invert deep-azimuthal resistivity and elasto-acoustic borehole measurements.

**THERM – Transport of Heat in hEteRogeneous Media**[34] (September 2020 – August 2022, EUR 0.2 million EU funding, topic: Individual Fellowships)

To develop and test new technologies for energy production and storage in geothermal reservoirs, deep understanding of heat transport in fractured media is critically needed. The project focuses on the investigation of heat transport and associated thermo-hydro-mechanical processes occurring during the lifetime of a geothermal reservoir.

### 8.4.3 H2020 projects started in 2021

**EXCITE – Electron and X-ray microscopy Community for structural and chemical Imaging Techniques for Earth materials**[35] (May 2021 – April 2024, EUR 5.0 million EU funding, topic: Integrating Activities for Starting Communities)

Understanding earth materials is critical to creating a sustainable, carbon-neutral society due to their involvement in many vital processes. The project, comprised of 15 European institutions for electron and X-ray microscopy, will enable access to high-end microscopy facilities to develop community-driven technological imaging advancements that will strengthen and extend the current implementation of leading-edge microscopy for earth materials research. The project will integrate joint research programmes with networking, training, and transnational access activities

[32] https://cordis.europa.eu/project/id/856670
[33] https://cordis.europa.eu/project/id/777778
[34] https://cordis.europa.eu/project/id/838508
[35] https://cordis.europa.eu/project/id/101005611

to enable both academia and industry to answer critical questions in earth materials science and technology. As such, the project will develop correlative imaging technologies and provide access to world-class facilities to particularly new and non-expert users that are often hindered from engaging in problem-solving microscopy of earth materials.

**IMPROVE – Innovative Multi-disciPlinary European Research training netwOrk on VolcanoEs**[36] (September 2021 – August 2025, EUR 4.0 million EU funding, topic: Innovative Training Networks)

The use of innovative methods in volcano science will advance our knowledge of volcanic and geothermal systems and may also result in economic and social benefits. The project will perform research to define the underground structure and dynamics of volcanic and geothermal systems aiming to significantly impact volcano science and the science–industry relationship. The project will employ exploration and monitoring approaches and disciplines such as geology, geophysics, geochemistry, engineering and informatics. The project consortium will train a new generation of volcano scientists to manage interdisciplinary understanding and knowledge, promote innovation and cooperate in an inter-sectorial open science environment.

**ORCHYD – Novel Drilling Technology Combining Hydro-Jet and Percussion for ROP Improvement in deep geothermal drilling**[37] (January 2021 – December 2023, EUR 4.0 million EU funding, topic: Advanced drilling and well completion techniques for cost reduction in geothermal energy)

Geothermal energy presents challenges in the form of low heat recovery efficiency, long drilling times and significant initial investment costs. The project will meet these challenges by developing ground-breaking drilling technology that could significantly improve drilling speed and reduce cost while providing the means necessary to improve energy recovery. The goal is to make geothermal energy more economically viable, securing another valuable energy source in Europe's fight against climate change.

**OptiDrill – Optimisation of Geothermal Drilling Operation with Machine Learning**[38] (January 2021 – December 2023, EUR 4.0 million EU funding, topic: Advanced drilling and well completion techniques for cost reduction in geothermal energy)

Drilling for geothermal energy requires technology and equipment solutions that ensure confidence, performance, and optimum cost-effectiveness balance. The project will introduce an innovative drilling advisory system based on a combination of enhanced monitoring systems and multiple data-driven machine learning modules for the analysis, prognosis and optimisation, each module responsible for one aspect of drilling or completion process. Bringing together a diverse team of drilling experts, the project aspires to enhance and digitise decision making and reporting, optimise the drilling process and provide utilisable resources for future application.

**MODERATE – Magma Outgassing During Eruptions and Geothermal Exploration**[39] (September 2021 – August 2026, EUR 2.8 million EU funding, topic: ERC Consolidator Grants)

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[36] https://cordis.europa.eu/project/id/858092
[37] https://cordis.europa.eu/project/id/101006752
[38] https://cordis.europa.eu/project/id/101006964
[39] https://cordis.europa.eu/project/id/101001065

Understanding magma-gas coupling is vital to understanding volcanic activity and its response to drilling operations when harnessing magma energy. The project will therefore determine the impact of external forcing mechanisms on the kinetics of vesiculation and quantify the development of magma permeability. It will also define thermo-mechanical strategies to moderate magma outgassing and reduce the risk of volcanic eruption associated with drilling and borehole operations. A map of magma vesiculation and permeability under a wider range of conditions and stressing scenarios than ever achieved before will help control permeability in magma and moderate magma outgassing. This will enable direct access to magma energy and eventually provide a means to control outgassing and reduce the possibility of an eruption.

**MaPSI – Mathematical and Numerical Modelling of Process-Structure Interaction in Fractured Geothermal Systems**[40] (August 2021 – July 2026, EUR 2.0 million EU funding, topic: ERC Consolidator Grants)

Complex dynamics such as boiling of geothermal fluids and deformation of fractured rock, resulting from the development and production of high-temperature geothermal resources, are not well understood. The project will (i) provide the necessary mathematical models and simulation technology to assess subsurface process-structure interaction in the context of hydraulic and thermal stimulation during the development and production of high-temperature geothermal resources; (ii) develop pioneering mathematical and numerical models to simulate multiphase flow and phase-change thermo-poroelastic media with deforming and propagating fractures; (iii) advance expertise and improve understanding of coupled processes in high-temperature geothermal systems development and production aiming at sustainable resource exploitation.

**ARMISTICE – Predicting earthquakes caused by deep fluid injection for geothermal energy production**[41] (September 2021 – August 2023, EUR 0.2 million EU funding, topic: Individual Fellowships)

An innovative solution to mitigate climate change is to combine CCS and exploitation of supercritical geothermal systems (SCGS) in volcanic areas. One hurdle of this promising geo-energy is the seismic risk resulting from deep fluid injection. Assessing its seismic hazard is challenging due to the complexity of the problem. This is why the project will couple $CO_2$ flow models with high-temperature rheology of rock and faults. It will also extend current models of subsurface $CO_2$ and water flow to very high temperatures, above 375°C. Ultimately, it will determine the potential for induced seismicity in CCS-SCGS and the conditions for safe exploitation.

[40] https://cordis.europa.eu/project/id/101002507
[41] https://cordis.europa.eu/project/id/882733

## 8.5 Other activities

### 8.5.1 DG ETIP

The European Technology and Innovation Platform on Deep Geothermal (DG ETIP) was created in 2016[42]. It complements the ETIP on Heating and Cooling, as well as the other existing thematic ETIPs on renewable energy technologies[43].

Between 2017 and 2019, DG ETIP received almost EUR 0.6 million of EU funding through topic LCE-36-2016-2017 of Horizon 2020. DG ETIP has developed a comprehensive Strategic Research Agenda for the geothermal sector, clarifying its R&D priorities for years to come [ETIP-DG 2018b]. The Strategic Research Agenda and Implementation roadmap for deep geothermal were published in 2019. Furthermore, DG ETIP has developed a dedicated Roadmap and suggested ideal ways to finance geothermal energy players and projects in ad-hoc factsheets. In 2020, DG ETIP published their Vision for Deep Geothermal [ETIP-DG 2020].

### 8.5.2 SET-Plan Deep Geothermal Implementation Plan

The Deep Geothermal Implementation Plan was developed by national representatives from Belgium, Cyprus, France, Germany, Iceland, Italy, the Netherlands, Portugal, Spain, Switzerland, and Turkey, as well as by the European Energy Research Alliance Joint Programme Geothermal Energy (EERA JPGE), DG ETIP, the European Geothermal Energy Council (EGEC), Euroheat & Power District Heating and Cooling Technology Platform, and the European Technology and Innovation Platform on Renewable Heating and Cooling. Finland, Ireland, and Sweden also joined at a later stage. The plan was adopted in early 2018 by the SET-Plan steering group.

The Deep Geothermal Implementation Plan (DG-IP) provides a comprehensive approach articulated in eight key research and innovation activities and two non-technical barriers. It provides a blueprint for the allocation of national and EU funds for geothermal R&D [SET-Plan Temporary Working Group Deep Geothermal 2018].

A high-level Deep Geothermal Implementation Working Group (DG-IWG) has been established to advance the DG-IP, with the aim of reaching collectively the technology targets that will place Europe at the forefront of the next generation of low carbon technologies. A support unit will help the DG-IWG (SU-DG-IWG) to achieve its goals efficiently and productively. The SU-DG-IWG kicked-off in February 2019 running run until July 2022. It has three main work streams:

- provide the DG-IWG with relevant information and data from the various stakeholder groups to support the decision-making process and the implementation actions of the DG-IWG on required actions
- promote and organise initiatives to mobilise growth of and implementation within the geothermal community, e.g. workshops, brokerages, consortium building and exploitation of RD&I results

[42] https://www.etip-dg.eu/

[43] ETIPs are networks of R&D experts coordinated at European level. As such, they play a pivotal role in defining the research priorities of their sectors and communicating them to decision-makers in charge of EU and national R&D funds. For this reason, they are strategic players in the EU energy and climate policy framework, contributing to the implementation of the SET-Plan and accelerating the development and deployment of low-carbon technologies.

- provide a secretariat for the DG-IWG for assistance on administrative issues and synergies & strategy support.

An updated version of the DG-IP was adopted in 2020 [SET-Plan Implementation Working Group Deep Geothermal 2020]. The document partly redefined the eight research and innovation activities and introduced two cross-cutting issues: knowledge transfer & training and recommendation of an open-access policy to geothermal information.

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# 9. France

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## 9.1 Introduction

The Geothermal Market Update in France (AFGP 2019) from the French Geothermal Association of Professionals (AFPG) documents that there are about 175,000 heat pumps in operation for a production of 3,4TWh. Regarding deep geothermal energy for heating applications we estimate that the production is around 2,29 TWh related to the deep reservoirs in the Paris area and the 80 geothermal district heating systems in operation.

Since 2009, the vertical geothermal probe single housing market has dramatically decreased due to competition with gas boilers and air-air heat pumps benefiting from the same tax credits as geothermal. The market for geothermal probes for individual housing has reduced from more than 20,000 installations annually to less than 2500 between 2010 and 2020 (1/7$^{th}$ of the 2010 installs). In contrast, the number of geothermal installations feeding collective housing and residential blocks, including office buildings, is growing significantly. The main barriers to more rapid geothermal uptake are the energy calculation rules for new buildings (RT 2020) even if free-cooling applications is included. In 2023, the geothermal market will reach 3000 MWth installed; if ecologically driven 3500 MWth could be attained.

Direct geothermal uses are mainly concentrated in Ile-de-France: the construction of geothermal doublet installations has been conducted with support from ADEME Heat funds, and more than 20 new deep wells have been drilled in Ile-de-France in the last 3 years.

For electricity generation, no new installations have been commissioned.

The following table provides information on geothermal energy use in France in 2020.

Table 9.1 Geothermal energy use in France in 2020

| Electricity | | Heating and cooling productions | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | 17,2 | Total Installed Capacity ($MW_{th}$) | 657,9 |
| New Installed Capacity ($MW_e$) | 0,06 | New Installed Capacity ($MW_{th}$) | 68,5 |
| Total Running Capacity ($MW_e$) | 17,2 | Total Heat Used (PJ/yr) | 17,17 |
| Contribution to National Capacity (%) (Total France in 2020 = 122385,7MWe **) | 0,014 | Total Installed Capacity Heat Pumps ($MW_{th}$) | 2131 |
| Total Generation (GWh) | 124 | Total Net Heat Pump Use [PJ/yr]s | 13,8 |
| Contribution to National Generation (%) (total France production in 2020 = 500TWh) | 0,025 | Target 2017 – 2030 (PJ/yr Primary Energy) | N/A |
| Target (% national generation in 2023) | 0,05 | Estimated Country Potential ($MW_{th}$ or PJ/yr or GWh/yr) | 100 000 MWth* |

| | | | |
|---|---|---|---|
| Estimated Country Potential ($MW_e$) | 300* | (no significant change in estimated direct use) | |

(N/A = data not available)(* indicates estimated values)(** RTE data)

In 2016, the Bouillante plant exploited by ORMAT had an installed capacity of 15 MWe to be upgraded to 25 MWe in the future.

Only one of the two geothermal doublets drilled near Strasbourg (3500 and 5500m depth) will continue. Because the Vendenheim geothermal cogeneration plant has led to significant seismic events during its test phases, the regional authority has stopped further development of the project. The project designed by Electricité de Strasbourg in Illkirch should be completed in the next years if authorization to restart is decided.

Small capacity ORCs (20-40 kWe) have been installed, one in Soultz-sous-Forêts in Alsace on the existing EGS plant and one in Chaunoy in Ile de France using old oil wells.

## 9.2 Changes to Policy Supporting Geothermal Development

The PPE (Programmation Pluriannuelle de l'Energie) adopted beginning 2020 marks the end of the Feed-In-Tariff (FIT; 246 €/MWh) for geothermal electricity in mainland France. This is expected to be a strong disincentive for new EGS deployment, however around ten EGS projects that are already underway should continue to benefit from the earlier tariff. The existing FIT (170€/MWh) will be maintained for overseas French territories.

Launched by ADEME in collaboration with French operators and local authorities, works on the refunding of the SAF Environment guarantee started this Autumn 2020. This risk mitigation scheme covers geological risk in deep geothermal projects for heat production in order to guarantee dry wells or lower resource output than expected. The first results have opened possibilities to an extension of the Fund to other geothermal areas of France (traditionally, 95% of projects covered by the Fund are based in the Paris Region where the Dogger aquifer represents a very well know geothermal resource and where the Regional Authority provides the Fund with 25% additional financial guarantees). The new Fund would take into account 3 main geothermal zones with different levels of risks determining different levels of premium and guarantees to cover deep geothermal drillings. Discussions have started with government to get this new Fund launched by 2022 with a total amount between 150 and 300 million euros. This new scheme should contribute to the realization of approx. 70 deep geothermal drilling projects in the next 10 years and to reaching the new French Energy Programming's objectives set at between 4 and 5,2 TWh at Horizon 2030.

At the beginning of 2020, the GEODEEP SAS Risk mitigation fund was adopted by the European Commission. It allows ADEME to feed the fund for EGS (16 M€) in addition to the share capital given by "La Caisse des Dépôts et Consignations" and the private shareholder companies. Nevertheless, due to the suppression of FIT for geothermal electricity and the resulting lack of viability for investors, the scheme was definitively closed by main stakeholders. This fund was created to cover the geological and hydrogeological risk of onshore exploration drilling for heat and/or electricity EGS projects in France. In this perspective, no new EGS projects are going to be implemented in France in the near future.

## 9.3 Geothermal deep project development

The Paris basin has five large aquifers, including the Dogger which has the largest number of low-energy geothermal operations in the world, providing geothermal energy to about 8 % of the total population of 11 million people. The geothermal use is limited to collective heating and production of sanitary hot water. A conventional plant covers the needs of 4,000 to 6,000 houses. The Dogger covers an area of over 150,000 km$^2$ with the temperature measured directly below the Paris region varying between 56 °C and 85 °C according to the depth of the reservoir (between 1,500 and 2,800 m vertical depth).

Regarding new geothermal doublets created from scratch, in the last 3 years there were:

- 3 projects tapping the Dogger aquifer: in Grigny, in Dammarie Les Lys and more recently in Champs-sur-Marne
- 2 tapping the Albian sands (Saclay).
- 1 tapping the Triassic sandstone in Bobigny but that appeared to be unproductive and led to again targeting the Dogger limestone. The failure to produce from the Triassic reservoir was reimbursed by the French RMS system.
- Champs-sur-Marne and Bobigny projects are expected to furnish water at around 350m$^3$/h at 70°C. Champs-sur-Marne doublet will also be equipped with heat pumps in order to lower the reinjection temperature.

Other drilling has been carried out to revamp old installations, creating:

- new doublets such as in Cachan (new doublet using horizontal drilling technology with a section in the reservoir up to 800m in length)
- and triplets whose development strategy is generally based on drilling new production wells with big diameters in order to upgrade the flowrate of installations from 200 - 250 to 300 - 350 m$^3$/h. The following sites have been revamped: La Courneuve Nord, Villiers Le Bel, Vigneux, Thiais and Bonneuil.

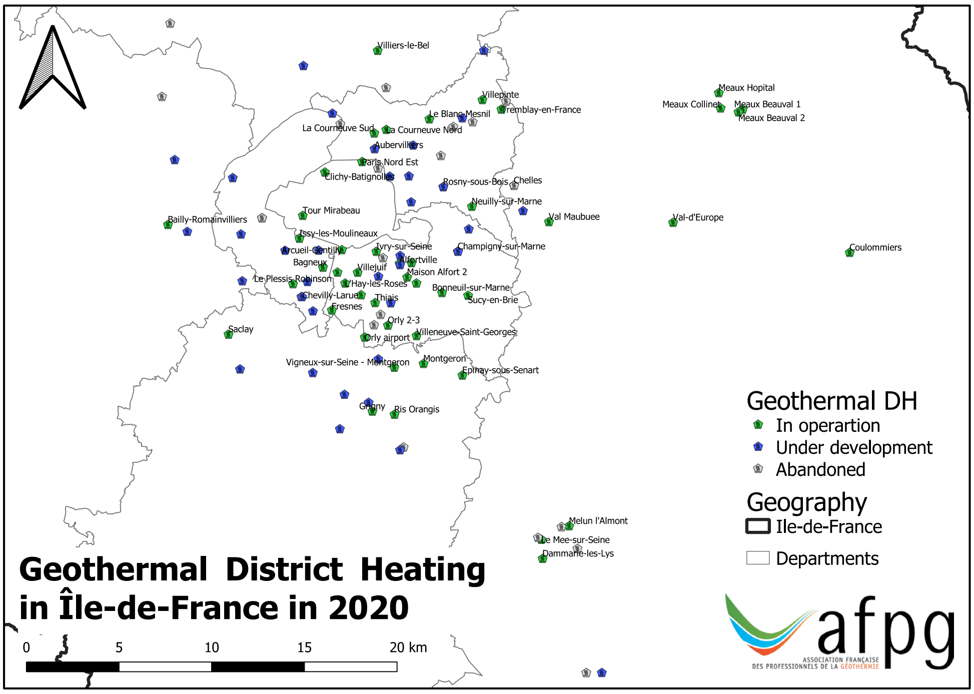


Figure 9.1 - Overview of the geothermal plants running in the Paris basin end of 2020

The district heating networks supplied by the Dogger geothermal resource are mainly exploited by private companies such as Dalkia (EDF Group), Cofely (ENGIE Group), IDEX Energie and Coriance, but also by local public-private ventures (Sociétés d'Economie Mixte). They have been operating for more than forty years and for many of them have thus been fully amortized, with an average availability rate still approaching 95%. The oldest of these installations is located at Melun-l'Almont, commissioned in 1969.

Recent technologies have been developed to exploit the Dogger resource, for example the use of horizontal drilling and the deployment of composite materials in order to cope with corrosion problems.

**Sub-horizontal geothermal wells in Cachan (Val de Marne)**

In 2018, GPC IP successfully tested the second sub-horizontal geothermal (injection) well, GCAJ2 in the Cachan site, thus validating an innovative well architecture, initiated on the previously drilled production well. The well design features two 1,001 m (GCAH1) / 1,005 m (GCAH2) long, 87 to 93° slanted, 8"1/2 open hole drains, drilled in the Dogger at 1,550 m true vertical (TVD) and 3,000 m drilled (mD) depths. Targeted at 450 -500 $m^3$/h production rate, the new doublet, managed by DALKIA (EDF Group) and the municipality of Cachan replace two existing, ageing (34 years) doublets rated 180 and 170 $m^3$/h respectively.

The concept raises considerable interest among geothermal operators reclaiming areas undergoing moderate to poor reservoir performance.

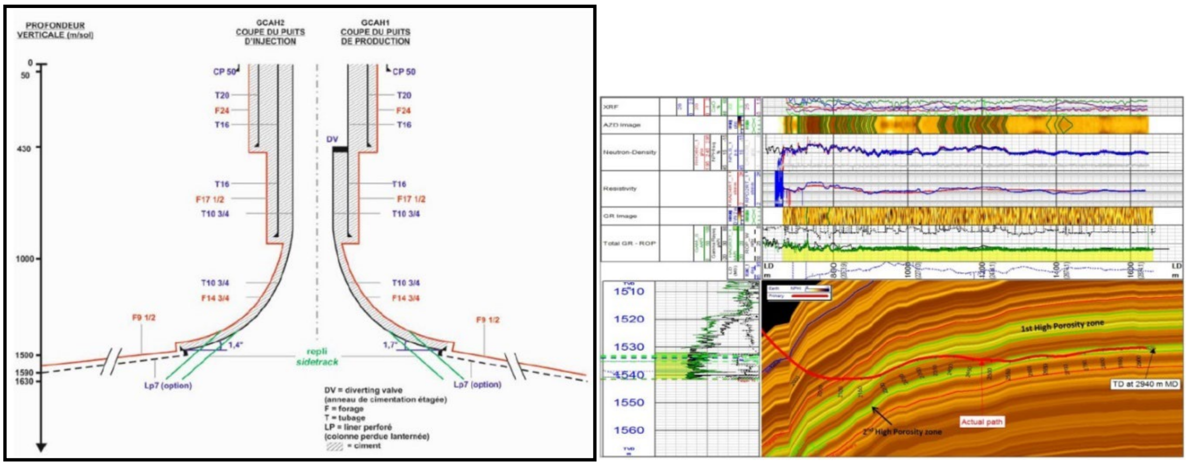


Figure 9.2 Well concept in Cachan (left) and wireline log (NMR-CMC and Sonic dipole porosity, permeability tools) correlating with well productive segments (GPC IP).

New sophisticated technologies while drilling have been deployed to secure optimum project achievement. These parameters recorded while drilling were linked to the conceptual reservoir model, making it possible to (re)adjust the well trajectory in real time. Within the context of the Paris Basin Dogger carbonate platform, geochemical monitoring based on (XRF / X-Ray fluorescence) elemental and (XRD / X-Ray diffraction) mineralogical analyses on cuttings sampled while drilling was implemented with a view to appraising varying reservoir properties in response to facies changes and diagenetic impacts on porosity/permeability trends.

### Use of composite casings

In 2018 a new production well was drilled in order to replace an old well that had a small diameter and was out of order. The use of composite casings had already been tested: in Villeneuve la Garenne in 1976; in Melun that is still in operation; in La Courneuve Sud where the pumping chamber partly had composite casing that was extracted 13 years after and showed no degradation; and more recently in 2015 by CFG in Chevilly-Larue and L'Hay Les Roses to reline 2 production wells with excellent results. This technology can be considered as an interesting alternative to standard steel casings in order to facilitate high production flow rates and to avoid corrosion and scaling.

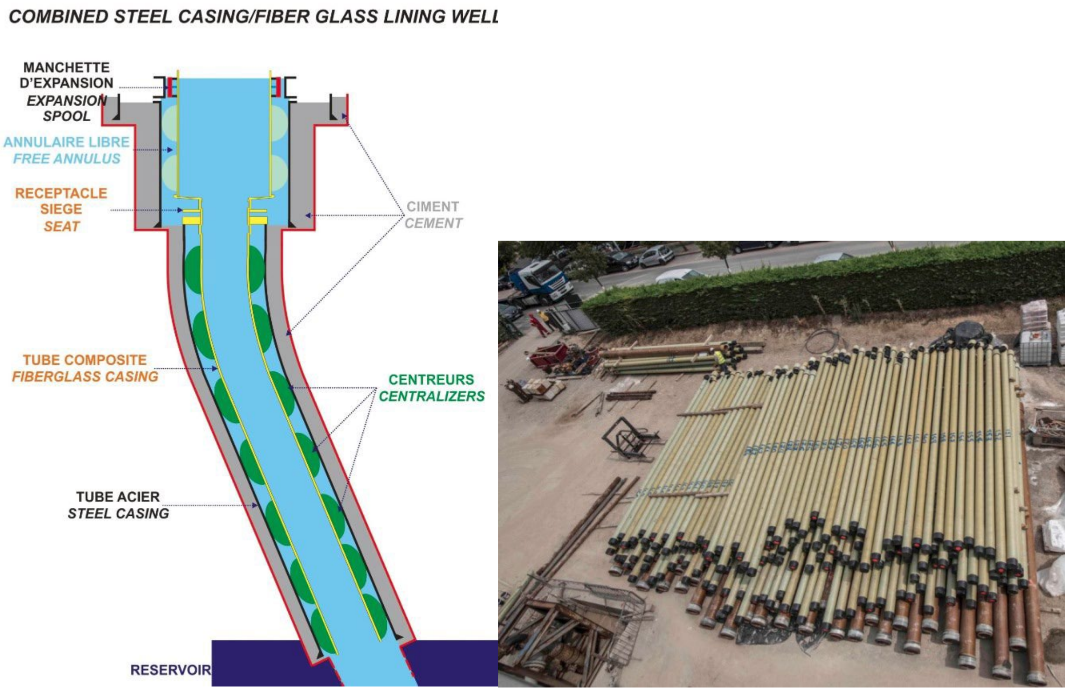


Figure 9.3 Concept of composite well and composite casing installed in Bonneuil (GPC IP)

### Multi drain technology

The latest experiment to develop the Dogger geothermal reservoir was carried out by ENGIE Solutions in Vélizy-Villacoublay, with the drilling of an experimental doublet utilizing the multi drain technology in October 2020 (Figure 9.4). The wells were drilled and tested successfully, with 3 legs in the first one for a total length of about (600 - 450 - 60m). The flowrate is up to 400m$^3$/h which is 30% above the productivity of one standard doublet with an associated 15% limited increase in the CAPEX.

This first demonstration plant is a disruption in the geothermal district heating sector in France which validates a new potential development of more than 200 MWth West of Ile de France where the transmissivity of the aquifer is lower compared to the deepest part of the basin in the East.

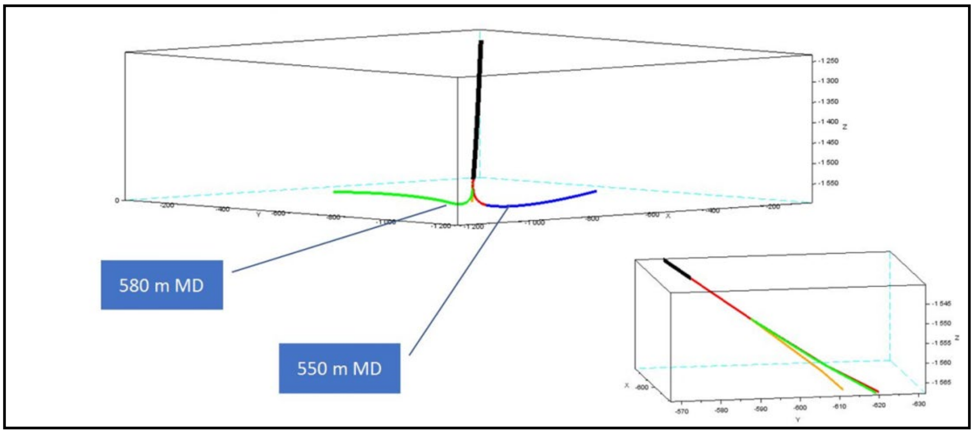


Figure 9.4 Multi-drain for the project of Velizy-Villacoublay (SW of Paris) - Source ENGIE Solutions

Recently Albian and Neocomian aquifers (Early Cretaceous) have been used for geothermal district heating and cooling applications, using big power heat pumps and for smaller housing projects. There are now 6 doublets using this resource: Paris Mirabeau, Issy Les Moulineaux, Le Plessis Robinson, Paris-Batignolles, Saclay 1 and Saclay 2. In 2020, new drilling was completed in Saint-Germain en Laye with the double objective to produce heat and tap water.

The second zone for direct use is **Aquitaine** with around 15 single production wells: these operations were installed in the beginning of the 1980s and this technical situation (no reinjection) was chosen as the geothermal water can be discharged at the surface. The regional geology is moreover quite complicated and the aquifers to be produced are made of sands and sandstones inter-bedded with clays. In these conditions, reinjection becomes a difficulty. In addition, the temperature is lower than in the Paris basin which makes the profitability of a doublet harder to achieve. Nowadays, secondary uses of the resource, as irrigation and agricultural uses are also being investigated.

A new plant launched mid 2019 on the right bank of the Garonne River will feed a district heating system constructed by Cofely Services. The geothermal production target was the Jurassic limestones which had never been drilled in the Bordeaux region. The deep limestones were not productive, consequently the doublet was installed in the well-known Cenomano-Turonien sandstones and the French RMS system reimbursed the extra cost related to the deep exploration.

## 9.4 Geothermal Heat pumps

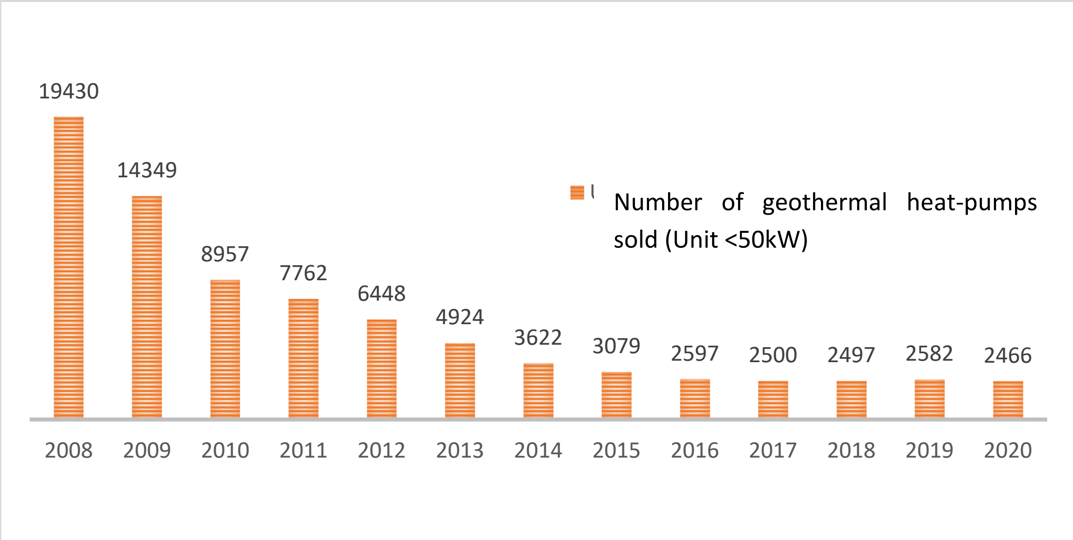


Figure 9.5 Sales of geothermal HP in the individual housing market (2008-2020)

Over the last 4 years about 2500 geothermal heat pumps have been sold each year and the market remains flat for individual housing. This market is facing strong competition from air/water and air/air systems. The French regions leading the geothermal market (individual housing and collectives), except horizontal geothermal, are Ile de France, Rhone-Alps, Midi-Pyrenees, Brittany, Alsace and Pays de la Loire.

At the country level the distribution of the types of installations is: 5% for single housing open loop, 25% for collective open loop based on water, 25% for individual vertical exchanger and 45% for collective vertical exchanger. Horizontal loops represent about 25% of the geothermal market for individual housing. Currently thermo-active foundations remain largely underdeveloped.

In 2020, a differentiated tax credit was implemented between geothermal and air heat pumps resulting in more geothermal installations in the individual housing market. Nevertheless, this differentiated rate won't be effective for new buildings or for well-off households who are usually renewable energy users.

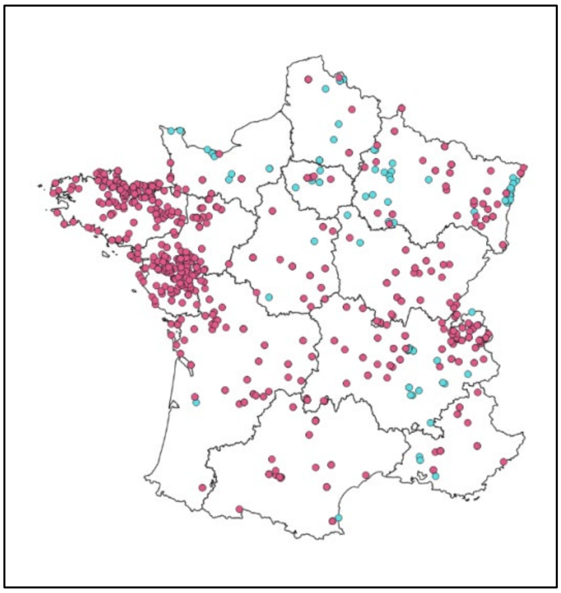

Figure 9.6 GSHP projects in the last 3years (In blue open loop based on water and in red closed loops: mainly vertical probes).

The French energy policy is very supportive for geothermal in collective housing. A study published by The Observ'ER (2018) shows there is a 10% per annum increase in the GSHP market in this sector. There were around 600 new plants installed in France in 2019. The concept of the low temperature geothermal loop, kind of "thermal smart grid", has been adopted in several towns with installed capacities between 1 and 4 MW.

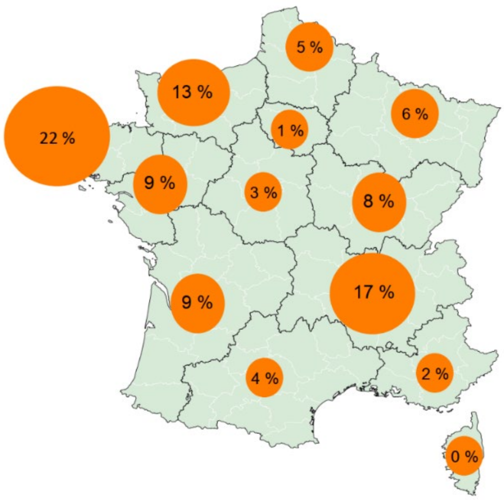


Figure 9.7 GSHP for individual housing in 2019: geographical distribution

The regional distribution of individual housing installations is shown in Figure 9.7 which identifies that the largest percentage of geothermal facilities in individual housing is found in the Bretagne region followed by the Auvergne-Rhône-Alpes region.

## 9.5 Schemes supporting geothermal energy industry

France has developed different schemes to assist geothermal sector development. One of them is the geological risk mitigation tool. The geological risk is linked to the fact that the exploitable geothermal energy resource can only be known after drilling the first borehole. This costly operation (more than 5 Million € for a 2000m geothermal target) may result in failure (e.g. due to a lack of resources, temperature or exploitable flow rates in relation to the forecasts, or the inability to exploit the geothermal fluid due to aggressive geothermal fluid chemistry).

For deep aquifer heat production, the SAF Environment guarantee has been existing for 40 years. For shallow drilling ranging up to 200m depth, the "Aquapac" guarantee (funded by ADEME, EDF and SAF), has been in place for 30 years ; it covers the geological risk for the first well drilled (open loops) and then the geothermal production during 10 years of exploitation.

Furthermore, there is a financial support scheme for heat production called "Renewable Heat Fund" (Fonds Chaleur Renouvelable in French). It was created in 2009 for collective housing, tertiary, industry and agriculture projects and aims at reducing the difference in investment between "conventional" energy solutions and renewable ones. At the end of 2020, 700 geothermal installations (including 600 geothermal heat pump) have been subsidized by the Fund. A total of 141 M€ has been given to the new heat plants (plotted by number by region) shown on Figure 9.8. The total additional heat production is some 2,79 TWh.

The recently voted PPE has also set up the objective to establish a regional network of geothermal coordinators. We can already count on 4 people doing the job that consists of creating a favourable eco-system for geothermal energy regionally and in giving better visibility to this renewable energy whose biggest benefit is to be discrete!

We can also quote the deployment of the French regulation for shallow geothermal energy called "Géothermie de minime Importance". This regulation that came into force in 2015 has extended the simple declaration procedure to drilling to 200m depth. In return, French drillers need to get a state qualification to have the right to drill for geothermal projects, according to a zoning map composed of green (simple declaration), orange (expert advice is required) and red (authorization procedure) areas. Since 2020, French geothermal stakeholders have been working on the development of those regional zoning maps.

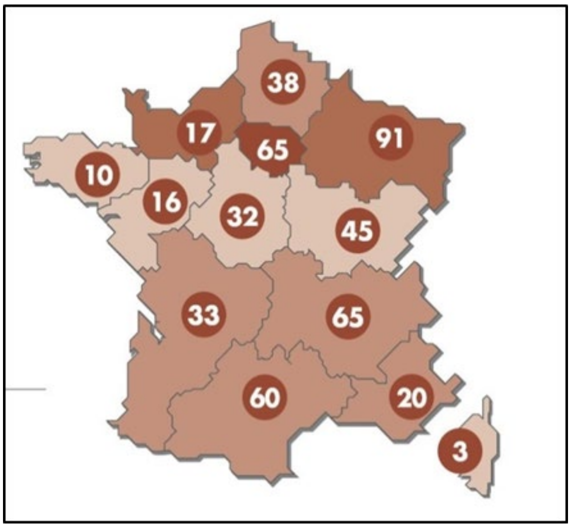


Figure 9.8 Heat fund subsidies recorded by region, showing the number of facilities supported between 2009 and 2018.

## 9.6 Research Highlights

Most of the national R&D budget for geothermal energy is managed by ADEME. Some funding can be accessed through upstream research funded by ANR (National Agency for Research) and technological innovation funded by FUI (Fund for Industrial Clusters).

After two calls for projects in all research domains in France, 171 Laboratories of Excellence (LabEx) received funding awards. The "G-Eau-Thermie Profonde" Laboratory received its official quality label in March 2012. Based in Alsace, it has a focus on deep geothermal energy and received an initial 3 M€ funding award for a 9-year period. At the moment, the yearly funding is around 2M€, sustained by National and European research projects, Electricité de Strasbourg, Strasbourg University, IDEX and CNRS. This illustrates and strengthens industry-university partnership engaged in the "Investments for the Future" framework. New partners such as Total and the Engie group have joined.

An Institute of Excellence for the use of the underground in the energy transition, called Géodénergies, was created in July 2015. It aims at supporting the development of three industrial sectors:

- $CO_2$ storage,
- energy storage, and
- geothermal energy production (heat and electricity).

This joint venture brings together industrial and public research organizations under the national funding program "Investments for the Future". In 2019-2020 Géodénergies will evolve into a new research institute jointly owned by public and private participants.

In order to promote the development of geothermal activities, Géodénergies has launched several research projects to bridge technological gaps (drilling hammers, high temperature pumps, monitoring of reservoir cooling), developing methodologies (micro-seismic measurements, exploitation and conceptual reservoir models in grabens) and developing co-activities along with heat utilisation (lithium production, $CO_2$ storage).

In addition, several national technological clusters have been established to develop collaborative industry and research institute R&D projects including:

- GEODEEP cluster of the AFPG for the promotion of French geothermal know-how for export
- Pôle AVENIA, based in Aquitaine, deals notably with deep geothermal applications;
- SYNERGILE, based in Guadeloupe, aims at developing renewable energies in the overseas territories;

## 9.7 Geothermal Education

BRGM (French Geological Survey) offers training, such as in drilling or building a geothermal energy project.

AFPG is also involved in geothermal training and will develop an offer dedicated to territories energy managers employed by local authorities or energy agencies. Initially focused on biomass industry, those personnel will develop skills in other heating renewable energies to be able to promote indistinctly all kind of energies.

The MEET project created a geothermal spring school in March 2020 for the students of the different partners of the project.

The University of Cergy-Pontoise delivers a master's degree in Energy including a number of courses in geothermal energy.

## 9.8 Publications

AFPG is currently writing a technical guide on temperate geothermal closed loops. The aim is to provide key information to engineering consultancies, so they promote the technology.

BRGM is currently translating good practice sheets based on good practice from deep geothermal drilling.

In shallow geothermal, AFPG is finalizing a technical guide with SER (Renewable Energy Union).

AFPG members have prepared many publications for the WGC 2020 in Reykjavik that will illustrate the involvement of both public and private participants in the French geothermal sector.

## 9.9 Useful Websites

BRGM website (French Geological Survey) and ADEME (the French Agency for Environment and Energy) for professionals and public at large: https://www.geothermies.fr/

AFPG (French Association of Geothermal Energy Professionals) website: http://www.afpg.asso.fr/

BRGM geological and drilling data website: http://infoterre.brgm.fr/viewer/MainTileForward.do

BRGM website with energy data (geothermal, oil & gas, etc): http://www.minergies.fr/fr

## 9.10 Future Activity

AFPG are promoting an innovative system known as the temperate geothermal closed loop which is a thermal smart grid. The potential is enormous as different energy types can be used; such as geothermal, ocean water, lake or water treatment plant water. In addition, there is no loss of energy due to the sharing of the energy in the loop.

French companies involved in deep geothermal energy are currently working with mining companies on the extraction of metals such as lithium from the Alsace fluids. The potential is great since from ~10 geothermal plants in Alsace (or Central Massif and Pyreneans) the production corresponds to the current needs for lithium for batteries for electric mobility in France.

There are ~20 deep geothermal projects in the pipeline waiting to be realized over the next 3 years and ~20 other projects under study, which if all get implemented will amount to an increase of the installed geothermal heating capacity of ~500 MW by 2028.

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# 10. Germany (2020)

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## 10.1 Introduction and Overview

The regions of Germany which have suitable conditions for electricity production are the Molasse Basin in Southern Germany (mainly in Bavaria) and the Upper Rhine Graben in South West Germany, due to an especially high natural increase in temperature at increasing depths in these regions.

According to information from the German Geothermal Association (BVG), there were 38 geothermal power and heating plants in operation across Germany in 2020. Most of these plants exclusively generate heat, with a related installed capacity of 350 MW (thermal). Nine of the geothermal plants generate electricity – either exclusively or supplementary to heat. They have an installed electrical capacity of around 47 MW megawatts.

| Region | Location | Mwel | MWth | Power plant |
|---|---|---|---|---|
| Upper Rhine Graben | Landau | 0,8 | 5 | ORC |
| | Bruchsal | 0,44 | 0 | Kalina |
| | Insheim | 4,8 | 0 | ORC |
| | | | | |
| South Molasse Basin | Dürrnhaar | 6,0 | 0 | ORC |
| | Sauerlach | 5,0 | 4,0 | ORC |
| | Kirchstockach | 6,0 | 0 | ORC |
| | Oberhaching-Laufzorn | 4,3 | 40 | ORC |
| | Oberhaching-Taufkirchen | 4,3 | 35 | ORC |
| | Traunreut | 5,5 | 12 | Kalina |

Figure 10.1 Electricity Producing Geothermal Power Plants in Germany in January 2020.

In Germany, deep geothermal energy is being increasingly used to generate heat. In terms of the prevailing geological conditions in Germany and the existing structure of demand, projects involving heating, such as supplying local and district heating systems, have higher prospects for being economically successful than projects for the generation of electricity only.

## 10.2 National Programme

In September 2018, the Federal Cabinet adopted the 7th Energy Research Programme entitled "Innovations for the Energy Transition". It contains the guidelines for energy research funding in the coming years. In the context of the 7th Energy Research Programme, the Federal Government is making around €7 billion available for projects.

The Federal Government has developed a new strategic approach and directed the programme's focus toward technology and innovation transfer. This includes the use of living labs to bring new, promising technological solutions to the market, and to explore and master challenges under real-life conditions. The experience gained will set the course for implementing the technologies tested on a large scale later on. Greater involvement by young, creative startups will also play an important role in this process.

The new programme strengthens technology and innovation funding in the energy sector and adds a new focus on systemic and societal questions. This involves placing a greater focus on the major, overarching trends in the energy sector. One of these is sector coupling, which enables interaction between the heat, transport and industrial sectors and is crucial for the development of the system as a whole. Another is digitisation, which plays a key role in modernising the energy system.

Lastly, the Federal Government's 7th Energy Research Programme is also designed around developing closer networking in research at both international and European levels. After all, the energy transition is, and will remain, a global-level challenge. In its preparation of the new programme, the Federal Ministry for Economic Affairs and Energy hosted a broad-based consultation process in which it surveyed a large number of stakeholders from science and business about the innovation steps needed in order to make the energy transition a success. This is because the new programme seeks to foster applied research and development in particular and to support the transformation of highly innovative ideas into successful products and processes. The results of the consultation process were fed into the development of the Energy Research Programme – undertaken by the Federal Ministry for Economic Affairs and Energy together with the Federal Ministry of Education and Research and the Federal Ministry of Food and Agriculture.

## 10.3 Industry Status and Market Development

Apart from funding carefully selected research projects, the Federal Government is also creating incentives for new projects by remunerating geothermal electricity under the Renewable Energy Sources Act (EEG). The last amendment to the EEG was adopted by the Bundestag (Lower House of Parliament) in 2017. The feed-in-tariff for geothermal electricity remains unchanged, fixed at 25.2 Euro-cents per KWh. For photovoltaics and wind energy an auction model was introduced.

The market incentive programme (MAP) of the German Government promotes renewable energy systems that provide space heating, hot water, cooling and process heat. It has a section for smaller buildings administered by the Federal Office of Economics and Export Control (BAFA), and one for large buildings and commercial uses, the latter being a premium component of the KfW Banking Group renewable energies program. Several geothermal technologies can be supported by the MAP; it subsidizes the installation of efficient heat pump systems in residential buildings with a repayment bonus, depending on the installation size.

The geothermal market predominantly comprises small and medium-sized enterprises from mechanical engineering, as well as some large-scale enterprises, whose portfolios belong more to the classical energy sector such as the hydrocarbon industry.

## 10.4 Research, Development and Demonstration/Deployment

With the 7th Energy Research Programme, the target of R&D funding has moved from electricity production toward direct heat use. Since more than 50% of primary energy in Germany is used to generate heating, the expansion of geothermal heating and cooling production is a key strategic target to supply energy in the future that is ultra-efficient and based on renewable energy. The increasing use of geothermal as a local energy source also reduces dependence on fuel imports and promotes added value domestically.

For broad market penetration it is important to minimize the risks associated with the use of geothermal and to increase public acceptance through transparent communication of the opportunities and risks based on scientific findings. In addition, energy production costs must be reduced and geothermal storage applications expanded.

R&D funding focuses on the following topics:

- Demonstration projects that implement innovative technological solutions that are easily transferable.
- The continued development of technology focused towards cost reduction, increased efficiency, plant availability, and automation and digitization of geothermal for electricity and heating.
- Further development of heating and cooling storage underground.
- Development of a geological database for potential geothermal uses.
- Security aspects of methods and use cases.
- Research on the material use of extracted geothermal liquids.
- Modelling and simulation of geothermal systems to increase forecasting reliability and minimize financial risk.

In addition to research institutions and companies, users such as energy suppliers and municipal utilities in particular will also be funded. Application-oriented research topics are to be accompanied by targeted demonstration projects. The participants exchange knowledge through the Energy Research Networks, particularly in the Research Network ENERGIEWENDEBAUEN due to the strong relationship with heating supply. In the future, the incorporation of users will become even more visible. Users are particularly well placed to carry the knowledge transfer into widespread use and to provide important feedback to researchers.

The Federal Government also supports international R&D cooperation, for instance through activities under the IEA as well as through the implementation of the SET-Plan and by participating in transnational funding instruments such as GEOTHERMICA.

In the area of geothermal research (deep and shallow), the BMWi approved funding for 41 new projects with a funding volume of around 41 million euros in 2020. At the same time, around 14.4 million euros were invested in 106 already ongoing research projects.

### 10.4.1 Research Highlights

**Geothermal heat for Munich**

Munich is located in the Molasse Basin in Bavaria. The underlying geological formations are particularly suited for the extraction of geothermal heat. The rocks are part of Malm, a geological formation that acts like an aquifer for hot thermal water due to its special structure. Stadtwerke München (SWM) intends to provide complete district heating for Munich from renewable energies by 2040, with the majority from geothermal energy.

SWM, as the coordinator, aims to lay an important foundation for this vision with the GRAME project which was finished at the end of 2018. SWM developed a consistent concept for determining what locations would be best suited for extracting heat and how it can then be integrated into the existing district heating network. The project partnered SWM and the Leibniz Institute for Applied Geophysics (LIAG), who completed in 2016 a three-dimensional image of the subsurface and used it to develop a suitable extraction strategy. In general, the results contributed to the better exploitation of the geothermal resources within the Molasse Basin and the utilization of the potential that was opened up for the generation of both electricity and heat. The goal is to generate electricity of around 50 megawatts or to extract heat in the range of 400 megawatts.

The project partners were using 3D-seismic to determine the structure of the reservoir and to decide about the most promising locations for future drilling. The measurements were taken over an area of 170 square kilometers. Investigations about the potential for geothermal use on this scale have never been carried out in the region before. Conducting 3D-seismic measurements beneath an urban area was also breaking new ground: amongst other things, traffic or construction work on the surface generates incessant vibrations that influence the measured values.

A subsequent project called GeoMARE was granted at the end of 2018 and is still running in 2020. The objective of the project is to provide comprehensive and conceptual design of the district heating system. A citywide efficient operation involves an adapted heat infrastructure along with sustainable reservoir management.

The Heizkraftwerk Süd (southern heating plant) in Munich should become the largest inner-city geothermal plant in Europe. SWM plans to supply around 80,000 Munich residents by 2020 using climate-friendly district heating.

By the end of 2019, six holes had been drilled from one site, which were between 3,700 and 4,300 meters deep. The thermal water temperature is around 100 °C and the flow rate is between 90 and 120 liters per second. A total output of up to 50 MW is thermally calculated.

The success of this project is stimulating further project developments in the Munich region and in Germany.

The main themes of R&D funding for geothermal energy addressed in 2020 were:

- Data collection (GeotIS.de)
- Corrosion and Scaling (for operating power plants)
- Advanced drilling technologies (laser, electro-impulse, plasma)
- Machinery (workover-rig, submersible pump, valves)
- District Heating (Munich, urban areas)
- Microseismisity

Germany is a participant of the EU-project GEOTHERMICA. GEOTHERMICA's objective is to combine the financial resources and know-how of 17 geothermal energy research and innovation programme owners and managers from 14 countries and their regions. Together with financial support from the European Commission, GEOTHERMICA has launched joint projects that demonstrate and validate novel concepts of geothermal energy deployment within the energy system, and that identify paths to commercial large-scale implementation.

## 10.5 Future Outlook

German Government consistently supports the development of renewable energies with a bundle of support mechanism, e.g. feed-in-tariffs, R&D budgets, investments subsidies.

One of the results is that the renewable energy share of gross electrical consumption is 45.4 %, with 0.04 % produced by geothermal power plants. Renewably-based heating and cooling remains at 179 TWh – 0.8 % from deep geothermal in 2020.

Numerous efforts have already been made to develop the potential of geothermal energy as a continuously available renewable energy source. These include the exploration and exploitation of suitable reservoirs, the development of drilling technologies, and innovations in plant construction to finally use the extracted heat for power generation or heating purposes.

There were several heat and building regulations that came into force in 2020. The states often have separate supporting programs, e.g. North-Rhine-Westfalia is supporting initiatives for the Rhein-Ruhr region, a former coal mine area. The idea is to substitute coal with geothermal energy for Europe's largest district heating system

Around 20,500 GSHP were newly installed, to a total of 440,000. The total number of heat pumps sold in 2020 was 120,000, which means an increase of 37 %, but with a share of around 79.4%, air heat pumps are dominating the market. The investments in geothermal energy increased to 1,6 bn € per year (heat pumps, deep geothermal power plants, ambient heat). From the beginning of 2021 the support mechanism for geothermal heat use, especially installation of GSHP will be improved.

In future, the use for heating and cooling supply as well as for seasonal heat storage will be expanded. Research projects are primarily designed to help reducing risks and costs, create storage possibilities, and to increase awareness and acceptance of this form of renewable energy.

With the 7th Energy Research Programme and further strategic approaches of the Federal Government, positive development for the use of geothermal heat can be expected.

**For details and statistics, it is highly recommended to go to the websites below, often published in English.**

## 10.6 Publications and Websites

Federal Ministry of Economic Affairs and Energy, BMWi:
https://www.bmwi.de/Navigation/EN/Home/home.html

BMWi publications in English: http://www.bmwi.de/EN/Service/publications.html

BMWI Report of Energy research:
https://www.bmwi.de/Redaktion/DE/Downloads/B/bundesbericht-energieforschung-2020.pdf

Reform of the Renewable Energy Sources Act: http://www.bmwi.de/Navigation/EN/Topic/eeg-reform.html

Renewable Energy Sources Act: http://www.bmwi.de/Redaktion/EN/Dossier/renewable-energy.html

International Engagement: https://www.bmwi.de/Redaktion/EN/Artikel/Energy/international-energyr-research.html

Marktanreizprogramm (Market Incentive Program, MAP: https://www.erneuerbare-energien.de/EE/Navigation/DE/Foerderung/Foerderprogramme/foerderprogramme.html

KfW-Funding energy and environment:
https://www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/F%C3%B6rderprodukte/F%C3%B6rderprodukte-(S3).html

KfW-loans deep geothermal energy:
https://www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/F%C3%B6rderprodukte/Erneuerbare-Energien-Tiefengeothermie-(272-282)/

German Energy statistics (AGEE-Stat): https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html

Database of R&D-projects in renewable energies governmental sponsored:
https://www.enargus.de/pub/bscw.cgi/?op=enargus.eps2

7th Energy Research Programme of the Federal Government:
https://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html

Energy Research: https://www.forschungsnetzwerke-energie.de/energy-research-networks

Project Management Jülich (Public Funding Agency):
https://www.ptj.de/projektfoerderung/angewandte-energieforschung

German Geothermal Association (BVG): http://www.geothermie.de/

Geothermal Information System for Germany (GEOTIS):
https://www.geotis.de/homepage/GeotIS-Startpage?url=&loc=en

Electricity Research: https://strom-forschung.de/en/

German heat pump association (bwp): https://www.waermepumpe.de/

GEOTHERMICA: http://www.geothermica.eu/about-geothermica

# 11. Iceland (2020)

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## 11.1 Introduction

Utilisation of geothermal resources has expanded rapidly in Iceland during the last two decades and is expected to increase further in the future. Electricity generation increased from 5.0 TWh in 2016 to 6.0 TWh in 2020 and geothermal heat use from 27.1 PJ in 2015 to 33.7 PJ in 2019. A population growth of 36% is expected by 2050, and geothermal utilization is estimated to increase by over 70% by 2050, to almost 50 PJ. Iceland's long-term objective is to ensure the sustainable utilisation of its resources, and the implementation of the Master Plan for hydro and geothermal energy resources in Iceland is a step in maintaining and sustaining this objective. Iceland has developed a great deal of know-how and experience in the harnessing of geothermal resources, both for space heating and electricity generation.

During the 20th century Iceland has emerged from being a nation dependent upon imported oil and coal, to a country where practically all stationary energy, and close to 90% of primary energy, is derived from domestic renewable sources, with near carbon-free electricity production in 2020. This is the result of an effective policy in making renewable energy a long-term priority in Iceland. Nowhere else does geothermal energy play a greater role in providing a nation's energy supply. Figure 11.1 identifies the main production wells in Iceland operated for electricity generation (red), and by heat utilities (blue) that have a natural monopoly license. Auto-producers, of which there are over 100 in Iceland, are excluded and they only contribute 14% of the final electricity use. However, for heat use, main activity producers dominate, with 91% of total heat use in 2019.

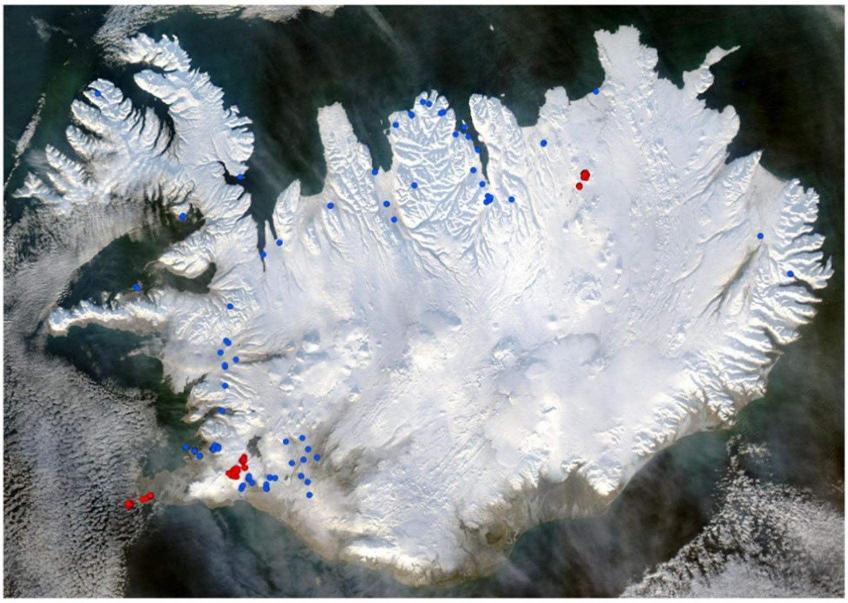

Figure 11.1 Satellite image of Iceland in winter showing geothermal production wells in operation. Geothermal power plants are shown in red, heat utilites in blue.

Table 2 2020 Iceland Geothermal energy use data

| Electricity | | Direct Use | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | 757.4 | Total Installed Capacity ($MW_{th}$) | 2500* |
| New Installed Capacity ($MW_e$) | | New Installed Capacity ($MW_{th}$) | 12* |
| Total Running Capacity ($MW_e$) | 755.4 | Total Heat Used (PJ/yr) [GWh/yr] | 33.7* PJ |
| Contribution to National Capacity (%) | 25.8* | Total Installed Capacity Heat Pumps ($MW_{th}$) | N/A |
| Total Generation (GWh) | 5960.6 | Total Net Heat Pump Use [GWh/yr] | N/A |
| Contribution to National Generation (%) | 31.6 | Target (PJ/yr) | N/A |
| Target ($MW_e$ or % national generation) | N/A | Estimated Country Potential ($MW_{th}$ or PJ/yr or GWh/yr) | N/A |
| Estimated Country Potential ($MW_e$ or GWh) | 4255 $MW_e$ | | |

(N/A = data not available)

(* indicates estimated values)

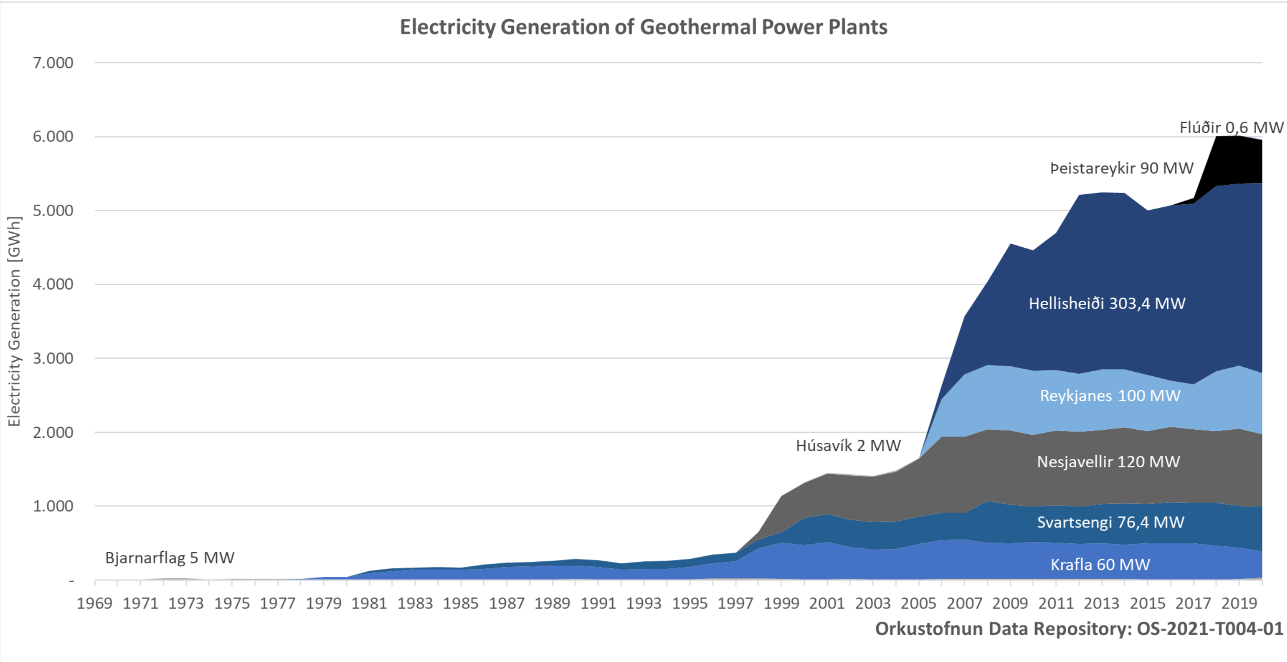


Figure 11.2: Electricity generation from geothermal power plants in Iceland 1969-2020

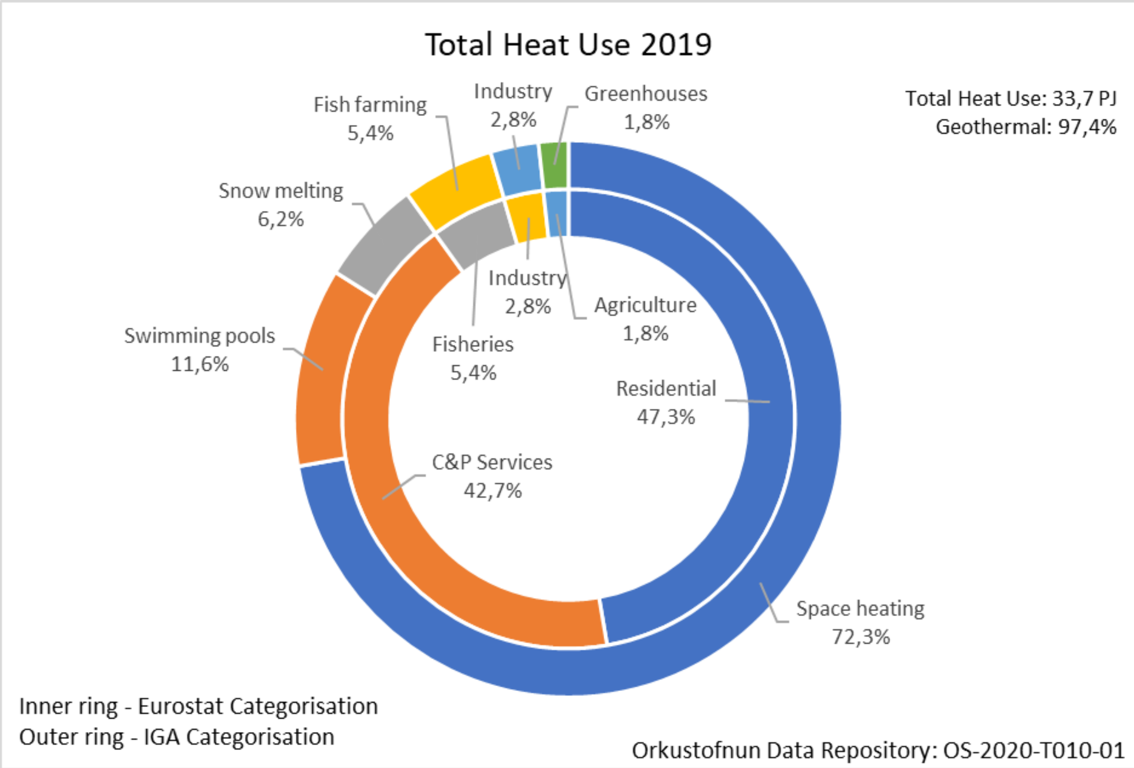


Figure 11.3: Total heat use in Iceland in 2019, of which 97.4% is from geothermal sources.

## 11.2 Changes to Policy Supporting Geothermal Development

Geothermal policy has essentially remained unchanged in recent years in Iceland. Geothermal development is mature with more than 90% of households using geothermal energy for heating, and over 30% of electricity being produced using geothermal. Geothermal power development is not supported by any market incentives in Iceland. The Energy fund, operated by Orkustofnun, supports geothermal development in areas where geothermal is not used for heating, often referred to as "cold" areas. In the "cold" areas heating is mainly electrical and subsidized by the government since it is more expensive than geothermal heating. A lump sum comprising 16 years-worth of subsidies is available to those who want to establish a geothermal heating system, or other more efficient means of heating, such as heat pumps.

## 11.3 Geothermal Project Development

### 11.3.1 Projects Commissioned

Currently there are several geothermal related projects being explored. Many are related to tourism, such as geothermal baths which have proven to be very popular with both visitors and locals. One such project is currently under construction in Eyjafjörður, N Iceland, and will utilise hot water that was unexpectedly discovered when a road tunnel was drilled through the Vaðlaheiði mountain in 2014. The hot water delayed the construction of the tunnel and was considered a nuisance, however the local authorities decided to launch a competition for ideas on how to use the water. The new baths are the result of this process and are expected to open in spring 2022.

Figure 11.4. Hot water in the Vaðlaheiði tunnel in 2014 (Source: Vaðlaheiðargöng)

Cascaded use of geothermal fluid as well as by-products of generation is increasing at Icelandic geothermal power plants. The Reykjanes Resource Park was established several years ago, with companies using wastewater and other waste products from the Svartsengi and Reykjanes power plants. This includes the Blue Lagoon geothermal spa, companies involved in fish drying, fish farming, agriculture and more. Now there are plans for a resource park at the Hellisheiði geothermal plant, including a hydrogen production facility that will use electricity produced by the power plant during off-peak hours. Hydrogen production might prove to be vital to Iceland's future plans for renewables in transport.

Figure 11.5. Hydrogen pilot plant at Hellisheiði (Source: ON power).

### 11.3.2 Low temperature Electricity and District heating

Several geothermal fields in Iceland have medium-enthalpy geothermal fluid with a temperature of over 100°C that is being used for district heating. However, the temperature of the fluid is too high to be used directly for district heating so in many cases cold water is mixed with the geothermal fluid to bring the temperature down to around 80°C, creating waste heat. In 2016, these areas were mapped by Orkustofnun and their electrical and thermal potential was assessed prompting interest from the geothermal sector (Björn Már Sveinbjörnsson, 2106). In 2018, a new geothermal plant at Flúðir, South Iceland, started producing electricity using water from a well that was already used for district heating. The same company, Varmaorka, is currently constructing two new plants in Reykholt, West Iceland, and Efri-Reykir, South Iceland. These geothermal fields are similar to the Flúðir field, as the geothermal fluid has a temperature over 100°C and is currently being used for district heating.

Figure 11.6. Electricity producing units by Climeon at the Flúðir field (Source: Climeon).

The new geothermal district heating system in Hornafjörður municipality started operations in December 2019. Previously, the town of Höfn (pop. 1710 in 2019) and the surrounding countryside had used subsidized direct electrical heating and district heating using an electric boiler, but now uses geothermal water from the field in Hoffell, 20 km north of the town.

Figure 11.7. Pumping station for the new geothermal district heating system in Hornafjörður municipality, SE-Iceland.

## 11.4 Research Highlights

New and effective exploration techniques have been developed to discover geothermal resources. This has led to the development of geothermal heating services in regions that were not thought to enjoy suitable geothermal resources. Iceland's geothermal industry is now sufficiently developed for the government to play a more limited role than before. Power companies now take the lead in the exploration for geothermal resources; either in geothermal fields that are already being utilized, or in discovering new fields.

The Icelandic Government supports the Iceland Deep Drilling Project (IDDP) with 342 million ISK, along with the three largest energy companies. If successful, this project could start a new era in geothermal development. The main purpose is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. The first well, IDDP-1 in Krafla yielded superheated steam after drilling into magma at roughly 2 km depth. The second well IDDP-2 was drilled from August 2016 to January 2017 in Reykjanes. For this phase Norwegian company Statoil joined the original partners, and the drilling was made possible with a €20 million grant from the EU Horizon 2020 programme. The drilling was successful and reached supercritical conditions at 4,659 m. The temperature was measured to be 427°C with a fluid pressure of 340 bars. Cores were retrieved for further study and the rock appears to be permeable at depth. There are exciting times ahead for this project and the third IDDP well is being planned in the Hengill area.

Figure 11.8: IDDP-2 in the process of drilling (Source: HS Orka).

Orkustofnun also supports several projects coordinated by the Icelandic Geothermal Research Cluster GEORG, e.g. the Deep Roots for Geothermal Systems (DRG-project) aimed at research of the roots of magma-driven high temperature geothermal systems.

The CarbFix and SulFix projects, operated by Reykjavík Energy, reinject gases from geothermal fluid extracted at Hellisheiði power plant with good results. According to research the gases mineralize in the basalt bedrock in less than two years. Currently, around 65% of $H_2S$ and 30% of $CO_2$ from the power plant is being injected. The project is ongoing and there are plans to expand it at Hellisheiði to capture more emissions, as well as further developing it for use in other locations. In 2019, Reykjavík Energy founded a new subsidiary that will be focused on further developing the CarbFix method. Additionally, there is a carbon capture pilot project, constructed by Climeworks, underway at Hellisheiði power plant, where $CO_2$ will be captured from the air and injected in already operational injection wells.

Figure 11.9. Climeworks $CO_2$ collectors at Hellisheiði power plant (Source: Climeworks).

## 11.5 Other National Activities

### 11.5.1 Geothermal Education

The UNESCO GRÓ Geothermal training programme (previously the United Nations University-Geothermal Training Programme, UNU-GTP) has been operating in Iceland since 1979, with the aim of assisting developing countries with significant geothermal potential to establish groups of specialists in geothermal exploration and development. A graduate programme was started in 2000 in cooperation with the University of Iceland, and several UNU-GTP students have since continued their studies to obtain MSc and PhD degrees. UNU-GTP receives its funding from the government of Iceland, 5 M US$/yr. Since 1979, 718 scientists have graduated from 63 countries. They have come from countries in Africa (39%), Asia (35%), Latin America (15%), Central and Eastern Europe (10%), and Oceania (1%). Amongst these have been 169 women (23.5%). On January 1, 2020 the name of the programme was changed to UNESCO GRÓ Geothermal Training Programme, as it is now operated under the auspices of UNESCO and no longer affiliated with the United Nations University.

Iceland School of Energy was established at Reykjavik University which offers postgraduate courses in the field of renewable energy. University of Iceland also offers specialized post graduate studies in renewable energy, focusing on geothermal energy.

### 11.5.2 Conferences

The World Geothermal Congress 2020 which was supposed to take place in Iceland was postponed due to the Covid-19 pandemic. The organisers announced that the event will take place online in 2021, as well as at an in-person event in Reykjavík in October.

### 11.5.3 Publications

Icelandic scientists produce numerous publications on geothermal development and research every year, in peer reviewed journals such as Geothermics.

Publications on projects supported by GEORG research group:
http://georg.cluster.is/publications/papers/

## 11.6 Useful Websites

Orkustofnun Data Repository: http://www.nea.is/the-national-energy-authority/energy-data/data-repository/

UNESCO GRÓ Geothermal training programme: https://www.grocentre.is/gtp

GEORG Geothermal Research Cluster: http://georg.cluster.is/

Iceland Deep Drilling Project: http://iddp.is/

Iceland School of Energy. https://en.ru.is/ise/

## 11.7 Future Activity

The Icelandic Government published a white paper on sustainability in the Icelandic society in 1997, in which the need for the development of a long-term Master Plan for energy use in Iceland was stressed. All proposed projects are to be evaluated and categorized on the basis of energy efficiency and economics, as well as on the basis of the environmental impact of power developments. The vision is to prepare an overview of the various potential energy projects in hydro, geothermal and wind, and to evaluate and rank these based on their energy and economic potential, feasibility, effects on national economy, and the estimated impact that each project would have on nature, environment, cultural heritage and society, as well as the potential for other uses of the areas in question. The Master Plan is to be based on the best available scientific information and the conclusions are to be transparent, reproducible, and made available to the public. It was of vital importance to establish public confidence in the evaluation process. The Master Plan aims to identify power projects that rank highly from an economical point of view, have a minimum negative impact on the environment, and a positive impact on the society. Such a score card for energy projects helps decision makers to filter out which of the proposed projects are likely to become controversial and disputed and which ones not. It also directs attention to those project areas that might have protection value and should be left untouched. The third cycle of the Master Plan, which includes 33 geothermal options, was presented to the Minister for Environment in September 2016, and in May 2017 parliament commenced reviewing the material. As of 2020 the third cycle has not been confirmed by parliament although work on the fourth cycle has also been completed. There are 10 planned geothermal projects categorised for utilisation in the third cycle, but since it has not been confirmed by parliament, development (drilling, construction etc.) cannot begin. The exception is geothermal projects that were also proposed in the second cycle, which is the last cycle to have been confirmed, back in 2013. The future of the Master Plan remains unclear.

Direct geothermal use is expected to increase with population increases. It is estimated that heat use will reach 50 PJ in 2050 (Figure 11.10).

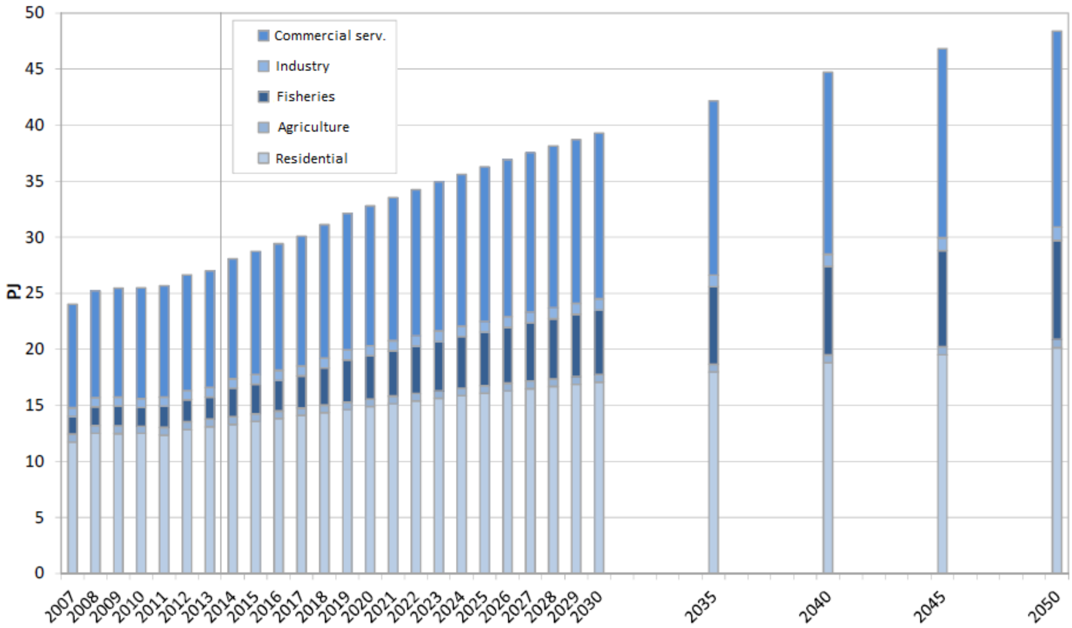


Figure 11.10: Geothermal utilization forecast 2007-2050 (Orkustofnun, 2015).

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# 12. Italy (2019)

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## 12.1 Introduction

Figure 12.1: Nuova San Martino Power Plant

In Italy, geothermal resources are used for both electricity generation and direct use. Power plants are located in Tuscany in the two "historical" areas of Larderello-Travale and Mount Amiata. Direct geothermal use is widespread over the whole of Italy.

To date, Enel Green Power (EGP) is the only geo-electricity producer in Italy. At the end of 2018 the installed capacity was 915.5 $MW_e$ and the gross electricity generation for the 2018 year reached 6,105 billion kWh.

No additional capacity was commissioned during 2019.

Regarding direct geothermal use, at the end of 2017 the installed capacity reached more than 1400 $MW_t$, with a corresponding total energy use of 10915 Tj/yr (+3,7% with respect to 2016). The main sectors using geothermal energy are space heating (42% of the total energy use) and thermal balneology (32% of the total energy use). Fish farming is third with 18% of the total geo-heat utilization. Heat utilization for agricultural applications, industrial processes and other minor uses amounts to less than 8% of the total.

Ground-source heat pumps (GSHPs) constitute the main technology to exploit and deliver geothermal heat, they account for 38% of the total installed capacity and some 30% in terms of energy.

District heating systems represent about 8% of the total geothermal heat utilization (863TJ/yr) with a total installed capacity of about 150$MW_t$. The main systems are in the Tuscany Region near the geothermal electric power production areas. The other main areas of Italian direct geothermal use applications are Ferrara and Milano.

There is an overall static situation for direct use in Italy, with DHs the only sector with a significant increasing trend, followed by industrial applications, which are still a small fraction of the overall capacity and energy used.

The following table provides information on geothermal energy use for Italy. Official electricity data are for 2018, direct use data for 2017.

| Electricity (2018) | | Direct Use (2017) | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | 915,5 | Total Installed Capacity ($MW_{th}$) | 1424 |
| New Installed Capacity ($MW_e$) | 0 | New Installed Capacity ($MW_{th}$) (2015-2017) | 52 |
| Total Running Capacity ($MW_e$) | 915,5 | Total Heat Used (PJ/yr) | 10.915 |
| Contribution to National Capacity (%) | 0.8 | Total Installed Capacity Heat Pumps ($MW_{th}$) | 532 |
| Total Gross Generation (GWh) | 6105 | Total Net Heat Pump Use [PJ/yr] | 3.262 |
| Contribution to National Generation (%) | 2.1 | Direct Use Targets (PJ/yr by when) | N/A |
| Target (% national generation) (data as 2016) | 1080 | Estimated Country Potential ($MW_{th}$ or PJ/yr or GWh/yr) | N/A |
| Estimated Country Potential ($MW_e$) (data as 2016) | 4000 | (no significant change in estimated direct use) | |

(N/A = data not available)

(* indicates estimated values)

## 12.2 Changes to Policy Supporting Geothermal Development

In 2018 the electricity needs of Italy reached 321.91 billion kWh, with a domestic contribution of ~87.0% and 13.0% imported (Terna 2018). As regards the 280.2 TWh of net domestic electricity generation, 66.0% comes from thermal, 17.6% from hydro and 16.4% from geothermal, wind and solar. Although the contribution of geothermal electricity generation is ~2.0% of the total Italian generation, it covers over 30% of the electricity needs of Tuscany, giving a substantial contribution in green energy generation.

In 2018 the average market price of electricity was 6.191 Eurocent/kWh (GSE, 2019). In 2018 the value of the GRIN tariff (Ex green certificates) for the geothermal plants that have access to this incentive was 9.9 Eurocent/kWh additional to the average electricity market price. To receive this an application, using the specific reduction coefficients for the technology type and the type of intervention, must be made (GSE, 2018a).

The 2016 FER Decree defined the new "Base Incentive Fee" for geothermal plants reduced by a percentage due to the auction reduction:

- 13.4 Eurocent/kWh (under 1 MWe installed Capacity),

- 9.8 Eurocent/kWh (for plants between 1 MWe and 5 MWe), and
- 8.4 Eurocent/kWh (over 5 MWe installed Capacity).

All these tariffs are inclusive of the average electricity market price (Ministerial Decree D.M. 23/06/2016).

Recent official documents forecasting energy production from renewables (RES) in Italy envisage only a small growth for geothermal energy applications. The Italian Energy Strategy released in 2017 (MISE, 2017) predicts a rather limited increase of production for electricity and declares the wish to establish a support scheme for geothermal innovative technologies demonstrating electrical power production with zero emissions. While a support scheme for zero emission or other innovative technologies has not yet been established, on January 2019 geothermal power plants were excluded from participating in the bids for incentive schemes offered to renewable power plants.

With the FER1 Ministerial Decree (4 July 2019) "Incentivazione dell'energia elettrica prodotta dagli impianti eolici on shore, solari fotovoltaici, idroelettrici e a gas residuati dei processi di depurazione (19A05099) (GU Serie Generale n.186 del 09-08-2019)", geothermal energy has now been formally excluded from incentives. In the previous, 2016 FER geothermal energy was included.

Moreover, in 2019 a new regional regulation in Tuscany has been approved "legge regionale 5 febbraio 2019, n. 7 , Disposizioni in materia di geotermia", with a significant step forward to the vision of the circular economy and environmental & sustainability improvement for geothermal power plants. The main points of the new regulation are that for the issuing of new leases (leases are expiring before 2024) it will be mandatory to:

- Use the best technology and operational procedures available
- limit the hours of non-operation of geothermal plants to no more than 2 percent of the total annual operating hours
- ensure the transfer and reuse of at least 10% of the $CO_2$ emitted (free of charge)
- ensure the reuse of at least the 50% of the residual thermal energy produced annually that is not used for the production of electricity, to be implemented within one year from the start-up of the plant;

Regarding thermal production, the Italian Energy Strategy released in 2017 (MISE, 2017) does not forecast any specific increase or promotion of heat production from geothermal energy sources, whist only vaguely referring to expanding heat pump uses and district heating infrastructure.

In Italy the promotion of RES in the heating and cooling sector is achieved through tax relief of 55% of the cost of installed RES technologies (the so-called "Conto Termico", i.e. Thermal Account), and as part of wider measures to promote energy savings in the building sector. This latter consists of:

1) for new buildings which are not yet fully operational, the obligation to cover a quota (50%) of their energy needs for domestic hot water with renewable sources, and
2) for existing buildings, the possibility of deducting 55% of the costs incurred for energy retrofit operations from personal income tax (IRPEF) or corporate income tax (IRES) obligations (so-called "Ecobonus").

Since 1998, tax incentives benefit users connected to district heating networks fed by geothermal energy sources. This mechanism pays the end user an incentive for the energy provided by district heating networks supplied by geothermal sources, which was 25.8 €/MWh up to 2014, when it was reduced to 21.95 €/MWh. Moreover, there is an installed capacity incentive of ~21.00 €/$kW_{th}$ paid to the end user through a tax credit mechanism to partially cover the cost of connection.

## 12.3 Geothermal Project Development

### 12.3.1 Projects Commissioned

In 2019 no additional geothermal electrical generation units were commissioned.

In 2018 Enel Green Power started the drilling phase for the construction of the 20MWe gross Monterotondo 2 geothermal power plant on a new lease located SE of the existing area, close to Lago Boracifero.

Between 2017 and 2019 four new district heating (DH) networks in geothermal areas in Tuscany have been established: two in the Travale-Radicondoli area (in Radicondoli and Chiusdino villages), and two in the Mount Amaiata area (Piancastagnaio). La Rota in the Mount Amiata area was completed in 2017 and provides heat to 19 enterprises, two farming facilities and a religious centre, with a capacity of 4,4MWt. The network in Radicondoli commenced operation in the winter of 2018-2019, with a capacity of 5.8 MWt. The Piancastagnaio village network development commenced operation in 2019 supplying 1100 buildings, while the Chiusdino network whilst only partially completed commenced production in 2019. An overall installed capacity of 9MWt is foreseen by 2020. The Chiusdino network comprises two districts (one working and one under construction) with energy delivery of 13,68 TJ/yr and 32,40 TJ/yr respectively.

Other DH networks are planned in Tuscany outside the traditional geothermal territories:

- in Castelfiorentino the planned networks will serve 1500 buildings, and
- in Montecatini the planning has recently started.

### 12.3.2 Projects Operational (at the end of the reporting year)

#### (a) Geothermal fields

All of the Italian geothermal fields in exploitation for electricity generation are located in Tuscany, Larderello, Travale-Radicondoli, Bagnore and Piancastagnaio (the latter two being located in the Mount Amiata area).

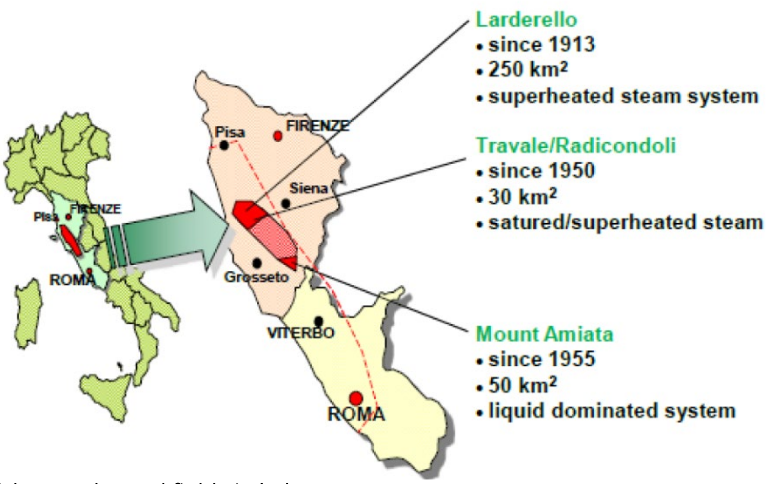


Figure 12.2: location of the geothermal fields in Italy

The activities carried out by EGP over the last three years have been concentrated in the Larderello and Travale-Radicondoli areas targeting field management optimization to reduce and ameliorate decline. Serious acceptability problems from local communities have hindered further developments in the Mt. Amiata area, where the high potential deep geothermal energy for expanded utilisation is located.

In 2018, following surface exploration started some 5 years before, EGP was granted two new development leases, one in Larderello and one in Mount Amiata: Boccheggiano and Roccalbegna.

In the period 2016 - 2018 a total of 27 geothermal wells were drilled in Italy, for a total drilled depth of 46.5 km.

### (b) Electricity generation

The historical trend of electricity generation from geothermal resources in Italy is given in Figure 12.3, where two periods of increased geothermal generation are shown: the first in the period from 1930s to the mid 1970s, related to the development of the shallow carbonate reservoir, with well depths down to about 1000 m. The second from the beginning of the 1980s to now, when the fluid production has increased due to deep drilling activity and to the recharge support of the depleted shallow reservoirs by means of the reinjection of water and condensed steam.

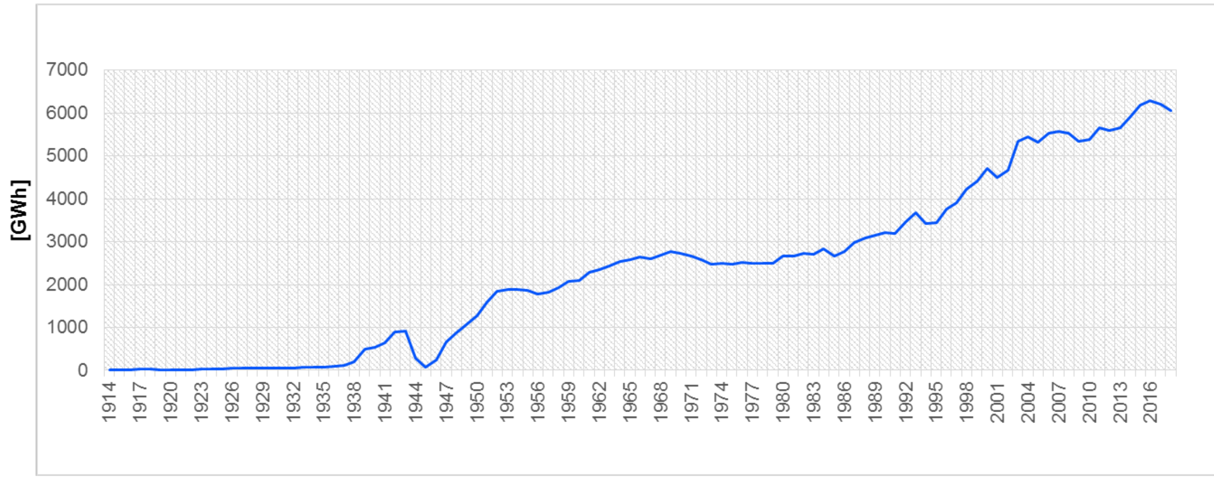


Figure 12.3: Historical trend of electricity generation from geothermal resources in Italy

All 34 of the Italy's geothermal power plants are managed by Enel Green Power. As of 2018 all these power plants had AMIS mercury and hydrogen sulphide abatement plant in operation. The average availability of the AMIS plants (hours of operation vs hours of operation of the associated power plant) exceeded 90%.

All of the geothermal power plants managed by EGP in Italy are remotely controlled and operated from a Remote Control Station located in Larderello, where 12 people work on shift around the clock (24/7) ensuring continuous operator oversight.

For 2018, with an installed capacity of 915.5 MWe, the gross electricity generation was 6064 GWh. A complete list of the operational power plants is given in Figure 12.4; taking into account the actual operating conditions in the different areas (pressure, temperature, non- condensable gas content in the steam, etc), the total running capacity, called Reference Net Capacity, is 806.6 MWe.

[1] N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

[2] 1F = Single Flash, 2F = Double Flash, 3F = Triple Flash, D = Dry Steam, B = Binary (Rankine Cycle), H = Hybrid (explain), O = Other (please specify)

| Locality | Power Plant Name | Year Com-missioned | No. of Units | Status[1] | Type of Unit[2] | Total Installed Capacity Mwe* | Total Running Capacity Mwe* | Annual Gross Energy Produced 2018 GWh/yr | Total under Constr. or Planned MWe |
|---|---|---|---|---|---|---|---|---|---|
| **Larderello** | | | | | | | | | |
| | Valle Secolo | 1991 | 2 | | D | 120 | 110,6 | 929,1 | |
| | Farinello | 1995 | 1 | | D | 60 | 52,4 | 488,6 | |
| | Nuova Larderello | 2005 | 1 | | D | 20 | 16,6 | 119,1 | |
| | Nuova Gabbro | 2002 | 1 | | D | 20 | 19,1 | 148,3 | |
| | Nuova Castelnuovo | 2000 | 1 | | D | 14,5 | 14,9 | 126,3 | |
| | Nuova Serrazzano | 2002 | 1 | | D | 60 | 47,5 | 320,9 | |
| | Nuova Sasso | 1996 | 1 | | D | 20 | 14,0 | 100,9 | |
| | Sasso 2 | 2009 | 1 | | D | 20 | 16,7 | 135,5 | |
| | Le Prata | 1996 | 1 | | D | 20 | 18,0 | 156,9 | |
| | Nuova Monterotondo | 2002 | 1 | | D | 10 | 8,0 | 52,0 | |
| | Nuova San Martino | 2005 | 1 | | D | 40 | 36,2 | 226,0 | |
| | Nuova Lago | 2002 | 1 | | D | 10 | 10,9 | 88,1 | |
| | Nuova Lagoni Rossi | 2009 | 1 | | D | 20 | 12,7 | 92,7 | |
| | Cornia 2 | 1994 | 1 | | D | 20 | 12,0 | 150,7 | |
| | Nuova Molinetto | 2002 | 1 | | D | 20 | 14,5 | 95,1 | |
| | Carboli 1 | 1998 | 1 | | D | 20 | 15,4 | 135,8 | |
| | Carboli 2 | 1997 | 1 | | D | 20 | 15,4 | 122,5 | |
| | Selva | 1997 | 1 | | D | 20 | 18,3 | 68,8 | |
| | Monteverdi 1 | 1997 | 1 | | D | 20 | 17,8 | 110,6 | |
| | Monteverdi 2 | 1997 | 1 | | D | 20 | 15,6 | 117,1 | |
| | Sesta | 2002 | 1 | | D | 20 | 13,9 | 92,8 | |
| Subtotal | | | 22 | | | 594,5 | 500,5 | 3877,8 | 0 |
| **Travale-Radicondoli** | | | | | | | | | |
| | Nuova Radicondoli | 2002 | 2 | | D | 60 | 58,5 | 358,2 | |
| | Pianacce | 1987 | 1 | | D | 20 | 14,1 | 67,7 | |
| | Rancia | 1986 | 1 | | D | 20 | 19,1 | 143,6 | |
| | Rancia 2 | 1988 | 1 | | D | 20 | 19,1 | 130,2 | |
| | Travale 3 | 2000 | 1 | | D | 20 | 16,5 | 100,1 | |
| | Travale 4 | 2002 | 1 | | D | 40 | 38,9 | 196,5 | |
| | Chiusdino 1 | 2010 | 1 | | D | 20 | 19,4 | 159,9 | |
| Subtotal | | | 8 | | | 200 | 185,6 | 1156,3 | 0 |
| **Mt. Amiata** | | | | | | | | | |
| | Bagnore 3 | 1998 | 1 | | 1F | 20 | 19,9 | 175,3 | |
| | Gruppo Binario Bagnore3 | 2013 | 1 | | B-ORC | 1 | 1,0 | 6,7 | |
| | Bagnore 4 | 2014 | 2 | | 1F | 40 | 39,6 | 363,5 | |
| | Piancastagnaio 3 | 1990 | 1 | | 1F | 20 | 20,0 | 174,7 | |
| | Piancastagnaio 4 | 1991 | 1 | | 1F | 20 | 20,0 | 171,4 | |
| | Piancastagnaio 5 | 1994 | 1 | | 1F | 20 | 20,0 | 179,2 | |
| Subtotal | | | 7 | | | 120,99 | 120,5 | 1070,9 | 0 |
| **Total** | | | **37** | | | **915,5** | **806,6** | **6105** | **0** |

* Installed capacity is maximum gross output of the plant; running capacity is the Efficient Capacity

Figure 12.4: Existing geothermal power plants, individual sites

The Enel Group Company is present in all continents, globally developing and managing renewable energy generation from a range of renewable sources, water, solar, wind and geothermal, with an annual energy production of 82 TWh, avoiding millions of tons of $CO_2$ emissions annually.

## (c) Thermal production

Between 2015 and 2017 the geothermal applications have grown in terms of both capacity (+1.6%/yr) and energy use (+1.8%/yr). Figure 12.5 and Figure 12.6 show the sector breakdown in energy use and capacity.

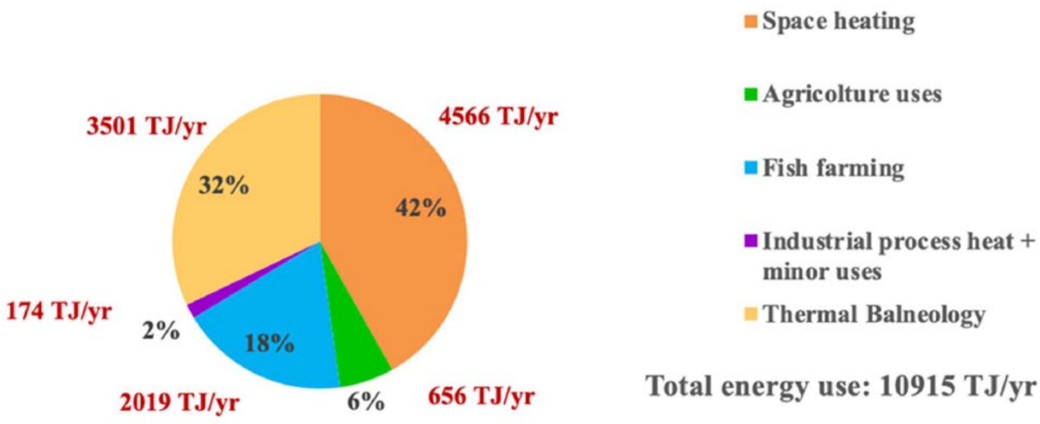


Figure 12.5: Share of geothermal energy utilization of direct uses in 2017

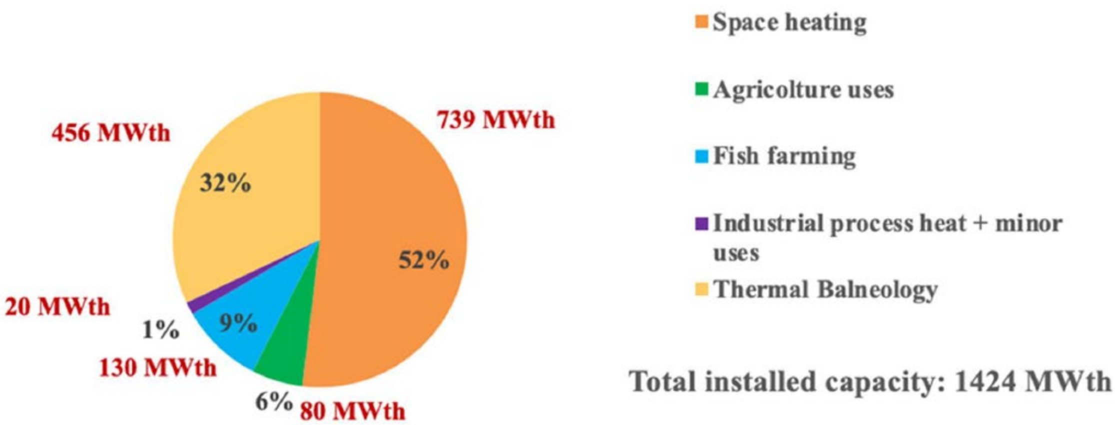


Figure 12.6: Share of geothermal installed capacity for direct uses in 2017

## 12.4 Research Highlights

In recent years, due to an increasing emphasis on sustainable development, and reducing and mitigating environmental impacts, a number of research projects have been carried out on these topics. Good results have been achieved.

In 2019 the EU H2020 program **Matching** concluded, with excellent results achieved in geothermal energy facilities. The **Matching** project achieved the target of demonstrating an up to 15% reduction in evaporative losses from cooling towers, through the replacement of wet cooling towers with hybrid towers equipped with advanced and more robust materials. The work was undertaken at the Nuova San Martino geothermal power plant.

Under the H2020 framework the **Geoenvi** project was established. Scheduled for completion by April 2021 the project aims to define Guidelines for Life Cycle Analysis (LCA) and environmental impact assessments of geothermal power plants.

The **Spirulina cultivation** project, carried out by Enel Green Power, successfully demonstrated the use of geothermal $CO_2$ and heat to grow spirulina algae. These integrated geothermal and algae production processes will reduce some $CO_2$ emissions from a geothermal plant.

Figure 12.7: Spirulina pilot plant at Chiusdino power plant

The recent evolution of the legislative framework (see section 12-2) focusses research towards reducing geothermal gas emissions (mainly $CO_2$) and the potential reuse of $CO_2$.

## 12.5 Publications


https://www.mise.gov.it/index.php/it/198-notizie-stampa/2040101-decreto-fer1-pubblicato-in-gazzetta-ufficiale

https://www.gazzettaufficiale.it/eli/id/2019/05/25/19R00137/S3


## 12.6 Useful Websites

https://www.unionegeotermica.it/

https://www.egec.org/

https://www.etip-dg.eu/

https://www.enelgreenpower.com/

https://www.enel.com/

https://www.mise.gov.it/index.php/it/198-notizie-stampa/2040101-decreto-fer1-pubblicato-in-gazzetta-ufficiale

https://www.gazzettaufficiale.it/eli/id/2019/05/25/19R00137/S3

http://matching-project.eu/

https://www.geoenvi.eu/

## 12.7 Future Activity

There are no other geothermal leases seriously under development in Italy other than the Enel Green Power geothermal developments.

Since 2010, with the liberalization of geothermal resource exploitation for power generation, ~120 new permit requests have been made. Ten of those are for permits dedicated to "Research for geothermal Resources focussed on testing with Pilot Plants", with nominal power up to 5 MW.

Currently, 34 Geothermal Research Permits have been released, listed as follows:

- Two located in Tuscany, are applying for the concession;
- Seven are currently applying for the authorization to drill exploratory wells (5 in Tuscany and 2 in Latium);
- One has obtained authorization to drill 2 exploratory wells (Tuscany);
- 20 Permit requests in Latium are waiting the final advice of award.
- Two Pilot Plants obtained EIA acceptance and are waiting for the final approval from both Region Administrations and the MISE (Ministry for Economic Development).

All the other Requests are still in the investigation phase;

The rate of development for geothermal resources for electricity generation in Italy is currently quite slow. There are many difficulties:

- time for authorization is very long and unpredictable,
- the electricity tariff is often not guaranteed for a sufficiently long period of time for business uptake or it results in an increased level of financial risk.
- Support schemes for geothermal energy are very limited in Italy, and the recent exclusion from incentive schemes for geothermal energy generation from the bids offered by RES power plants adds further difficulty, and
- the long period occurring prior to the release of the new FER2 ministerial decree is slowing down activity and investment planning in geothermal projects.

Regarding the direct use of geothermal heat, the lack of effective support schemes and regulation leads to the very slow growth of geothermal energy uptake currently seen in Italy. The situation is particularly evident for both geothermal district heating systems, which could contribute so much more towards residential heating and cooling demand, and for GSHPs, that were expected to grow at a much higher rate because it is well-established technology that is in use in numerous countries.

## 12.8 References


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https://unmig.mise.gov.it/index.php/it/dati/risorse-geotermiche

# 13. Japan

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## 13.1 Introduction

Located along the Circum-Pacific Volcanic Belt "Ring of Fire," Japan is blessed with an abundance of geothermal energy. The total capacity of geothermal power plants reached over 500MW in 1995 and then due mainly to socio-economic factors the installation of new capacity stagnated for almost two decades. Measures to intensify deployment of renewable energy by the Ministry of Economy, Trade and Industry (METI), following the nuclear power plant accident in Fukushima in 2011, have renewed interest in geothermal development. Matsuo-Hachimantai (7,499 kW) and Wasabizawa (46,199 kW) were commissioned in 2019 in addition to many small geothermal power plants that have opened in recent years. In 2021 changes were made to the legal framework of the "hot spring law" and the "natural park law" which regulate geothermal drilling in Japan. More details are described in Section 2.

The promotion of ground source heat pump (GSHP) started in Japan at the beginning of 21$^{st}$ century and the number of installations has been increasing with support from Ministry of the Environment (MOE). More details are described in Section 4.

Table 1. Status of geothermal energy use in Japan in 2021.

| Electricity | | Direct Use | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$)* | 536.9[1] | Total Installed Capacity ($MW_{th}$)*** | 2,407[2,3] |
| New Installed Capacity ($MW_e$)* | 0.0 | New Installed Capacity ($MW_{th}$) | N/A |
| Total Running Capacity ($MW_e$)** | 296[1] | Total Heat Used (TJ/yr)*** | 29,958[2,3] |
| Contribution to National Capacity (%)** | 0.2% | Total Installed Capacity Heat Pumps ($MW_{th}$)** | 163.4[4] |
| Total Generation (GWh)** | 2,313[1] | Total Net Heat Pump Use (TJ/yr)** | 764.9[4] |
| Contribution to National Generation (%)** | 0.2% | Target (PJ/yr) | N/A |
| Target (% of national generation) | 1.0-1.1% | Estimated Country Potential (GWh/yr) | N/A |
| Estimated Country Potential ($MW_e$) | 23,470[5] | | |

N/A = data not available

* As at March 2020. For data consistancy with the total generation and running capacity, an older data than that in the 2020 annual report, in which capaticy data at December 2020 was used, is shown here. Compared with the data of March 2019, new installed capacity is 42.982MW.

** Based on the data of FY 2019 (April 2019 to March 2020), which is the latest available data. Running capacity was calculated from capacity factor of 55.2% in FY 2019.

*** No data exists for recent years. For data year, see the data sources : [2][3] for Direct Use, and [4] for Heat Pumps.

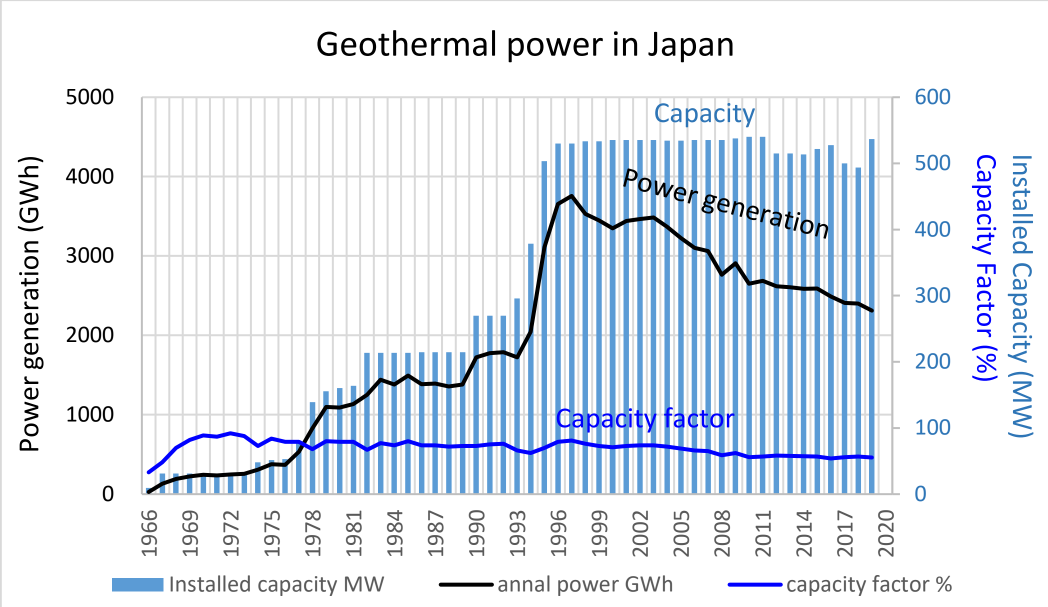

Figure 13.1 Geothermal power in Japan: total installed capacity (blue columns), power generated (black line), and capacity factor (blue line).

Figure 13.1 shows the long-term trend of geothermal power plant capacity and generation in Japan. The average capacity factor of the geothermal power plants has been decreasing since the 1970's. It is because, with immature knowledge of geothermal reservoir management, developers built larger capacity power plants that were beyond the ability of the reservoirs to support the facilities long-term, resulting in declining steam production with time. Therefore, some older power plants have been decommissioned with new smaller capacity units replacing the older units. Thus, although the total number of units has increased in recent years, the total capacity decreased between 2012 and 2018 (Refer Figure 13.1). The increase in capacity during 2019 was from the Wasabizawa geothermal power plant (46,199 kW) in Akita and the Matsuo-Hachimantai geothermal power plant (7,499 kW) in Iwate. Another reason for decreasing capacity factor is that many of the new small power plants are operating with quite low capacity factors due to lack of technical investigation beforehand, or run by local business people who have been attracted by a high FiT price.

## 13.2 Policy Supporting Geothermal Development

### 13.2.1 Recent promotion measures of renewable energy by MOE

Toward a carbon neutral society - In early 2021 a taskforce under the cabinet of Japan reviewed laws which prevent / limit deployment of renewable energy. For geothermal power generation, the taskforce requested amendment of a guideline and a notification under the hot spring and natural park laws. MOE made these amendments in September 2021 as described below.

In Japan, permission for geothermal-well-drilling is given by the local government (prefecture) under the "hot spring law" which has a guideline that cautions against drilling of new wells to protect already existing hot spring wells. Under this law, many prefectures set regulation on well spacing or drilling density. However, such regulations may not be appropriate for geothermal drilling, in which multiple well paths emanate from a common drilling platform. Also, permission for each well is not necessarily appropriate from a reservoir management standpoint. Therefore the amendment in 2021 changed the guideline from "well to well control" to "reservoir control." MOE ordered local governments to withdraw the regulation that limited spacing or density of geothermal drilling. Under the new guideline, drilling permission for a second or later well into an same reservoir by the same geothermal developer should be easier to obtain than before, but only if a proper reservoir evaluation is undertaken. On the other hand, drilling into a reservoir by another developer or drilling without rigorous reservoir evaluation may not be permitted. The new guideline seeks to encourage larger geothermal development but discourage "overfishing."

Natural parks in Japan (national parks and prefecture parks) are divided into five zones from special protected to less protected zones as follows:

- special protection zone,
- special zone 1,
- special zone 2,
- special zone 3, and
- normal zone.

Among them, special zones 2 & 3 and the normal zone are used for residential and commercial activities. Geothermal power generation in special zones 2 & 3, the normal zone, and directional drilling toward special zone 1 are allowed under some conditions as described in notifications under the natural park law. However, the conditions such as "not disturbing the scenery" or "with special caution on environment" are not very specific so that the rulings and judgements by the local authority have not been uniform. Furthermore, since the earlier prescription of the notification clarified that "geothermal power generation is basically prohibited in natural parks," meant that most geothermal projects in natural parks have been rejected although they might have satisfied the conditions. The easing of the regulations in 2021 saw the prescription deleted and a new sentence inserted; "Geothermal power generation with special caution on environment should be encouraged". Geothermal projects "not disturbing the scenery" and "with special caution on environment" are now encouraged.

### 13.2.2 FiT and other economic supports given by METI

The Japanese government initiated a Feed-in-Tariff (FiT) for wind, geothermal, hydro, and biomass power in July 2012 in addition to the FiT for solar PV (2010). The tariff price of geothermal power has been kept high while that for solar PV and wind have been reduced every year.

The government is planning to replace the FiT with a Feed-in-Premium (FiP) in 2022. In the plan the FiT will partially remain after 2022 under certain conditions, parallel with the new FiP. The condition for the geothermal FiT, for example, will be for small capacity geothermal power projects led by the local government or local community.

Beside FiT, METI has been supporting geothermal energy development through various support measures. METI's budget for JOGMEC (Japan Oil, Gas and Metals National Corporation) includes subsidies of geothermal exploration including drilling, and low interest loans for construction of geothermal power plants. These measures have brought renewed interest in geothermal development by private sector organisations (such as electric power companies, oil companies, construction companies), local governments, and other entities. METI has also been funding geothermal technology development.

## 13.3 Geothermal Development Projects

### 13.3.1 Projects Supported by JOGMEC

A geothermal development project generally takes a long time from exploration to power generation. In addition, there are resource risks, which makes geothermal power projects different from other thermal power projects. In order to assist in managing these risks, JOGMEC supports the development of geothermal resources using three financial support mechanisms;

- grant subsidies,
- equity capital investment, and
- loan liability guarantees for geothermal development.

The Matsuo-Hachimantai project is a model case in which JOGMEC's support mechanisms have worked effectively, from grant subsidies, equity capital investment, through to the liability guarantees. The operation of this power plant commenced in January 2019.

In FY2021 (April 2021 to March 2022), 20 projects were accepted for grant subsidies (shown in red in Figure 13.2), for which between 50-100% of the investigation cost is supported. Three out of the 20 projects are new in 2021. In FY 2021 the total value of grant subsidies was ~6 billion JPY (~55 million USD).

After initial survey work is completed, developers need to estimate the production capacity. At this stage, JOGMEC may invest up to 50% of the cost.

At the construction stage, significant funding is required to drill the wells and to construct the facilities. When private developers construct a geothermal power plant with loans from private financial institutions JOGMEC may provide a liability guarantee of up to 80% of the total loans. To date, JOGMEC have provided loan liablity guarantees for six projects; four (Tsuchiyu, Sugawara, Matsuo-Hachimantai and Wasabizawa) have commenced operation, with two (Minami-Kayabe and Appi) under construction.

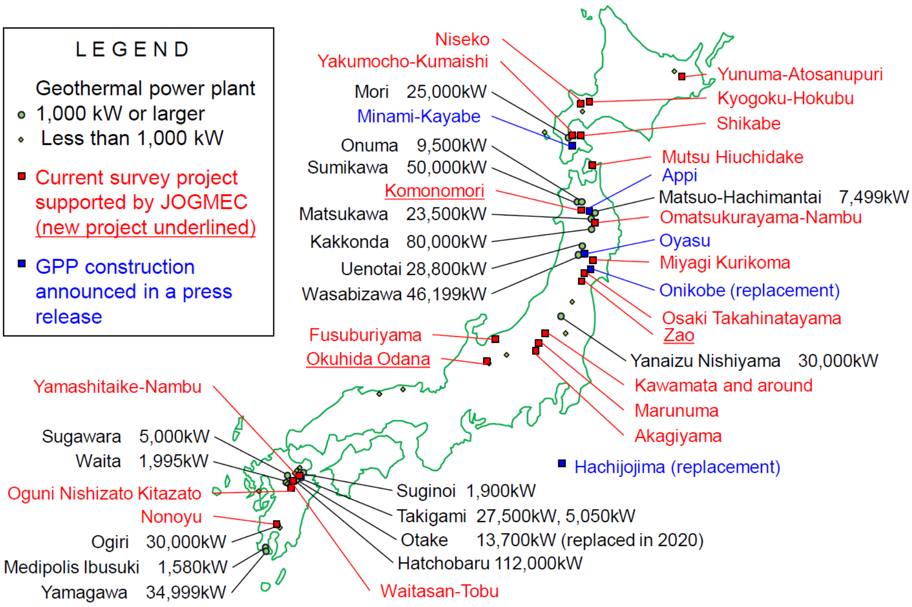


Figure 13.2 Geothermal power plants and ongoing projects in Japan as of December 2021

## 13.3.2 Projects Operational

Construction of geothermal power plants has been announced in several areas. At Minamikayabe, Hokkaido, a binary power plant of 6.5 MW will begin operation in 2022. At Appi, Iwate, a geothermal power plant of 14.9 MW has been under construction since 2019 and scheduled to begin operation in April 2024. It has been announced that the construction of a geothermal power plant at Kijiyama, Akita will begin in 2025, to be completed by 2029. The smallest double flash system of 1.9 MW has been installed at Nakao, Gifu, and scheduled to begin operation in late 2022. The excess hot water is provided to local hot spring owners seeking to assist with the creation of good working relationships with the local residents. In some other regions, geothermal power generation projects with capacities smaller than 1 MW are also being progressed.

Several older geothermal power plants are at the stage of facility replacement. Matsukawa geothermal power plant (23.5 MW since 1966) in Iwate, the oldest GPP in Japan, is currently under environmental assessment to be renewed with a new unit of 14 MW in 2025. Construction will begin in 2022. Onikobe geothermal power plant (15 MW since 1975), Miyagi was shut down in 2017 and environmental assessment for the new power plant was completed in November 2018. The project is currently under construction with operations scheduled to recommence in April 2023. Hachijojima geothermal power plant (3.3 MW since 1999), Tokyo, was shut down in 2019, with the new power plant scheduled to commence operation in 2022 with a capacity of 4.4 MW. At Otake power plant, Oita, construction of a new power plant began in 2018 when the old power plant (12.5 MW since 1967) was still in operation. It was replaced with the new plant (13.7 MW) on 5 October 2020.

## 13.4 Ground Source Heat Pump (GSHP)

### 13.4.1 Trends and Current Status

The census on GSHP in Japan is conducted every other year by MOE and the latest "census 2020[6]" data was released in 2021. The installation of GSHP in Japan has been increasing in recent years, although the total number is still rather small (Figure 13.3). The total number of facilities using GSHPs is 2,994 (2,662 in "census 2018") including 2,511 (2,314) closed-loop, 460 (327) open-loop, and 22 (21) using both[4,6]. No data is shown for capacity and energy use in the 2020 census data. According to a report based on the 2018 census, installed capacity of all the GSHPs is 163 $MW_t$, and annual energy use is 765 TJ/yr [7].

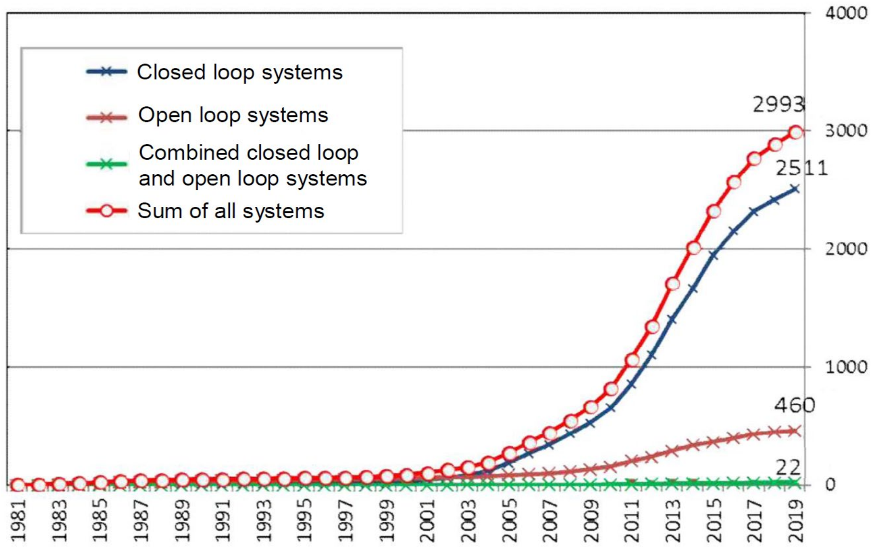


Figure 13.3 Cumulative installations of GSHP systems in Japan[6]

Many systems have been installed in the northern regions including Hokkaido where heating needs are intensive, indicating the superior economic performance of GSHPs when they replace an old oil boiler. GSHPs are also widely used in other parts of Japan; cooling needs are quite high in the middle to south-western Japan, and GSHP with high performance COPs for cooling are contributing to electricity savings.

Figure 13.4 shows the cumulative number of GSHP systems by different facilities category[6]. The largest share is individual housing, followed by offices and public buildings. There are 36 installations in apartments which was zero in the 2018 census data.

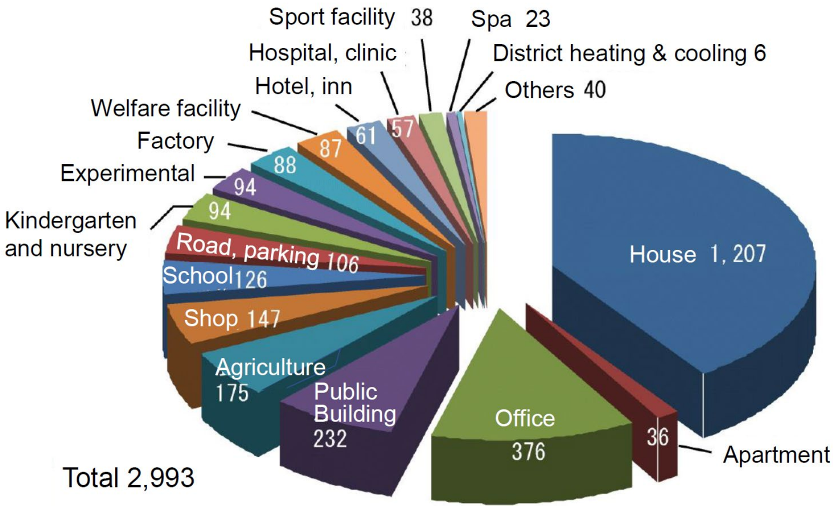


Figure 13.4 The number of facilities using GSHP system [4]

## 13.5 Research Highlights

Two METI funded agencies; JOGMEC and NEDO (New Energy and industrial technology Development Organization), started geothermal projects in 2013 developing technology. The NEDO work is focusing on geothermal technologies that are to be realised in the longer term whilst JOGMEC is focusing on surveys, technologies and support that are effective in the short term.

NEDO began research on subduction-origin supercritical geothermal resources with a target year of 2040 for a pilot plant to be operational. This is one of the NESTI2050 projects, which is looking to contribute to the 2050 $CO_2$ reduction targets set by the Cabinet of Japan in 2017.

In order to promote geothermal development, JOGMEC has undertaken a survey program to acquire basic data for the evaluation of some geothermal prospects since 2013. The program currently consists of airborne helicopter geophysical survey, land-based geological and geophysical surveys, and slim-hole drilling for subsurface temperature data. The acquired data is published and used by private companies to develop their new exploration projects. By the end of 2021, airborne surveying had been conducted in 19 regions, land-based survey in 18 regions, and slim-hole drilling in 17 regions as shown in Figure 13.5

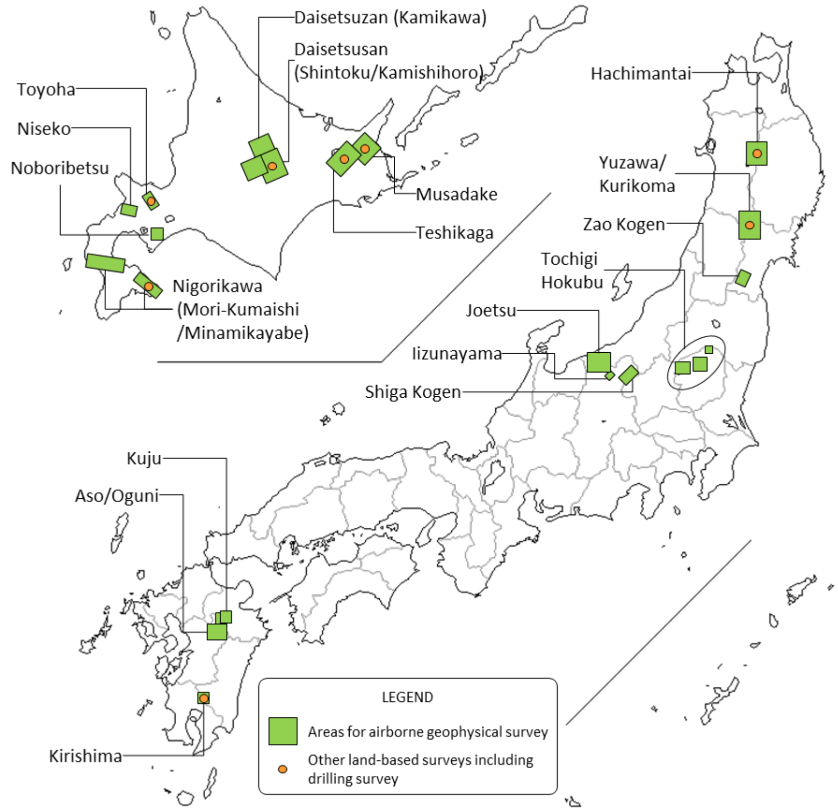


Figure 13.5 Regions for airborne geophysical survey and other surveys conducted by JOGMEC.

JOGMEC has four technology development R&D project themes with the specific projects under these themes shown in Table 1. Theme D) was added in FY2021 and four projects have commenced in FY2021 as shown in Table 1. Among these new projects the concept of EGS technology development using supercritical Carbon Dioxide is shown in Figure 13.6.

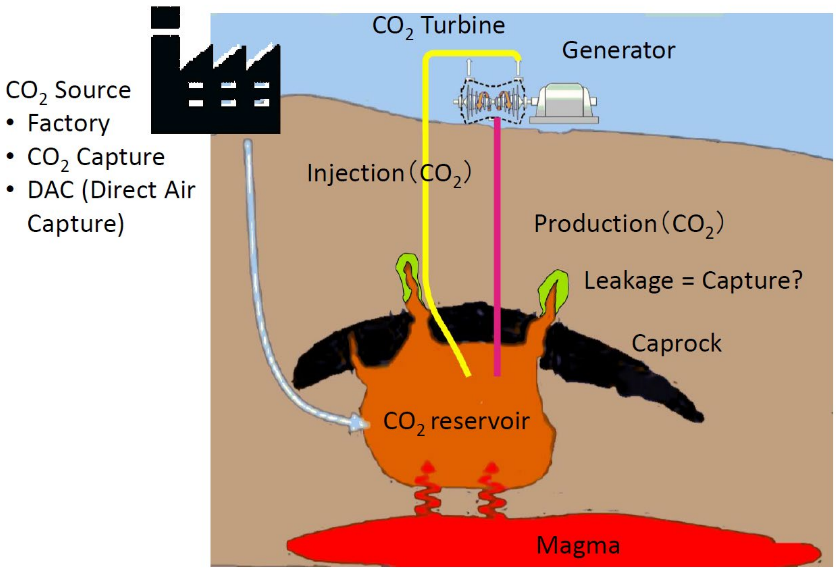


Figure 13.6 Concept of EGS technology development using supercritical Carbon Dioxide

Table 1. Geothermal Technology Development by JOGMEC

| Theme | Project | Status |
|---|---|---|
| A) Technology for Exploration of Geothermal Reservoirs | Exploration for acid fluid control | FY2018- |
| | Efficient and dense exploration | New |
| B) Drilling Technology | Highly-declined well drilling | New |
| | PDC bit for geothermal well | follow up |
| C) EGS (Enhanced Geothermal Systems) technology | Artificial recharge by river water | FY2013- |
| D) Innovative Geothermal Technology | EGS technology development using supercritical Carbon Dioxide | New |
| | Closed circuit heat exchange technology | New |

Since 2017, NEDO has been conducting an R&D project "Development of subduction-origin supercritical geothermal resources" to utilize 400 to 500°C supercritical fluid at a depth shallower than 5km. Earlier surveys suggested supercritical geothermal resources may exist in/around many of the volcanic zones in Japan with total potential possibly of several tens of giga-watts. 2040 is targeted for the operation of a pilot plant.

To overcome problems with acid fluid in supercritical conditions, the project covers various fundamental scientific studies in; rock mechanics, material science, geo-science, as well as technology development, numerical simulation and drilling. The basic studies are being led and conducted by the National Institute of Advanced Industrial Science and Technology (AIST) and Kyoto University. The first phase of the project was completed in 2020 and the second phase began in 2021 to select a region for deep drilling in the 3rd phase.

## 13.6 Other National Activities

### 13.6.1 Promotion of Geothermal Development

METI began a program in 2013 to raise social acceptance of geothermal power generation amongst local residents. It is a subsidy scheme for general public educational activities undertaken by local governments and/or private sector organisation. Seven projects were adopted in 2021 (8 in 2020).

Every year since 2013, JOGMEC has held a Geothermal Symposium promoting geothermal power generation amongst the general public, seeking to increase the knowledge and the understanding of geothermal energy use. In 2021, the symposium was held in Aizuwakamatsu city, Fukushima as a hybrid event (in-person meeting and live stream). More than 1600 people accessed the symposium from all over Japan and 64 people, including local citizens and members of the Diet, local parliament and local government, attended at the venue.

A wide technical knowledge gap exists between geothermal energy business people and local government officials, making it difficult for the officials to moderate local opinions with local social acceptance being quite important for geothermal projects. Aiming at bridging this gap, JOGMEC established in June 2016 a third-party expert organization, the "Advisory Committee for Geothermal Resources Development". Matters of consultation from eight municipals were discussed in FY2021.

### 13.6.2 International collaboration and human capability development

Human resource development is an important issue in the international geothermal community. The Japan International Cooperation Agency (JICA) is organizing training courses for geothermal specialists from developing countries. The program is basically provided by Kyushu University and supported by lecturers from other universities, institutes and private companies in order to cover all aspects of a geothermal energy development. JICA has also been active in conducting Official Development Assistance (ODA) projects in geothermal development in Asian, African and Latin American continents for many decades.

JOGMEC and GNS Science (New Zealand), have a memorandum of understanding for collaboration in geothermal technology. A joint online seminar "Carbon neutral geothermal" was held on 10 December 2021, in addition to four past workshops held in Japan and in New Zealand on scaling, community acceptance, reservoir engineering and geothermal geology.

For domestic capability development, JOGMEC has been providing a three-week-long geothermal training course every year. In 2021, it was held from late November to mid-December in Kosaka city, Akita and in Tokyo. It covers the basics of geothermal energy including technical, economic and social aspects of geothermal energy projects. This course is valuable for private developers, many of whom have little experience in geothermal business.

## 13.7 Useful Websites

- Ministry of Economy, Trade and Industry (METI), "Japan's Energy": https://www.enecho.meti.go.jp/en/category/brochures/pdf/japan_energy_2021.pdf
- Japan Oil, Gas and Metals National Corporation (JOGMEC), "geothermal": https://www.jogmec.go.jp/ /english/geothermal/geothermal_10_000001.html
- New Energy and Industrial Technology Development Organization (NEDO): https://www.nedo.go.jp/english/activities/activities_ZZJP_100066.html
- Japan International Cooperation Agency (JICA): https://www.jica.go.jp/english/index.html
- Geothermal Energy Team, Institute of Advanced Industrial Science and Technology (AIST): https://www.aist.go.jp/fukushima/en/unit/GET_e.html
- Geothermics, Faculty of Engineering, Kyushu University: https://www.eng.kyushu-u.ac.jp/e/lab_earth03.html

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[9] Shrestha et al. : Assessment of the Installation Potential of a Ground Source Heat Pump System Based on the Groundwater Condition in the Aizu Basin, Japan, Energies 2018, *11*, 1178 (2018

# 14. Mexico

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## 14.1 Introduction

In December 2021, the total installed capacity for electric power generation in Mexico was 86,153 $MW_e$. Of that, 64.2% of the capacity in the country uses fossil fuels, mainly natural gas and coal, and the remaining 35.8% use clean energy sources, composed of hydroelectric 14.6%, wind power 8.1%, solar (photovoltaic) 6.9%, efficient cogeneration 2.7%, nuclear 1.9%, bioenergy 0.4%, and geothermal-electric plants 1.1% (SENER, 2022).

A little more than half (44,181 $MW_e$) of the installed capacity is owned and operated by the government utility CFE (Comisión Federal de Electricidad), including almost all (97%) of the installed geothermal-electric capacity. The remaining power plants in operation are owned and operated by private companies, except 920 $MW_e$ owned and operated by PEMEX, the state-owned oil company (SENER, 2022).

The geothermal-electrical capacity of 1001.9 $MW_e$ in December 2021 was practically the same as that reported in 2020. The difference is due to adjustments in the reports, particularly in the power plants at the Los Azufres field. There were five geothermal fields in operation: Cerro Prieto, BC, Los Azufres, Mich., Los Humeros, Pue., Las Tres Vírgenes, BCS, and Domo de San Pedro, Nay.

Figure 14.1 Night Drilling Los Azufres

The running or operational capacity of 959 $MW_e$, was a little higher than reported last year, due to the same adjustments (Table 1).

Table 1. Status of geothermal energy use for electric power generation and direct uses in Mexico in December 2021.

| Electricity | | Direct uses | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | 1001.9 | Total Installed Capacity ($MW_{th}$) | 156.0 |
| New Installed Capacity ($MW_e$) | 0 | New Installed Capacity ($MW_{th}$) | 0 |
| Total Running Capacity ($MW_e$) | 959.0 | Total Heat Used (GWh/yr) | 1,162.1 |
| Contribution to National Capacity (%) | 1.1 | Total Installed Capacity Heat Pumps ($MW_{th}$) | 0.13 |
| Total Gross Generation (GWh) | 4511.5 | Total Net Heat Pump Use [GWh/yr] | N/A |
| Contribution to National Generation (%) | 1.4 | Target (PJ/yr) | Not set |
| Target ($MW_e$ or % national generation) | Not set[a] | Estimated Country Potential ($MW_{th}$) | 40,589[c] |
| Estimated Country Potential ($MW_e$) | 2,500[b] | | |

a) There is no specific target set for geothermal energy. A target of 35% of the total installed power generation capacity is set for clean energy sources by 2024. “Clean energy sources” are defined by law as those producing little or no greenhouse gas emissions to the atmosphere, and they include geothermal energy and the rest of renewable sources, but also nuclear, efficient cogeneration, and other clean technologies.

b) Estimated potential from conventional hydrothermal resources with temperatures > 150°C (Gutiérrez-Negrín et al., 2020). A recent estimate of EGS potential in Mexico, comprising hot-dry resources located between 3 and 7 km depth, is around 47,000 $MW_e$ (Hernández-Ochoa et al., 2020).

c) 0.1 % of recoverable resources using a world average load factor of 0.27, based on Iglesias et al., 2015, for resources between 36°C and 208°C.

The electricity generation in the country during 2021 was 323,527 GWh, of which 224,701 GWh was generated by fossil-fuelled (mainly natural gas and coal) power plants, representing 69.5% of the total. The remaining 30.5%, i.e., 98,826 GWh, was produced by clean energy sources, composed of 10.7% hydroelectric, 6.5% of wind, 5.3% of solar (PV), 0.2% of bioenergy, 3.6% nuclear, 2.9% efficient cogeneration and 1.4% (4511.5 GWh) from geothermal (data from SENER, 2022, except geothermal data collected from the field managers).

It is worth mentioning that the share (30.5%) of clean energy sources in the total of electricity generated in the country in 2021 reached the partial objective defined for this year, in order to comply with the national goal of 35% of the total electric energy produced from clean-energy sources by 2024, according to the Energy Transition Law (Gutiérrez-Negrín et al., 2020), and was even a little higher. However, it is estimated that percentage will remain the same in the following three years (2022 through 2024), and therefore it’s probable that the clean energy source goal will not be achieved in 2024 (SENER, 2022).

Regarding direct uses of geothermal heat, these remain largely undeveloped in Mexico. They are limited to mainly bathing and swimming facilities for recreational or therapeutic purposes, despite the many thermal manifestations identified at the surface. Balneology is the primary direct use of geothermal heat in Mexico representing around 155.3 $MW_{th}$ in heated pools and spas, with ~0.8 $MW_{th}$ of other direct uses (heating, drying, and GHP), giving a total of 156.1 $MW_{th}$. These amounts are the same as reported in the previous year (Table 1; Gutiérrez-Negrín et al., 2020).

It's worth recalling that Mexico has significant potential for developing geothermal heat uses. Based on surveys made by CFE in the eighties, Iglesias et al. (2015) estimated that there are more than 1,600 hot springs and other thermal manifestations in more than 900 geothermal systems, in 26 states of the country. About one-half of those systems have temperatures in the range 62 to 100°C, 40% with temperatures 100-149°C, and 10% with temperatures below 62°C (5%) or higher than 149°C (5%). The authors estimated that if only 0.1% of these resources were used, it would represent more than 40,000 $MW_{th}$ of installed capacity (Iglesias et al., 2015).

As mentioned in past reports, some demonstration projects were developed in the period 2014-2019 sponsored by the Mexican Center for Innovation in Geothermal Energy (CeMIE-Geo) promoting the direct use of geothermal heat (Romo-Jones and Group CeMIEGeo, 2015). The first geothermal heat pumps (GHP) installed in Mexico were from this effort. After the demonstration projects 11 GHP units are operating in four locations in the country, representing an installed capacity of 133 $kW_{th}$ (Table 1). One spin-off company derived from the CeMIE-Geo projects is dehydrating local fruit using the residual steam of the Domo de San Pedro power plant in Nayarit. They are using a geothermal dehydrator of 0.53 $MW_{th}$ in capacity (Aviña, 2022).

## 14.2 Changes to Policy Supporting Geothermal Development

The Geothermal Energy Law and its regulatory framework remain in force in Mexico. The former Geothermal Direction of the Energy Ministry (SENER) has awarded six exploitation concessions and 24 exploration permits as of December 2021. CFE obtained and holds exploitation concessions for four geothermal fields in operation (Cerro Prieto, Los Azufres, Los Humeros and Las Tres Vírgenes) and for one field in standby (Cerritos Colorados, located in the State of Jalisco). Grupo Dragón holds the concession for the Domo de San Pedro field, which is the only field in private ownership in operation in Mexico. One exploitation concession was granted by SENER to the private company Energías Alternas Estudios y Proyectos (ENAL) for the geothermal zone of Celaya, Guanajuato, where the company is developing a 25 $MW_e$ project with investment estimated at 77 US$ million, which includes drilling of three exploration-production wells. A prototype small power plant of 500 kW is currently installed in the zone to test the reservoir (Espíndola, 2022, personal communication).

CFE also holds 13 of the exploration permits awarded by SENER, and carried out complementary geological and geophysical surveys in a few of those geothermal zones during the last year, including the design and location of a new deep exploration well in one of the granted zones. Some of the private companies awarded the remaining 11 exploration permits have developed geological, geophysical and geochemical surveys in their respective areas in an intermittent way due to the restrictions of the Covid19 pandemic. In particular, ENAL has completed the exploration activities in one of its three granted areas and is ready to drill the first deep exploration well (Espíndola, 2022, personal communication).

There have not been any new grants for exploration because of the delays caused by the COVID-19 pandemic. During 2020, several private developers sought to file for exploration permits in new geothermal zones, but SENER's offices suspended all administrative procedures from March 2020. At the beginning of 2022 the offices were re-opened, ready to receive and process applications.

Regarding financing and risk-mitigation, the former Geothermal Financing Mexican Program (PGM) was conceived as a risk transfer and financing program supported by the Inter-American Development Bank (IDB) and the Mexican development bank Nafin, structured under the global loan modality. As informed in the 2020 report, it consisted of two main components: risk mitigation and financing adapted to the different phases of project exploration and execution, and a third minor component of technical assistance. The program's total amount is US$108.6 million and aims to finance up to 300 MW of geothermal capacity over ten years (IGA News, 2018).

The national institute INEEL (Instituto Nacional de Electricidad y Energías Limpias), particularly the geothermal division, was chosen by SENER as the technical executor of the program. INEEL carried out several activities in 2020 and 2021, but finally SENER decided to update and modify the Call for Proposals, the bidding procedures and other relevant parts of the program, including its name, which is now PFTRG (Programa de Financiamiento y Transferencia de Riesgo en Geotermia, or Program for Geothermal Financing and Risk Transfer). Calls for more proposals are to be requested in early 2022.

There is another financing fund available for geothermal in Mexico, which is the Geothermal Development Facility for Latin America (GDF-Latam). It is not a public program or policy of the Mexican government, but it is worth mentioning that GDF-Latam was originally aimed at geothermal projects in Latin America except Mexico due to the level of development of geothermal energy already in Mexico. However, the fund started to accept proposals from Mexico in 2020. The main donors of this fund are the German Federal Ministry for Economic Cooperation Development (BMZ) and the EU through the Latin America Investment Facility (EU-LAIF). CFE and several private developers have submitted Expressions of Interest (EoI), with no public results released up to now.

## 14.3 Geothermal Projects Development

### 14.3.1 Projects Commissioned in 2021

No additional projects were commissioned in 2021.

### 14.3.2 Projects Operational in 2021

There are five operational geothermal fields in the country. Their main features, already mentioned in previous reports, are as follows (see also Table 2 below):

**Cerro Prieto, BC.** This field is located in north-western Mexico, near to the USA border. The first two geothermal power plants, of 37.5 $MW_e$ each, were commissioned in 1973. It is owned and operated by CFE. The installed current capacity is 570 $MW_e$ composed of four condensing, flash units of 110 $MW_e$ each, one condensing, low-pressure unit of 30 $MW_e$, and four condensing flash units of 25 $MW_e$ each. The operational capacity is the same (570 $MW_e$). The four oldest power plants, with a combined capacity of 150 $MW_e$, were dismantled several years ago. In 2020 Cerro Prieto produced 24 million tons of steam, with 129 production and 28 injection wells in operation. Unit 3 of Cerro Prieto IV (CP-IV), with 25 $MW_e$ of net capacity, generated 214 GWh in 2021, presenting the highest capacity factor of the field (97.7%), quite an achievement for a plant with 21 years in operation. The Unit 5 of CP-I, which is the only one working with low-pressure steam, produced 231 GWh and reaching a capacity factor of 88.1%, despite its 39 years of operation. The Unit 1 of CP-III (110 $MW_e$) was out of operation during the most part of 2021 due to major maintenance. The gross electricity generation in Cerro Prieto was 2510.6 GWh during 2021 (CFE, 2022, personal communication).

**Los Azufres, Mich.** This field is in central Mexico, within the physiographic province of the Mexican Volcanic Belt (MVB), at an average altitude of 2850 meters above the sea level (masl). The first power units were commissioned in 1982. The field and the power plants are owned and operated by CFE with an installed capacity of 275.1 $MW_e$, composed of seven condensing, flash units (one of 53.4, one of 50, three of 26.6, one of 26.8 and one of 27.2 $MW_e$), seven back-pressure units each of 5 $MW_e$, and two binary cycle units each of 1.45 $MW_e$. Three out of the seven back-pressure and the two binary cycle units are out of operation, and thus the running capacity is 257.2 $MW_e$. In 2020 there were 49 production wells in operation, which produced 16.4 million tons of steam. Unit 18, which is the most recent unit in the field with 27.2 $MW_e$ of gross capacity, produced 219 GWh during 2021, operating at the best capacity factor in Los Azufres (91.9%). The Unit 17, of 53.4 $MW_e$ in capacity, was out of operation most part of the year. The gross electricity generation in Los Azufres was 1370.6 GWh in 2021 (CFE, 2022, personal communication).

**Los Humeros, Pue.** This field is located in the central-eastern part of Mexico, also inside the MVB but on its easternmost tip. The oldest units were commissioned in 1990-1991. CFE is the owner and operator of the field, which has an installed capacity of 120.7 $MW_e$. It comprises three condensing, flash units, two of 26.8 $MW_e$ each, and one of 27.1 $MW_e$, and eight back-pressure units, each of 5 $MW_e$. The running or operational capacity is 95.7 $MW_e$ because five of the back-pressure units are out of operation. In 2020 there were 29 production wells in operation in the field, producing around 5.8 million tons of steam. The electricity generation in 2021 was 479.7 GWh (CFE, 2022, personal communication). The Unit 10, of 26.8 MWe in gross capacity, generated 184 GWh in 2021, at an average capacity factor of 78.4%, which was the best of the field.

**Las Tres Vírgenes, BCS.** This field is located in the middle of the Baja California Peninsula and is operated and owned by CFE. It has two condensing, flash type power units with a capacity of 5 $MW_e$ each, being the same its operational capacity (10 $MW_e$). Both power units started to operate in 2002. During 2020 CFE operated three production wells in this field, producing around 0.6 million tons of steam. The electricity generation during 2021 was 43.1 GWh (CFE, 2022, personal communication) at an annual average capacity factor of 49.2%. This capacity factor is the lowest of all the fields operating in Mexico, but it’s worth to recall that Las Tres Vírgenes plays a significant role, as it provides around 25-30% of the electrical demand to the Mulegé isolated system, which is a small electric network independent of the national grid.

**Domo de San Pedro, Nay.** This is the most recently developed field in Mexico, located in central-western Mexico, inside the MVB. It is owned and operated by the private company Grupo Dragón and has an installed capacity of 26.1 $MW_e$, with a condensing flash power plant of that plate capacity, commissioned in 2016. Originally two back-pressure units, each of 5 $MW_e$, were installed in this field in 2015, to test the reservoir, but they have been out of operation since April 2016, when the new unit was commissioned, and now have been dismantled. The total electric output of the field in 2021 was 107.6 GWh (Grupo Dragón, 2022, personal communication).

Data from every field are reported in Table 2. Data for wells in operation are for 2020.

Table 2. Geothermal fields in operation in Mexico in 2021. (*Data for 2020)

| Field | Capacity (MW) | | Owner / Operator | Wells in operation* | |
|---|---|---|---|---|---|
| | Installed | In operation | | Production | Injection |
| **Cerro Prieto, BC** | 570.0 | 570.0 | CFE | 129 | 28 |
| **Los Azufres, Mich.** | 275.1 | 257.2 | | 49 | 6 |
| **Los Humeros, Pue.** | 120.7 | 95.7 | | 29 | 3 |
| **Las Tres Vírgenes, BCS** | 10.0 | 10.0 | | 3 | 1 |
| **Domo San Pedro, Nay.** | 26.1 | 26.1 | Grupo Dragón | 3 | 1 |
| **Total** | **1001.9** | **959.0** | | **213** | **39** |

## 14.4 Research Highlights

The GEMex project was a bilateral initiative between Mexico and the European Community aimed to investigate two unconventional geothermal opportunities: a possible EGS system in Acoculco, Pue., and a superhot system in Los Humeros, Pue., both sites licensed to CFE for geothermal exploration and exploitation, respectively. In Mexico the project was led by the university of Michoacán (UMSNH: Universidad Michoacana de San Nicolás de Hidalgo), commencing in February 2017 and concluding in December 2021 after some time extension due to the pandemic restrictions.

The multidisciplinary results of Los Humeros geothermal field and Acoculco prospect area have been reported in specialized journals and in the World Geothermal Congress 2020+1, held in Reykjavik in May-October 2021, and made available to CFE for decision making.

The CeMIE-Geo project successfully requested an extension for 2021 and 2022, with the inclusion of five new projects, additional to the original projects that were finished in 2019. One of these new projects is the operation of the system of specialized laboratories of CeMIE-Geo and is being executed by CICESE. The other four relate to geothermal direct uses being executed by the Engineering Institute of the national university (UNAM). The latter are: a desalination plant (40 $m^3$/day) in Baja California using low temperature resources, design and construction of a geothermal heat pump, design and development of a small (10 kW) binary-cycle plant and scaling up to 100 kW, and the scaling of an ORC turbine using super-critical $CO_2$. It is expected that all these projects will be completed in 2022.

## 14.5 Other National Activities

### 14.5.1 Geothermal Education

After the pause due to the pandemic's restrictions, training courses with topics related to geothermal energy continued to be offered by several Mexican universities. Most are aimed at undergraduate students in geosciences, physics, chemistry, engineering, and energy. Specialized graduate programs are available at a few universities and scientific research institutions.

During 2021 the CeMIE-Geo continued to offer the online Introduction to Geothermal Energy course which has been followed by more than 9000 participants with more than 600 graduated (https://es.coursera.org/learn/geotermia).

### 14.5.2 Conferences

The annual congress of the Mexican Geothermal Association (AGM), that was postponed to 2021, was again postponed in April 2022 due to the COVID-19 pandemic.

The Mexican Geophysical Union (UGM) annual meeting took place on October 31st through November 5th 2021 in Guadalajara, Jal., with a hybrid format, virtual and on-site. Some papers with results from the GEMex project were presented.

### 14.5.3 Publications

CeMIE-Geo's Digital Collection (https://colecciondigital.cemiegeo.org/xmlui/) includes 114 papers in peer-reviewed international journals, 118 theses, and 45 conference posters. It contains a register of the 1,727 papers published about Mexican geothermal fields since 1970. These papers were compiled from the GRC Geothermal Library, the IGA's Geothermal Paper Database, DOE Scientific and Technical Information repository, SCOPUS, and WEB of Science.

### 14.5.4 Useful Websites

Asociación Geotérmica Mexicana (in Spanish): www.geotermia.org.mx

Centro de Investigación Científica y de Estudios Superiores de Ensenada (CICESE) (in Spanish): http://www.cicese.edu.mx/

Centro Mexicano de Innovación en Energía Geotérmica (CeMIE-Geo) (in Spanish, with parts in English): http://www.cemiegeo.org/?lang=1

Colección digital CeMIE-Geo: https://colecciondigital.cemiegeo.org/xmlui/

Comisión Federal de Electricidad (in Spanish): http://www.cfe.gob.mx/paginas/Home.aspx

Instituto Nacional de Electricidad y Energías Limpias (INEEL) (in Spanish): https://www.ineel.mx//inicio.html

Proyecto GEMex: http://www.gemex-h2020.eu/index.php?lang=en

Secretaría de Energía (SENER) (in Spanish): http://www.gob.mx/sener#prensa

## 14.6 Future Activity

The Mexican government has continued its policies and plans to strengthen energy companies owned by the state, particularly the oil company PEMEX and CFE. It is expected that the CFE's geothermal-electric operations might benefit from such a policy and get more resources to develop its portfolio of 13 geothermal zones that have been granted to it. It is also expected that more private companies will resume exploration and development activities in the geothermal zones granted to them.

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# 15. New Zealand

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## 15.1 Introduction and Summary

In summary, during 2021, most of New Zealand's geothermal generation facilities have been running at near maximum capacity, and geothermal generation has contributed ~18.1 % to the national electricity supply, amounting to 7820 GWh (similar to 2020).

Optimization of the operation of existing geothermal power-plants has continued. Adjustments in well operation or steam field inter-connections to accommodate changes in production well discharge enthalpy, along with reinjection strategy changes, have improved utilization efficiency and environmental sustainability.

Construction of the staged expansion of the Tauhara II project near Taupō township continued through 2021. Site preparation, drilling and well testing are close to completion. Using existing resource consents (up to 250 MWe), the first stage (a 168 MWe single shaft, triple flash, turbine) is now planned to be commissioned by late 2023 (Contact Energy, 2022).

The Top Energy Ngawha geothermal project expansion (OEC4) of 31.5 MWe has successfully operated for its first year through 2021, more than doubling the previous output of 25 MWe from the TOP facilities.

With respect to Direct Use of geothermal energy, the Bay of Plenty Region and the TaupōDistrict continue to promote geothermal business development. Implementation continues of a nation-wide geothermal direct use strategy initiative through the New Zealand Geothermal Association (NZGA, 2022). Operators and investors are working on commercial projects that would benefit economically from a supply of geothermal fluids. The development of an Innovation hub is under consideration in the industrial area east of Taupō.

The following table provides information on geothermal energy use for New Zealand during 2021. Electricity generation information is from MBIE, a government ministry (MBIE, 2022), while the direct use information is modified from the New Zealand Country update report to the WGC2020+1 (Daysh et al 2021) and direct use report (Climo et al 2021).

| Electricity | | Direct Use | |
|---|---|---|---|
| Total Installed Capacity* ($MW_e$) | 1039 | Total Installed Capacity ($MW_{th}$) | 500 ** |
| New Installed Capacity (MWe) | 0 | New Installed Capacity (MWth) | 0 |
| Total Net Running Capacity (MWe) | 1039 | Total Heat Used (PJ/yr) | 7.3 |
| Contribution to National Capacity (%) | 11% | Total Installed Capacity Heat Pumps (MWth) | ~20 |
| Total Generation (GWh) | 7820 | Total Net Heat Pump Use [PJ/yr] | 0.4 |
| Contribution to National Generation (%) | 18.1% | Target 2017 – 2030 (PJ/yr Primary Energy) | +7.5 |

| | | | |
|---|---|---|---|
| Target (% national generation) | 20-25% | Estimated Country Potential (MWth or PJ/yr or GWh/yr) | N/A |
| Estimated Country Potential (MWe) | 4000 | reduced direct use July (Kawerau) | -2.4 |

(N/A = data not available), (*Here instralled capacity excludes decommissioned turbines), (** indicates estimated values)

In 2021, the weighted average $CO_2$ (equiv.) emissions factor from New Zealand Geothermal power stations was approximately 64 g/KWh (lower than 2020, NZGA 2022, Figure 15.1). The emission factors in New Zealand are declining because of degassing of the reservoirs (typically by 50% per decade) and the selective utilization of wells with lower gas contents. The weighted average emissions factor is also affected by changes in fluid production from reservoirs with higher gas content (such as a reduction at Ohaaki and an increase at Ngawha).

## 15.2 Changes to Policy Supporting Geothermal Development

The New Zealand Climate Change Commission (CCC) issued its report in January 2021, which recommended accelerated conversion of transport from fossil fuels to electricity, supporting demand for renewable electricity generation growth (including geothermal).

Although there are no government subsidies for renewable energy to reduce greenhouse gas emissions in New Zealand, a strategic (albeit challenging) target of 100% renewable electricity generation by 2035, in a normal hydro-generation year, has been announced. This is in addition to the previous target of 90% renewable by 2025.

The New Zealand government is also exploring the establishment of targets for renewable heat and electrified transport in addition to its targets for renewable electricity. The Energy Efficiency and Conservation Authority in conjunction with MBIE continues to develop a strategy on Process Heat in New Zealand. The Energy Efficiency and Conservation Authority has called for projects to be funded through the Government Investment in Decarbonising Industry (GIDI) initiative and concluded two award rounds in 2021 (April and September).

The New Zealand Geothermal Association (NZGA, 2022) prepared geothermal submissions for Government policy documents during 2021 on the following topics: Climate Change Commission Advice, Transpower's Transmission Grid Plans, Planned Resource Management Act (RMA) replacement with Natural & Built Environments Act, MfE Emissions reduction plan, and Electricity Authority consultation on security and resilience.

The Geoheat Action Group prepared and released their third action plan (https://www.nzgeothermal.org.nz/news--events/), focusing on promoting tangible, industrial-scale, projects in developed fields. This consortium of service providers, economic development agencies, Iwi (Maori trusts), and research organisations collaboratively execute the activities that are the focus of the plan for 2022 and 2023 (NZGA, 2022).

## 15.3 Geothermal Project Development

### 15.3.1 Projects Commissioned (and other changes)

There were no new geothermal electricity projects commissioned in 2021.

Halcyon Power (Tuaropaki Trust & Obayashi Corp JV) completed a geothermal powered, green hydrogen project at Mokai on the 9th of December 2021. This consists of a pilot plant with a design capacity of 250 $Nm^3$ per hour. It uses up to 1.25 MW of power from the Mokai power station and is expected to produce 180 tonnes of $H_2$ per year for the New Zealand market (mostly for transport). The plant will optimize its operation during periods of low electricity demand and low wholesale power prices.

Mercury Energy incrementally increased its operating capacity at Rotokawa by about 5 MWe through an optimisation project that reconfigured the steam-field to better balance the enthalpy and pressure requirements of the existing Rotokawa binary plant and the Nga Awa Purua triple flash steam turbine.

Eastland Energy purchased the TOPP1 binary power plant (Kawerau) from NTGA for NZ$83M (about NZ$4M per MW) and Contact Energy acquired Western Energy Services.

### 15.3.2 Projects Operational (at the end of the reporting year)

During 2021, normal operation of the existing geothermal power plants continued at near maximum generation capacity, specifically at Wairakei-Tauhara, Mokai, Rotokawa, Ngatamariki, Kawerau and Ngawha. Ohaaki operates at reduced capacity owing to constraints on fluid supply, as described in previous reports. New Zealand geothermal power-plant availability factors are typically 85-99%. These vary depending on individual turbine performance (including refurbishments that facilitate operation at greater than nameplate capacity), seasonal atmospheric conditions (e.g. air-cooling efficiency), and reservoir performance (especially changes in fluid enthalpy and operating pressure).

$CO_2$ emissions from geothermal power plants continue to be monitored; a carbon emissions cost is effectively applied to all large industrial emitters through the Government's Emissions Trading Scheme (NZETS). The New Zealand spot carbon price has risen significantly from about NZ$25/tonne $CO_2$e during 2019 to NZ$70/tonne in December 2021. This has provided geothermal power plant operators with an added incentive to further reduce gas emissions through selective well operation strategies or trial NCG reinjection schemes. Figure 15.1 illustrates the trends over time for the $CO_2$ total emissions and emissions factor (weighted average of kg $CO_2$e/MWh) compared to geothermal generation in GW per quarter (3 months). The figure illustrates the downwards trend (currently about -6% per annum) in emissions factor as developed geothermal reservoirs deplete in gas content (McLean and Richardson 2021, NZGA 2022). By comparison, the emissions factor for industrial direct use of geothermal heat varies between about 7 kg- $CO_2$/GJ at Kawerau for paper processing and about 3.5 kg-$CO_2$/GJ at Tauhara for timber drying.

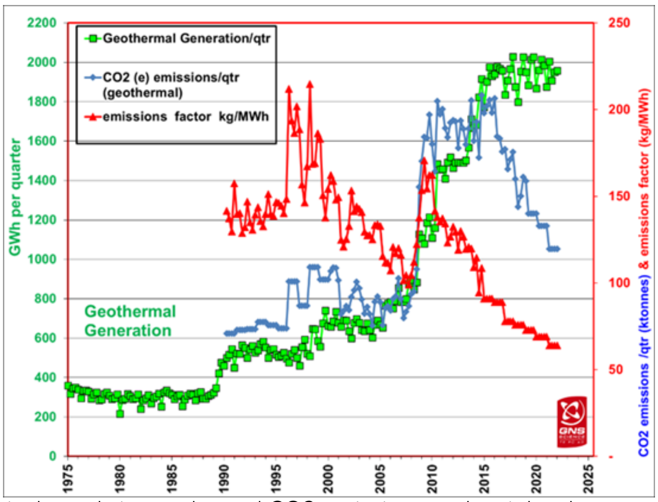


Figure 15.1 Historical trends in geothermal CO2 emissions and weighted average emissions factor (kg CO2e/MWh) compared with New Zealand geothermal generation. Data from MBIE (2022), McLean et al (2021), NZGA (2022).

Simulation modelling of Ohaaki $CO_2$ gas emissions (combined natural and power station venting) by O'Sullivan et al (2021) has demonstrated that production-induced depletion of reservoir gases that occurs during a typical production cycle (~100 years), when following by a period of natural recovery (~200 years), results in a net zero emission effect from the power project when considered over the long term (~300 years). That is, the increased anthropogenic power station emissions are offset by reduced natural emissions. Despite this, the short-term anthropogenic increase remains important with regards to emission reduction targets.

The Geo40 project (https://geo40.com/), a collaborative development at Ohaaki, involving Contact Energy, and Ngati Tahu Trust, has seen commissioning and operation of a commercial silica removal plant producing colloidal silica 'sol' for the international market. The plant (The Northern Plant) processes 6700 tonnes/day of separated geothermal water, prior to reinjection, and recovers 5000 tonnes/year of colloidal silica. Geo40 has now developed a small-scale process to extract lithium from the silica depleted fluid. At laboratory scale, samples of geothermal brine types from across Europe, the Americas and New Zealand have been successfully processed. A pilot plant for lithium extraction is scheduled for 2022.

The newly completed 31.5 MWe expansion (OEC4) of the Ngawha project is operational.

Taheke drilling and well testing commenced for a planned 25 MWe development. Eastland Generation (85%) and local iwi partners (Taheke 8C, 15%) received a NZ$11.9 M New Zealand Government funding contribution for the 1st stage.

Large industrial direct use applications (paper manufacture, timber drying, space heating, aquaculture, milk processing and horticulture) at Kawerau, Tauhara, Ohaaki, Wairakei and Mokai, has continued. Industrial direct heat uses in Kawerau include CHH wood products, Essity (Asaleo Care) (tissue paper), Oji Fibre Solutions (pulp and paper), Sequal Lumber (timber drying) and the Waiū milk drying factory (about 20 MWth). Tissue maker Essity announced final investment approval for its Kawerau geothermal steam-drying project. ECCA contributed a $1.65 million GIDI fund grant to this NZ $16 million investment that will reduce carbon emissions by 136,610 tonnes over the project life. After 66 years of operation, the Norske Skog Tasman mill closed down in June 2021, but the demand for renewable geothermal energy to process pulp for toilet and tissue paper has expanded. Smaller-scale geothermal direct-use applications for bathing, building heat, tourist facilities, etc, also continued at a similar level to previous years.

## 15.4 Research Highlights

Geothermal the Next Generation (GNG) has been funded from 2019 to 2024 at about NZ$2M/yr by the New Zealand Government (MBIE) to investigate the future development potential of New Zealand's supercritical geothermal resources, mostly located within the deep roots of conventional systems. This research involves laboratory geochemical experiments, geophysical surveys, simulation modelling and community engagement. The research will also investigate technologies to capture and reinject gas emissions and includes international collaboration and advisors from IEA-Geothermal member countries (Switzerland, Iceland and USA).

Core geothermal research, funded by the government at about NZ$2.5M / yr continued at GNS Science under the title "New Zealand's Geothermal Future". Topics are:

- Shallow resources and direct use,
- TVZ - Structure and Dynamics;
- TVZ – Source models; and
- Reservoir Chemistry.

The "Endeavour Fund" has supported research into "Empowering Geothermal Energy; Increased Utilisation of Geothermal Energy Through New Integrated Geoscience Methods". This project addresses the geoscientific uncertainties of accessing underground resources. The project is funded at NZ$1.3M / yr until 2022.

A "Marsden" research project (2019-2021) addressing the topic of improved understanding of natural $CO_2$ flux passing through Taupō Volcanic Zone geothermal systems concluded in 2021.

Industry-funded research activities include applied research projects through collaboration between government-funded, company-funded and university graduate research programs. These projects focus on opportunities and practical problem-solving tasks associated with diverse topics such as: scaling, tracer performance, mineral extraction, subsidence, reservoir simulation and injection technology.

MB Century and Western Energy Services continue to improve and develop practical technology for servicing the geothermal industry, both locally and internationally.

Waikato and Bay-of-Plenty Regional Council science staff continue to investigate methods and commission research to improve environmental monitoring of surface geothermal features (ranking for significance, drone infrared surveys, ecological change assessments and heat-loss monitoring).

The potential for utilisation of deep hot brines in abandoned oil wells within the Taranaki province (west coast North Island) remains under investigation.

Capture and reinjection of $CO_2$ gas emissions and modelling long-term net emissions was initiated in several projects by Mercury Energy, Contact Energy and Ngawha Generation. Operators and researchers at GNS Science and Universities are collaborating on this topic. While details are not yet available, trials will continue in 2022 with preliminary results appearing encouraging.

## 15.5 Other National Activities

### 15.5.1 Geothermal Education

The University of Auckland PGCert geothermal diploma course had just 6 students enrolled in 2021 because of COVID19 travel restrictions for overseas students. In normal years government-sponsored scholarships (up to 25 students) target the training needs of countries such as Indonesia, Philippines, Mexico, Kenya and the Caribbean. The Geothermal Institute also supervises research, involving Masters or PhD students, on a variety of topics including reservoir modelling, subsidence, induced seismicity, 2-phase flow, etc.

The University of Canterbury continues to run a geothermal graduate program (Geothermal Energy Systems Engineering Group within Department of Mechanical Engineering, and Geothermal Resource Research Group within Department of Geological Sciences).

Geoscience and engineering professional training courses normally run by GNS Science and universities in several geothermal nations were also suspended in 2021 due to COVID19.

Using largely online services through 2021, the NZ Ministry of Foreign Affairs and Trade (MFAT) working with NZTE (Trade and Enterprise) funded contributions and specialist advice to off-shore geothermal projects in Africa (NZAfrica Geothermal Facility, Djibouti, Ethiopia, and Tanzania), Indonesia (geothermal training and technical assistance), and Caribbean (advice for Grenada, St Lucia, and Dominica).

### 15.5.2 Conferences

The 43rd New Zealand Geothermal Workshop was organised by the Geothermal Institute for November 2021 but was postponed due to Covid and was then held virtually on the 2nd and 3rd February 2022 https://www.geothermalworkshop.co.nz/2021-workshop/ . Papers can be accessed through the IGA website.

A one-day seminar was organised by the New Zealand Geothermal Association (NZGA website) in Taupō on the 29th July, 2021 [150 participants]. It was themed "Geothermal in a low carbon future". Topics addressed were: green-house gases, climate change policies, finance, supercritical research, and wood processing. It formed part of Taupō's "Geothermal Week" involving the wider community with field trips and public presentations.

NZ authors contributed a substantial volume of material to the proceedings of the World Geothermal Congress published in 2021. Presentations were made as part of the virtual events (March to July) and New Zealand had a booth at the congress on site event in Reykjavik, Iceland in October 2021.

## 15.6 Publications

Publications documenting recent geothermal research and operational history from New Zealand can be found in the following conference proceedings and journals for 2021: World Geothermal Congress (2020+1), 43rd NZ Geothermal Workshop, 46th Stanford Geothermal Workshop, Geothermal Rising 2021 annual meeting, and Geothermics journal.

## 15.7 Useful Websites

Contact Energy: https://contact.co.nz/aboutus/our-story/our-projects/tauhara

Geoheat: http://www.nzgeoheat.nz

Geothermal Institute: http://www.geothermal.auckland.ac.nz/

Geo40 Limited: http://geo40.com/about

GNS: http://data.gns.cri.nz/geothermal

GNS: https://www.geothermalnextgeneration.com/knowledge/geothermal-co2-reinjection/

IPGT: https://ipgtgeothermal.org/about-us/

MBIE: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/new-zealand-energy-quarterly/

NZGA: https://nzgeothermal.org.nz/

## 15.8 Future Activity

Figure 15.2 shows an updated historical (to year-end 2021) and projected growth (initially predicted from 2015 out to 2025) in geothermal electricity generation for New Zealand, relative to other generation options. Combined renewable power generation increased in 2021 from 80.8% to 82% due to normal hydrological conditions being experienced through the year increasing hydro generation relative to 2020. The forward projection assumes a demand growth rate of 0.5% per year. Although recent demand growth has been relatively static, electric vehicle uptake is expected to contribute to renewable electricity demand growth, (NZGA, 2022), perhaps by up to 1% per year over the next 10 years (assuming 50% of the vehicle fleet replaced is electric). Solar power is expected to gradually grow above 0.5% of total generation, and bio-gas/wood waste generation should grow to about 1.5 %. If new or expanded geothermal (rising to about 24%) and wind projects (rising to 8%) eventuate, as predicted, then coal-fired generation is expected to reduce to near zero, and gas-fired generation to about 9%, resulting in more than 90% renewable electricity generation (in a normal hydrological year) which is a key 2025 (year-end) strategy target set by the government. This assumes the NZ Aluminium Smelter at Bluff (consuming ~12% of total generation) continues to operate beyond its scheduled closing in 2024. Official government predictions (MBIE, 2022) are similar, but with coal-fired generation tapering off and ceasing in 2024. Uncertainty in long term gas supply, and commitment to turbine maintenance, affects uncertainties in these predictions.

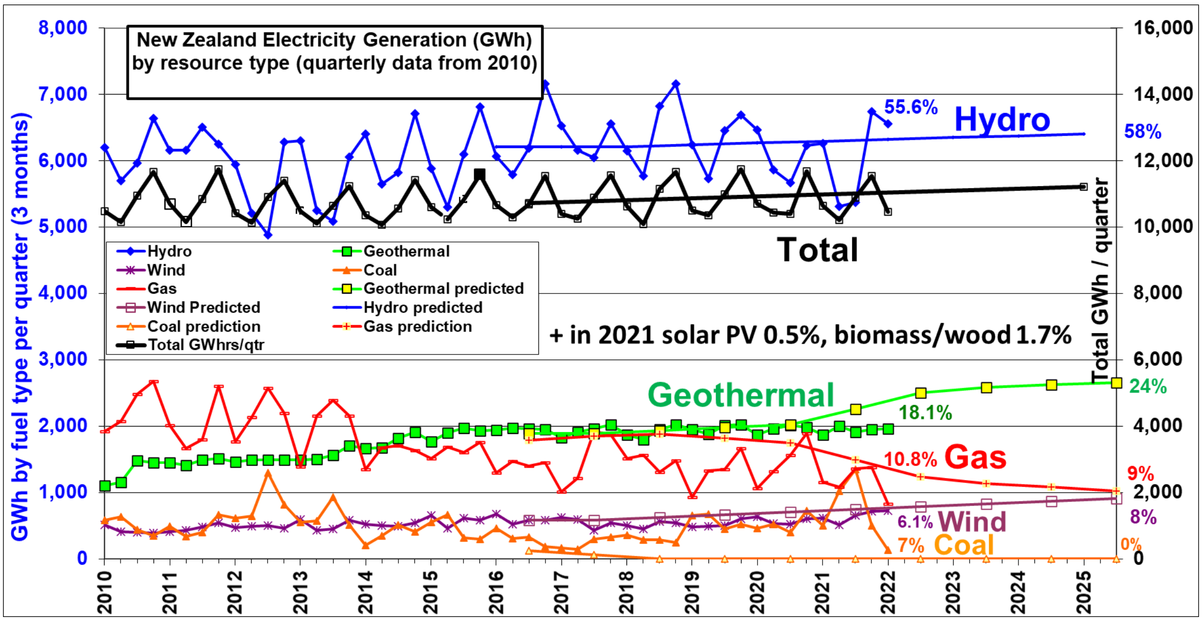


Figure 15.2 Updated plot of actual (>2010) and projected growth (to 2025, since 2015) in generation fuel-types in New Zealand. The geothermal share of 18.1% in 2021 is projected to grow to as much as 24% by 2025, if investment conditions remain favourable. Historical data source: MBIE (2022).

Kawerau: NTGA (Kawerau) has consents in place for an expansion of fluid take and reinjection (45 kt/day) for industrial direct heat and power. Current demand for steam from NTGA includes the Waiū facility for milk drying, Sequal Lumber timber drying kilns, and Oji-fibre clean steam plant to process some of their pulp production.

Ngawha: Following commissioning of the 31.5 MWe power plant in 2020, a proposed 2nd-stage expansion is being considered. This could ultimately mean the Northland Region will become self-sufficient in electricity.

Ngatamariki: Station operators (RJV and Mercury Energy) have commenced planning for an additional (5$^{th}$) ORC unit of ~25 MWe capacity, with a consent application to allow for increased fluid take and reinjection planned to be lodged in 2022.

Taheke: Plans to develop a 25 MWe power plant at Taheke are progressing and await testing of a well drilled in 2021.

Tauhara: As noted above, the Tauhara II 250 MW project has commenced through incremental stages of expansion. Well testing and drilling (production and reinjection wells), and most of the civil works for the first 168 MWe stage were completed in 2021 and commissioning of the triple flash turbine is anticipated in late 2023. Proposed additional stages of this project are anticipated to add another ~80 MWe between 2025 and 2035.

Wairakei: Wairakei operational consents expire in 2026, and preparations continue for consent renewal application. A submission to the Waikato Regional Council and application hearing is planned for 2022. This involves the planned shutdown of the original Wairakei power stations (A and B) and expansion of the Te Mihi power station by 82 MWe to utilize a total of 250 kTonnes/day of geothermal fluid.

Ohaaki: During 2021 the 'Rohe Hot-house' scheme was granted resource consents for an 18 Ha glass-house adjacent to the Ohaaki power station. This greenhouse is expected to use $CO_2$ from the Ohaaki Power Plant to promote plant growth.

Deep drilling of 7 geothermal wells in 2021 included 3 production and 3 reinjection wells at Tauhara for the Tauhara II expansion.  The MB Century Rig 32 was used for these wells. One deep well was also drilled at Taheke (north of Lake Rotoiti) by Tiger Drilling for Eastland Energy. Shallow drilling (<1 km deep) of 10 production wells and 1 reinjection well for direct use purposes were completed in Rotorua, Tauranga and Kawerau.

Mercury Energy, Contact Energy, and Ngawha have all initiated pilot schemes to examine the feasibility of injecting non-condensing gasses (NCG), that is, $CO_2$, $CH_4$ and $H_2S$, from binary plants. These experiments are expected to continue into 2022.

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# 16. Norway

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## 16.1 Introduction

Geothermal energy use in Norway is dominated by the relatively widespread deployment of geothermal heat pumps. There is no electricity production from geothermal resources, and there are no deep geothermal energy installations in operation. As the third-largest exporter of energy in the world and with an electricity supply almost totally dominated by hydropower, Norway has a large share of renewable energy in both its total primary energy supply and in its electricity supply. Although energy use per capita is close to the average for European countries, the electricity consumption ratio is very high (23 MWh per capita), second only to Iceland.

There is a strong lobby from academic institutions (universities / research institutes) and industry to promote geothermal energy (including deep geothermal) to politicians and the public. The umbrella organisation is the "Norwegian Centre for Geothermal Energy Research" (CGER) established in 2009. Membership of CGER has been steady since 2016. There are currently the following partner organisations:

- NORCE Norwegian Research Centre AS (host institution, https://www.norceresearch.no/)
- GCE NODE (http://gcenode.no/)
- GTML (http:/www.gtml.energy/)
- GREENSTAT (http://greenstat.no/)
- Huisman (https://www.huismanequipment.com/en/about_huisman/locations/norway)
- Innovative Solutions
- Institute for Energy Technology (IFE, http://www.ife.no/)
- NORSAR
- NTNU (http://www.ntnu.no/)
- SINTEF (https://www.sintef.no/en/)
- EQUINOR (https://www.equinor.com/)
- University of Bergen (http://www.uib.no/)
- University of Stavanger (http://www.uis.no/?lang=en_GB)
- WELL ID AS (http://wellid.no/)

Increasing the use of geothermal energy in Norway is aligned with the country´s energy policy of increasing the use of renewable energy resources. Additionally, the Norwegian industrial and academic expertise in offshore technologies should be readily utilised in an emerging geothermal industry with emphasis on deep drilling, well technology, reservoir management, corrosion and scaling mitigation, and tracer technology.

To date all geothermal installations in Norway are geothermal heat pumps (GHP). Statistics from the Norwegian Heat Pump Association (NOVAP) identifies a peak of 3979 GHP installations in 2018 (Figure 16.1). The high sales figures in 2018 and 2019 are due to a ban on fossil oil for heating in buildings from 2020.

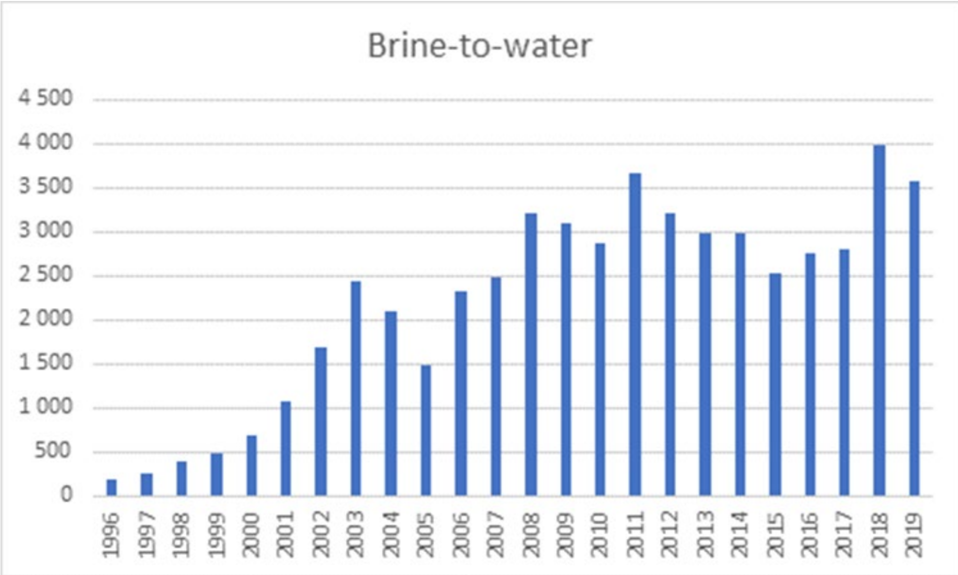


Figure 16.1 Geothermal Heat pump sales statistics for Norway from 1996 to 2019. Source: Norwegian Heat Pump Association (NOVAP)

NOVAPs statistics cover approximately 90% of the Norwegian heat pump market. NOVAP has estimated that there are about 53,336 brine-to-water units sold in Norway in the period 1996-2019.

The majority of the GHP systems in Norway are vertical closed loop systems extracting heat and/or cold from crystalline rocks through borehole heat exchangers (BHE).

A typical Norwegian GHP is based on one or more boreholes drilled to between 50 and 300 meters. A trend towards deeper boreholes has been observed, partly due to reduced drilling costs for deeper boreholes. A representative Norwegian GHP system uses a 115 mm diameter borehole with a single 40 mm U tube installed. Some BHEs use alternative collectors, such as coaxial arrangements or collectors with a rougher surface which produce turbulent flow at lower flow rates. The Norwegian drilling industry has historically been dominated by Norwegian companies, but in the last few years some companies from Finland and Sweden have started servicing the market.

NOVAP collects statistics on heat pump systems in Norway from the leading suppliers in the 0-20kW range. In the over 20kW size, there are a few suppliers that do not provide sales data. NOVAP is seeking to collect this data and will include it in future reports when available. The data from NOVAP is for all types of liquid-to-water heat pumps including systems that source energy from rock, the sea, ground (subsoil) water etc. However, by far the dominant source is heat from rocks. Summary data from NOVAP on liquid-to-water systems is displayed in Table 1.1.

Table 16.1 summarises the status of geothermal energy use in Norway in 2017.

| Electricity | | Direct Use | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | 0 | Total Installed Direct Use (MWth) | na |
| Contribution to National Capacity (%) | 0 | Total Heat Used TJ/yr<br>Total Heat Used TWh/yr | 5746<br>1,6 |
| Total Generation (GWh) | 0 | Total Installed Capacity for Heat Pumps (MWth) | 904 |

Table 16.1 Geothermal energy use in Norway 2017.

(The data is based on NOVAP statistics. na=data not available )

It should be emphasized that data in Table Table 16.1 includes only liquid-to-water heat pump systems which are considered truly geothermal. However, Norwegian buildings are primarily heated by less efficient (but cheaper) air-to-air systems and by air-to-water systems. NOVAP also collects statistics for these systems. In the period 1996-2017, 40,175 air-to-water systems and 967,158 air-to-air systems have been sold, with corresponding heat production in 2017 of 0.6 TWh/yr and 6TWh/yr, and installed capacities of 541 MWth and 5,091 MWth. NOVAP identifies the SPF for both of these systems to be 2,5, while the SPF is 3.5 for liquid-to-water systems.

## 16.2 Changes to Policy Supporting Geothermal Development

The Research Council of Norway (RCN) is supporting geothermal research projects through its programme "ENERGIX" with IPN and KPN projects (see Section 3). Funding from national agencies "Enova" and "Innovation Norway" is also possible for larger industrial projects such as deep well drilling. Norway is contributing to the EU funded Horizon 2020 programme, and some Norwegian organisations have been involved in these geothermal projects.

## 16.3 Research Highlights

The following section describes the research highlights of some organisations involved in geothermal energy in Norway.

### 16.3.1 CGER - Norwegian Center for Geothermal Energy Research

Based on a steering group decision, CGER has recently applied to become an affiliated member of the International Geothermal Association

As a result of the covid-19 situation all CGER meeting activities have been moved to online.

CGER has held two meetings. On June 25th CGER held an extended online partner meeting with presentations on ongoing and completed projects. Presentations covered deep geothermal, drilling fluids, casing, scale handling, $CO_2$ enhanced geothermal systems and modelling of supercritical systems. On September 28$^{th}$, a webinar was held in collaboration with GCE NODE, with contributions from ISOR on casing solutions for high temperature systems, from EGEC on EU activities and plans, and from Qmatek on drilling solutions. Presentations from the webinar are available on the CGER website.

### 16.3.2 Current nationally led research projects

| Project | Project lead | Project type | Project period |
|---|---|---|---|
| Improving the energy efficiency of geothermal energy utilisation by adjusting the user characteristics | NORCE | EEA | 2020-2023 |
| Digitalization of multi-reservoir geothermal systems for optimal control of heat production, storage and peak-load management. | RUDEN AS | IPN | 2020-2023 |
| Simulation of governing processes in superheated and supercritical geothermal systems: mathematical models, numerical methods and field data | UiB | KPN | 2020-2024 |
| DeepScale - Deep geothermal flow assurance; cost-efficient scale handling and heat fluid robustness. | SINTEF (IFE) | KPN | 2019-2022 |
| Low cost drill bit body material for geothermal applications. | Lyng Drilling | IPN | 2018-2021 |
| Novel concept for energy efficient hard rock drilling towards cost-effective geothermal energy harvesting | SINTEF | | 2018-2021 |
| Modeling of high temperature, high pressure geothermal energy production system | NTNU | KPN | 2017-2021 |
| Cost-effective and Reliable Engineered Casing Systems for super-HT Geothermal Wells | Equinor | IPN | 2017-2021 |
| Thermo-mechanical subsurface energy storage (TheMSES) | UiB | | 2016-2021 |
| Technology platform for research-based innovations in deep geothermal drilling (INNO-Drill) | Sintef | KPN | 2016-2019 |

| | | | |
|---|---|---|---|
| Fellesløsning grunnvann til varme og kjøling i Melhus sentrum (ORMEL2) | Melhus kommune | | 2018-2021 |
| Enhancing geothermal reservoirs - hydraulic and thermal stimulation technology | UiB | KPN | 2017-2020 |
| Modeling of high temperature, high pressure geothermal energy production system | NTNU | KPN | 2017-2020 |
| Cost-effective and Reliable Engineered Casing Systems for super-HT Geothermal Wells | Statoil ASA | IPN | 2017-2020 |
| Integrerte varme- og kjølesystem for sykehusbygg med mål om minimal brutto energibruk | Norconsult | IPN | 2017-2020 |
| RockStore - develop, demonstrate and monitor the next generation BTES systems | NORCE | KPN | 2018-2021 |
| Cryogenic cooling canister for downhole tools | Norwegian Well | IPN | 2018-2020 |
| Deep geothermal flow assurance; cost-efficient scale handling and heat fluid robustness. | Sintef | KPN | 2019-2020 |

In addition, IFE is involved in two EU HORIZON 2020 geothermal projects related to deep geothermal energy (GECO and REFLECT).

## 16.4 Other National Activities

### 16.4.1 Geothermal Education

Please refer to previous Norway country reports.

### 16.4.2 Conferences

CGER is planning the international conference GeoEnergi in 2021 with participation from international scientific guests, politicians and media.

### 16.4.3 Useful Websites

www.rcn.no
www.cger.no
www.enova.no

http://www.energi21.no/
www.novap.no
www.innovasjonnorge.no
www.nve.no

## 16.5 Future Activity

The geothermal community in Norway continues expanding its activities. This involves more than academic institutes and universities. Small Norwegian enterprises which are spin-offs from a declining oil industry are motivated to penetrate emerging domestic and international geothermal markets. They are encouraged and co-financed by Norwegian government organizations (RCN, ENOVA, INNOVATION NORWAY) and the EU, which support development and deployment of renewable energies.

# 17. Republic of Korea

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## 17.1 Introduction

Geothermal utilization in Korea is primarily direct use from ground-source or geothermal heat pump (GHP) installations, because there are no high temperature resources associated with active volcanoes or tectonic activity. Installed GHP capacity has increased rapidly since the middle of the 2000's, with more than 100 $MW_{th}$ of new installation annually until 2018. Annual new capacity shows a decreasing trend since 2019, with ~74 $MW_{th}$ estimated installed in 2021. The total installed capacity is estimated to be ~1.6 $GW_{th}$ as at the end of 2021 (See Table 1 below).

All activities associated with deep geothermal development or exploration were stopped after the 15th November 2017 Mw 5.4 earthquake which occurred in the vicinity of the Pohang EGS pilot plant site. R&D funding to other geothermal use such as topics related to geothermal heat pumps was also reduced partly because of the negative perception regarding geothermal.

**Table 1.** Geothermal utilization in Korea as of December 31, 2021.

| Electricity | | Direct Use | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | - | Total Installed Capacity ($MW_{th}$) | 43.6 |
| New Installed Capacity ($MW_e$) | - | New Installed Capacity ($MW_{th}$) | 0 |
| Total Running Capacity ($MW_e$) | - | Total Heat Used (PJ/yr) [GWh/yr] | 0.594 [164.9] |
| Contribution to National Capacity (%) | - | Total Installed Capacity Heat Pumps ($MW_{th}$) | 1,579.0* |
| Total Generation (GWh) | - | Total Net Heat Pump Use [GWh/yr] | 893.5* |
| Contribution to National Generation (%) | - | Target (PJ/yr) | N/A |
| Target ($MW_e$ or % national generation) | - | Estimated Country Potential ($MW_{th}$ or PJ/yr or GWh/yr) | N/A |
| Estimated Country Potential ($MW_e$ or GWh) | 19,600 MWe | | |

(N/A = data not available)

(* indicates estimated values)

## 17.2 Changes to Policy Supporting Geothermal Development

Renewable energy is becoming a more important element in the national energy policy, but as yet geothermal is not separately specified in the policy. The Korean Government Third National Energy Master Plan finalised and declared in June 2019 has a vision of "Sustainable growth and improving the quality of people's life through energy transition".

It specifies five major tasks:

1) Converting energy policy paradigm to focusing on consumer innovation,
2) Switching to a clean and safe energy mix,
3) Enlarging distributed and participatory energy systems,
4) Strengthening global competitiveness of energy industry, and
5) Expansion of foundation for energy transition.

For Task 2, renewable power generation is targeted at 30-35% by 2040. There are ongoing subsidy programs and a mandatory act supporting renewable energy deployment which includes geothermal heat pump installation.

In addition, in December 2020 the government declared 'Carbon neutrality' or 'Net zero' by 2050 with a 'Green New Deal' policy. The Fifth New and Renewable Energy Basic Plan which was declared at the end of 2020 states that the target of renewable electricity's share is 22.2% (installed capacity of 80.8 GW) by 2034, while final consumption of renewable energy is targeted at 12.4% (23.5 TOE) by 2034.

Renewable power generation, especially solar PV and wind, is expected to increase rapidly under the policy, but investment in geothermal power is not active due to growing concern on possible links with damaging earthquakes. There has been a notable decrease in government geothermal R&D funding since 2019 which means that R&D investments not only for deep geothermal but also for GHP have significantly declined.

## 17.3 Geothermal Project Development

### 17.3.1 Projects Commissioned in 2021

No new deep geothermal projects were commissioned in 2021, as was the case in 2019 and 2020. Planning for a project initiating geothermal power generation at a remote Ulleung island in the East Sea (see 2016 Country Report) was stopped after the release of the official report on the relationship between the Pohang earthquake and the nearby EGS project, the project development was stopped.

### 17.3.2 Projects Operational at the end of 2021

The Pohang EGS pilot project, which was the only active development in Korea, was terminated due to the earthquake, and thus there are currently no operational projects.

## 17.4 Research Highlights

There were no notable results or publications on EGS or deep geothermal in 2021.

As part of Working Group 8 activities of IEA Geothermal, we developed a new data collection spreadsheet for GHP statistics. Data for the new statistical scheme is collected through an Excel spreadsheet with input options for installations including individual residential houses, commercial/institutional/multi-family buildings, and others such as greenhouses separately. By adopting a concept of gross and net energy production with input of equivalent full load hours and seasonal performance factors, which are different not only for each installation type but also depending on heating or cooling, annual thermal energy use and renewable energy production are automatically calculated for heating and cooling applications separately. The information sources and the accuracy of the information can also be included, allowing the reliability of the statistics to be evaluated. Additionally, the new statistical questionnaire of IEA Geothermal includes a separated sheet for 'free cooling', if data is available. This questionnaire comes with a user guide to better understand the underlying principle. All the technical details were presented at the World Geothermal Congress 2020+1 (Song et al., 2021).

## 17.5 Other National or Academic Activities

No national or academic activities regarding deep geothermal development are available since 2020. GHP installations continue to increase but at a lower rate of annual increase over the last few years.  The blue columns in Figure 17.1 shows the trend in GHP installations since 2006.

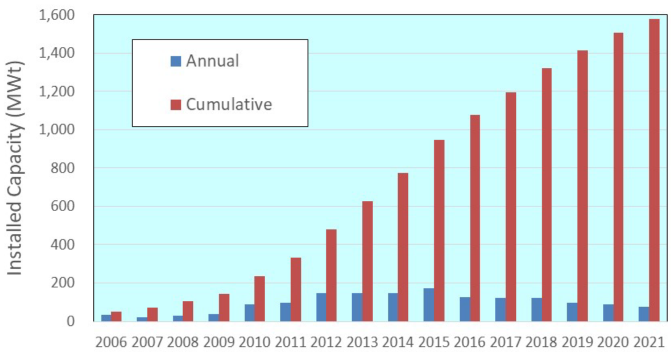


Figure 17.1 Increasing trend of GHP installation since 2006.

## 17.6 Future Activity

Geothermal utilization in terms of GHP installation will continue to steadily increase but at a lower rate: less than 100 $MW_{th}$ expected annually. The rapid increase was due to the active subsidy programs and the special 'Mandatory Act'. However, the installation plan of GHP according to the 'Mandatory Act' shows a decreasing trend since 2017, while the total subsidy stayed more or less at the same level, between 20 and 30 million USD annually.

Geothermal utilization statistics are an on-going issue. In Korea, official geothermal energy statistics deal only with GHP and thus other direct uses including space heating, spas, and greenhouse heating are not included in the national statistics. Korea has been reporting other direct use statistics to IEA Geothermal with the help of hot spring survey data. For GHP statistics, there is no official distinction between heating and cooling, but just a lump sum of all energy production throughout a year, which does not consider the 'pure geothermal contribution' as yet. Effort is needed to establish a revised method of collecting official statistics on geothermal uses that is compatible with international standards such as the IEA statistics. Since 2018, IEA Geothermal has collected GHP statistics with the new scheme proposed as a result of IEA Geothermal Working Group 8 activities (see Chapter 4) and this scheme could guide the updating of Korean GHP statistics once it is accepted by the international community.

The outlook for geothermal power generation in Korea is not positive due to concerns of possibly damaging earthquakes. After the Mw 5.4 earthquake occurred close to the Pohang EGS site, all deep geothermal exploration activity was stopped and all projects are currently in hiatus. The government is very keen to foster renewable energy deployment to substitute for nuclear power, but even so the outlook for geothermal investment is not promising at least for the time being.

## 17.7 References

Song, Y., Link, K., Yasukawa, K., and Weber, J., 2021, Proposal of new data collecting spreadsheet for geothermal heat pump statistics - An outcome of IEA Geothermal Working Group activities, Proceedings World Geothermal Congress 2020+1, Reykjavik, Iceland, October 24-27, 2021.

# 18. Spain

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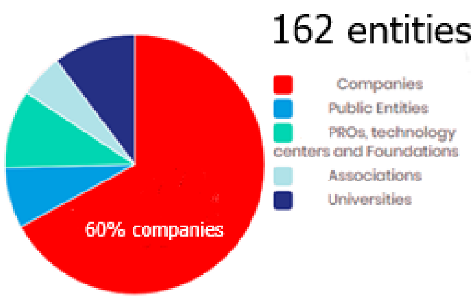
## 18.1 Introduction

The Spanish Geothermal Technology and Innovation Platform (GEOPLAT) is a sectorial coordination group led by industry, consisting of all relevant stakeholders involved in geothermal energy in Spain (Companies and SMEs, Technology Centres and Foundations, Associations and Cooperatives, Universities, Public Entities, Public Research Centres). It aims at identifying and developing sustainable strategies for the promotion and marketing of geothermal energy in Spain. It's constituted by 162 members, 26 of them are sponsors (refer below).




**GEOPLAT Sponsor Members**

GEOPLAT is a public-private entity promoted by the Spanish Ministry of Science and Innovation.

GEOPLAT focuses on geothermal energy as a renewable resource and associated technologies. It covers the identification and evaluation of geothermal resources, as well as sustainability and regulatory aspects.

GEOPLAT has a Steering Committee that coordinates the actions of the platform, to ensure the compliance of the objectives of each of the working groups and to encourage participation and connection between them.


GEOPLAT focuses on identifying and developing sustainable strategies for the promotion, implementation and dissemination of geothermal energy in Spain. It covers research, development and innovation activities in terms of identification and evaluation of resources, and the use of geothermal energy in all its forms and technologies. Sustainability, and policy and regulatory aspects are included in the activities of the Platform, as are the fostering of relationships and collaboration with similar platforms, both national and European.

<u>Specific objectives:</u>

- To provide a framework within which all agents work together in a coordinated manner to ensure the commercial viability and continuous growth of geothermal, in a competitive and sustainable form.

- To analyse the status of geothermal energy in Spain considering all stages of the value chain, from the different types of resources to its end use, considering all the technologies that allow its use.

- To identify R&D needs and to recommend funding for research in strategic areas.

- To coordinate different participants of the science-technology companies involved in the technological chain (at national and international level), and to encourage business participation in the development of action plans, R&D and marketing.

- To participate in international forums and other activities.

- To publicize the potential of geothermal energy as well as the results and recommendations of GEOPLAT in all related sectors.

- To promote training at all levels related to geothermal energy, to raise awareness and to mobilize society and governments at national, regional and local levels.

Main activities of GEOPLAT:

- Close collaboration with public bodies and institutions with competencies in the geothermal sector at a national level.

- Participation in European and international activities including European Technology Platforms (Deep Geothermal and Renewable Heating and Cooling; Deep Geothermal ETIP), and IEA Geothermal.

- Official training courses on geothermal energy. Establishment of the basis of an official professional qualification in geothermal.

- Communication and dissemination: Editing of official documents, reports and analysis from the geothermal sector. Organization of workshops and geothermal events.

## 18.2 Geothermal Highlights in 2021

In 2021, geothermal energy in Spain avoided the pandemic and began preparation for the geothermal decade.

Geothermal heating and cooling systems performed well guaranteeing the security of supply even in extreme weather events such as the Filomena event at the beginning of 2021.

Users with geothermal systems are able to reduce the economic impact of the electricity rate increases which came into force in Spain on 1st June 2021. The new electricity tariff has three time periods when electricity is either cheaper or more expensive (peak/off-peak), theoretically giving consumers a chance to save by concentrating their appliance use outside peak hours. The cheapest periods are midnight to 8 a.m. Monday through Friday, on weekends, and on national holidays (off-peak). The priciest tiers are 10 a.m. to 2 p.m. and 6 p.m. to 10 p.m. on weekdays (peak time). At other times the rate is an average price (medium rate). Users of geothermal heating and cooling systems can maximize savings by shifting the production of domestic hot water (DHW) to the off-peak period.

In March 2021, the Institute for the Diversification and Saving of Energy – IDAE, (a body assigned to the Ministry for the Ecological Transition through the Secretary of State for Energy) published, for the first time, the statistics of the heat pumps (aerothermal, geothermal and hydrothermal) in Spain. The official data is based on a census of installations collected between 2014 and 2019 which shows this technology is increasingly being implemented. The installed thermal power capacity in 2014 was 12,940,178 kW, while in 2019 it was 28,246,826 kW. These figures are below the actual capacity because the census doesn't record all of the installed GSHPs. However, it's a good starting point from which updating will enable the sector trends to be observed.

GEOPLAT continued with its activities at the beginning of the 'geothermal decade' as the backbone of the Spanish geothermal sector. GEOPLAT organized an online meeting on geothermal energy in Asturias together with the Government of the Principality of Asturias and Hunosa, where it became clear that geothermal energy will play a fundamental role in giving coal mines a second life and, at the same time, help achieve environmental objectives, decarbonisation and fair energy transition in Asturias.

GEOPLAT collaborated with the Government of the Canary Islands and the ITC to implement geothermal energy in the islands. In 2021, the Government of the Canary Islands worked on its Canary Islands Energy Transition Plan (PTECan). The preparation of PTECan was entrusted to the Canary Islands Technological Institute (ITC), to promote the development of a sustainable energy model based on energy efficiency and renewable energies, promoting geothermal energy in the Islands out to 2030. The publication of the Geothermal Energy Strategy and Roadmap is pending, the objective of which is to identify the necessary actions to increase the use of low enthalpy geothermal energy and to promote high enthalpy geothermal energy in the Archipelago.

Likewise, in February 2021, GEOPLAT encouraged geothermal sector participants to submit their expressions of interest on innovative initiatives to the Recovery, Transformation and Resilience Plan, the fundamental instrument for the development of European Next Generation recovery funds. Following the unprecedented crisis due to the pandemic, Spain's Recovery, Transformation and Resilience Plan aims to respond to the urgent need of fostering a strong recovery and future-proofing Spain. The reforms and investments will help Spain become more sustainable, resilient, and prepared for the challenges and opportunities in the green and digital transitions. To this end, the plan outlines 112 investments and 102 reforms. They will be supported by €69.5 billion in grants. 40% of the plan will support the climate objectives and 28% of the plan will foster the digital transition. On 16 June 2021, the Commission approved the plan which was in turn adopted by the Council on 13 July opening the door to commence implementation and financing.

In July 2021, GEOPLAT celebrated its Annual Assembly which took place virtually. During this Assembly, GEOPLAT analyzed the role of geothermal energy in the Canary Islands, the rest of Spain and Europe.

Especially relevant to the geothermal sector was publication in June of 2021 of the first professional training qualifications on geothermal heating and cooling systems in the State Agency for the Official State Gazette (BOE).

## 18.3 Geothermal Activities in 2021

### 18.3.1 Projects Commissioned in 2021

#### Geothermal heating & cooling projects

In March 2021, the work on a geothermal district heating network from a geothermal well at Fondón, in the municipality of Langreo, in Asturias, a region in Northern Spain, was completed. It involved the construction of a heat network supplying the demand for heating and domestic hot water in buildings located in the nearby city of Langreo (public health center, a residential building, the Juan Carlos Beiro sports center, the Nuestra Señora del Fresno elderly residence, and the Langrehotel building) through the use of pumped mine water. The first of three phases sees geothermal generation plant with a heat output of 1.5 MW thermal operating. The DH Pozo Fondón has the support of the European Union and the Government of the Principality of Asturias financing part of the project through Feder funds.

The Pozo Fondón scheme is the second geothermal based mine water project promoted by Grupo Hunosa. In Mieres, the district heating network of Pozo Barredo provides geothermal heating and cooling to the Polytechnic School of Mieres (EPM), the secondary school Bernaldo de Quirós (IBQ) and a group of buildings located in the Vasco-Mayacina area. The project was awarded the Global District Energy Climate Award 2019 by the International Energy Agency (IEA), under the "emerging markets" category.

#### Geothermal projects

In 2021, a deep geothermal direct use project in Almeria, in Southeast Spain, was initiated using geothermal energy beneath the Níjar region to heat greenhouses with grant funding under the Spanish Ministry for the Ecological Transition and the Demographic Challenge.

The project, headed by Cardial Recursos Alternativos, contemplates reaching depths of more than two thousand meters to heat greenhouses. The first well was completed in Tristanes, in Campo de Níjar at

2,000 meters reaching a temperature in its lower zone of 105 ºC.  This well provides evidence of the enormous geothermal potential underground in Almeria. The drilling process allowed valuable experience and knowledge to be acquired that will assist in the drilling of the next wells, which are expected to reach a depth of 2,500 meters. The development of a borehole network will allow Cardial to supply thermal energy to as many greenhouses as possible. This initial activity is a decisive step in the implementation of deep geothermal energy in Spain.

### 18.3.2 Participation of GEOPLAT in geothermal European R&D&I projects

GEOPLAT works to achieve the commercial implementation of geothermal in Spain and its continuous growth competitively and sustainably. Among its activities, GEOPLAT is participating in several European projects aimed at the development of geothermal energy, which address aspects such as geothermal resource exploration, increasing the competitiveness of European SMEs, development of alternative financing schemes and public acceptance models for geothermal energy.

**GEO-URBAN. Identification and Assessment of Deep Geothermal Heat Resources in Challenging Urban Environments**

The GEO-URBAN project aims to explore the potential of deep geothermal resources in low-enthalpy regions and to evaluate this energy source as a heating supply for urban areas. The ability to use geothermal resources to generate heat in urban areas, where demand is highest, has the potential to significantly reduce dependence on fossil fuels and support sustainable national and European Union energy policies.  The project focuses on two areas - Dublin, Ireland, and Vallès, Catalonia, Spain - and will provide a feasibility analysis for the commercial exploitation of geothermal resources in these regions with different types of geology.

The financing of this project is part of the "GEOTHERMICA Cofund" call, which is part of the European Union's ERA-NET plan.  The consortium is formed by a total of 10 members from 3 participating countries of the European Union: Ireland (Dublin City Council, DIAS, GDG, GIA, ICRAG), Denmark (GEOOP) and Spain (BSC, ICGC, UB, GEOPLAT).

GEO-URBAN and PIXIL projects organized a Workshop entitled "Exploring the subsoil in search of geothermal energy. A local and global perspective" in January 2021. The workshop was co-organized by Barcelona Supercomputing Center (BSC), GEOPLAT and POLE AVENIA. The workshop was relvant for the geothermal sector as issues such as the state of this renewable energy in the European Union and large-scale geothermal  projects were discussed, as well as many important geothermal projects on a local scale and success case studies.

The GEO-URBAN project finished in May 2021.

**GEO-ENERGY EUROPE. Geo-Energy for the XXIst Century (Phase 2)**

GEO-ENERGY EUROPE was established to create a transnational cluster dedicated to improving the development and competitiveness of European small and medium geothermal enterprises working in the geothermal energy sector in the EU and in global markets. The GEO-ENERGY EUROPE meta cluster partners are Geoscience Ireland (Ireland), Pole Avenia (France), GeoDeep (France), Geo Energy Celle (Germany), the European Geothermal Energy Council (Belgium), Consorzio per lo Sviluppo delle Aree Geotermiche (Italy), Cluster of Applied Earth Sciences (Hungary), GEOPLAT (Spain), and Jeotermal Elektrik Santral Yatırımcıları Derneği (Turkey).

The second phase of the Geo Energy Europe project is bringing the skills and expertise of European small and medium sized companies to the target markets identified in the first phase of the project (Canada, Kenya, Chile, Costa Rica). In addition, the second phase is also establishing business links between European small and medium-sized enterprises and their counterparts in mature and emerging geothermal energy markets around the globe.

In May 2021, the partners of the GEO-ENERGY EUROPE meta cluster met with representatives of the Canadian geothermal sector to exchange ideas on future cooperation between European and Canadian companies with interest in involvement in international projects. Both regions are something of an outlier in the geothermal world market but are putting a stronger emphasis on the development of geothermal heating and cooling applications rather than on geothermal power generation.

In November 2021, the GEO-ENERGY EUROPE meta cluster partners met with Geothermal Development Company through a web workshop. This meeting came to consolidate the relationship between the GEOENERGY EUROPE partners and the Kenyan geothermal community, with the objective to facilitate the implementation of joint projects between European and Kenyan companies.

**CROWDTHERMAL. Community-based development schemes for geothermal energy**

The CROWDTHERMAL project aims to enable the European public to directly participate in the development of geothermal projects with the help of alternative financing systems, such as crowdfunding, and social commitment tools. The project has been funded within the framework of the European Union's research and innovation programme Horizon 2020. The consortium is led by the European Federation of Geologists (EFG) and consists of 10 partners from 7 countries, with extensive experience in the development of large-scale geothermal projects, alternative financing, social media engagement, innovation, education, and international geothermal energy networks (EFG, IZES, UoG, GeoT, LPRC, CrowdfundingHub, SZDH, GEORG, Eimur, and GEOPLAT).

Since the project started in September 2019, the project team has developed a set of reports, addressing social, environmental, financial and risk aspects of community-financed geothermal projects. To date, the CROWDTHERMAL team has addressed the following specific goals:

1. Understand the requirements for social licensing and develop a Social License to Operate (SLO) model for the different geothermal technologies and installations

2. Review successful case studies, as well as national or EU bottlenecks to alternative financing of geothermal energy

3. Formulate new financial models for crowdsourcing on a national and trans-national basis, covering individual member-states and Europe as a whole

4. Develop recommendations for a novel risk mitigation scheme that can complement the alternative financing solutions while also protecting private investors' interest

5. Develop guidelines for public engagement

6. Validate the findings of three case studies in Hungary, Iceland and Spain

In 2021, the project team worked on a core services looking at alternative financing of geothermal projects in close collaboration with existing structures and conventional players. These core services will assist the geothermal sector, contributing to accelerated market development in Europe, whilst fully addressing the needs for public engagement, transparency and trust concerning the management of environmental impacts.

Further insights into the project's findings and the future core services will be published as part of the European Deployment Campaign which commenced on 1 September 2021 under the hashtag #CROWDTHERMAL4ALL.

## 18.4 Other National Activities

### 18.4.1 Geothermal Education and Training

For five years now GEOPLAT has worked jointly with the National Institute of Qualifications of the Spanish Ministry of Education (INCUAL) to develop the material for the qualification of professionals in managing the installation and maintenance of geothermal heat exchange systems.

In June of 2021, the first professional training qualifications on geothermal heating and cooling systems were published in the State Agency for the Official State Gazette (BOE)[44]:

- 'Installations, commissioning and maintenance of closed-loop geothermal exchange facilities' (level 2)
- 'Organization and projects of closed-loop geothermal exchange facilities' (level 3)

This was a milestone being the first qualifications published both in Spain and in Europe on geothermal heating and cooling systems for buildings. Their publication will serve to create advanced vocational training courses, as well as vocational training courses for the unemployed. In addition, it will officially accredit experienced installers with the corresponding title.

A few months later, in September of 2021, ENAE06 'Installations, commissioning and maintenance of closed-loop geothermal exchange facilities' (level 2) was included in the Catalogue of Formative Specialities of the Spanish Public Service state employment (SEPE)[45]. This will allow any Spanish accredited training center to teach this program.

All this work will help to advance the professionalization of the sector, assisting to improve the quality of installations.

### 18.4.2 Conferences

- **PIXIL and GEO-URBAN workshop: Exploring the subsurface for geothermal energy. A local and global perspective**
  Online, 28th and 29th January 2021
  Info

- **Round table 'The energy transition and its effect on technology and the supply chain'. European Meeting on Science, Technology and Innovation – TRANSFIERE 2021**
  Málaga, 14th April 2021
  info

- **GEOPLAT workshop: 'Geotermia en Asturias'**
  Online, 15th April 2020

[44] https://www.boe.es/diario_boe/txt.php?id=BOE-A-2021-8975

[45] https://sede.sepe.gob.es/es/portaltrabaja/resources/pdf/especialidades/ENAE06.pdf

Info

- **PIXIL workshop: 'From science to praxis. Experiences employing geophysical methods to characterise geothermal anomalies'**
  Online, 26th May 2021
  Info

- **Coordination Committee of the Spanish Energy Technology Platforms (CCPTE) - CCPTE workshop: 'Ayudas en el marco de los programas europeos Horizon Europe y LIFE para la I+D+i energética'**
  Online, 26th May 2021
  Info

- **Geothermal exchange system: Best Available Technique for heating and cooling - 15th edition of National Congress on the Environment (CONAMA)**
  Madrid, 3rd June 2021
  Info

- **Coordination Committee of the Spanish Energy Technology Platforms (CCPTE) - CCPTE workshop: 'Ayudas Ley de Transición Energética y Fondos de Reconstrucción para la I+D+i energética'**
  Online, 12th June 2021
  Info

- **Webinar GEOPLAT/Spanish Centre for Industrial Technological Development (CDTI): 'Geothermal energy in Horizon Europe'**
  Online, 15th June 2021
  Info

- **GEOPLAT Annual Assembly 2021**
  Online, 12th July 2021
  Info

## 18.5 Future Activity

In 2022, GEOPLAT will work primarily promoting and boosting the development of geothermal R&D&I projects in Spain (identification of calls, monitoring of proposals, assisting and encouraging the formation of consortia, etc.).

GEOPLAT will continue to assist its members in the identification of potential partners and projects and, will work to improve and update the catalogue of capacity of the Spanish geothermal sector. This catalogue is a public directory of GEOPLAT entities that has information on scientific-technological, industrial, training capacities, geothermal facilities, etc. of the different actors in the sector. Furthermore, this data will contribute to draft sectorial reports considered relevant to the geothermal sector in Spain.

GEOPLAT will organize a webinar in collaboration with the Spanish Institute for Diversification and Saving of Energy (IDAE) with the objective of presenting the updated heat pump statistics published on the geothermal sector.

Within the framework of the European project CROWDTHERMAL, GEOPLAT will organize an international conference with the main objective of introducing CROWDTHERMAL services for community-funded geothermal projects. The event will be in a hybrid format, on-site in Madrid and online.

GEOPLAT will celebrate its Annual Assembly and promote other events and activities of interest for its members.

## 18.6 References

- GEOPLAT Website: www.geoplat.org
- GEOPLAT Blog: http://blog.geoplat.org
- Spanish Institute for Diversification and Saving of Energy (IDAE): http://www.idae.es
- Geological Survey of Spain (IGME): http://www.igme.es/
- GEO-ENERGY EUROPE project: https://www.geoenergyeurope.com/
- Crowdthermal project: http://www.crowdthermalproject.eu/
- PIXIL project: https://pixil-project.eu/en
- Spanish Centre for Industrial Technological Development (CDTI): https://www.cdti.es/
- Spanish State Research Agency (AEI): http://www.ciencia.gob.es/portal/site/MICINN/aei
- IDAE Heat pump statistics: https://estadisticas-bombasdecalor.idae.es/
- National Institute of Qualifications of the Spanish Ministry of Education (INCUAL): https://www.educacion.gob.es/educa/incual/ice_incual.html

Spain's Recovery, Transformation and Resilience Plan:
https://www.mineco.gob.es/stfls/mineco/comun/pdf/201015_des_recovery.pdf

# 19. Switzerland

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## 19.1 Introduction

Switzerland's uptake of shallow geothermal continues at pace. The theoretical potential for direct use geothermal, geothermal heating and cooling and geothermal for power generation is considered very large. Current estimates of the technical and economic potential (with support mechanisms) for geothermal energy is about 2 TWh for power production. There is currently no target for heat production, however the potential for heat production both from direct use and ground sourced heat pumps is estimated to be as high as 25% of the heat demand in Switzerland (estimates from geothermie-schweiz.ch).

The Swiss government supports the development of geothermal energy use through a range of measures for both power production (based on the Energy Act revised in 1 January 2018) and direct use of geothermal energy for heat production (CO2-Act partially revised in 1 January 2018). Additionally, research and development, as well as pilot and demonstration projects are supported through a number of energy research programs. Swiss participation in European funding programs such as the Era-net GEOTHERMICA as well as the Clean Energy Transition Partnership under Horizon Europe are maintaining and developing an international network of stakeholders focussed on accelerating implementation of geothermal energy.

Table 2 Status of geothermal energy use in Switzerland (figures from 2020)

| Electricity | | Direct Use | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | 0 | Total Installed Capacity ($MW_{th}$) | 23.8 |
| New Installed Capacity ($MW_e$) | 0 | New Installed Capacity ($MW_{th}$) | 0.0 |
| Total Running Capacity ($MW_e$) | 0 | Total Heat Used (PJ/yr) [GWh/yr] | 0.72 (201.0) |
| Contribution to National Capacity (%) | 0 | Total Installed Capacity Heat Pumps ($MW_{th}$) | 2'335.0 |
| Total Generation (GWh) | 0 | Total Net Heat Pump Use [GWh/yr] | 3'823.6 |
| Contribution to National Generation (%) | 0 | Target (PJ/yr) | N/A |
| Target 2050 (GWh/yr) | 2'000 | Estimated Country Potential ($MW_{th}$ or PJ/yr or GWh/yr) | N/A |
| Estimated Country Potential (GWh/yr) | N/A | | |

(N/A = data not available)

## 19.2 Changes to Policy Supporting Geothermal Development

During the period of 2008 to 2017, the Swiss federal government solely supported geothermal power generation projects through direct incentive measures. Switzerland employed two principal policy instruments that were oriented towards development and deployment of deep geothermal energy technology for power generation: feed-in tariffs and a geothermal risk guarantee program. Before 2018, the feed-in tariffs for electricity from geothermal energy depended on the installed electricity capacity of the project and the project type; hydrothermal or EGS. When granted, the payment of the feed-in tariffs was guaranteed for 20 years. The risk guarantee scheme covered up to 50% of the costs associated with the geological risk of finding a geothermal resource. The risk guarantee payment was made only if partial or total failure of the project occurred. Therefore, project developers seeking to use the risk guarantee scheme had to define success and failure cases for their projects, principally in terms of wellhead temperature, production rate and also in terms of chemistry of the produced fluids. Overall, there has been very little uptake of either of these support mechanisms by local project developers with t barriers to entry being too high.

Switzerland recognized the potential of geothermal among other renewable energies while setting the targets in its Energy Strategy 2050. In 2017, a major revision of the Energy-Act was adopted and a series of revised and new ordinances also adopted. These came into effect on the 1st of January 2018. Within this legislative framework, the government and its federal administration enhanced the geothermal policy measures which now encourage both geothermal direct use heat and power production through a set of subsidies, including:

- Two subsidies for the upstream exploration and development activities that lead to the uptake of geothermal direct use for heat production. The subsidies cover up to 60% of the costs associated with the geological risk of finding, assessing and developing a geothermal resource for subsequent heat production – in practice these are all the subsurface investment costs required for first heat into a heat plant. A budget of up to CHF 30 million per year (1 CHF ~ 1 US$) was allocated to support geothermal direct use projects. No expiry date for these risk mitigation schemes has been set to date.
- Geothermal power projects are encouraged through a set of subsidies comparable to those for the geothermal direct use schemes. Prospecting and exploration activities for geothermal power projects up to the stage where a geothermal reservoir has been proven may be supported by a financial contribution of up to 60% of the admissible costs.
- The geothermal risk guarantee (pre 2018 mechanism) remains available and has been extended to cover up to 60 % of the investment in exploration and development of geothermal resources for power generation. Both the risk guarantee scheme and the subsidies for geothermal power generation are available until 2031. About CHF 50 million annually may be committed to geothermal power projects.
- Switzerland decided to make the lodging of all types of data and analyses from subsidised projects to the Swiss Geological Survey, Swisstopo, compulsory. While Swisstopo is allowed to make full use of all the data and analyses, only specific raw or processed data sets will be published and open to the public for use.
- The feed-in tariffs remain available to geothermal power projects until 2023, but the duration has been reduced to 15 years.

Strong political support for renewable energy deployment has contributed to improving and adapting the support schemes for geothermal energy. A series of major revisions underway will lead to new support mechanisms being implemented from 2023, including the replacement of the feed-in-tariff mechanism by an investment grant covering up to 60% of the costs of the geothermal power plant. In addition, the exploration subsidy for geothermal power projects will be extended to cover up to 60% of all subsurface development costs, similar to the support mechanism in place for direct use geothermal heat projects.

The Energy Strategy 2050 includes an “action plan coordinated energy research”. Financial support for geothermal research and innovation has grown considerably in the last 5 years from about US$ 10 million to US$ 20 million per year.

## 19.3 Geothermal Project Development

### 19.3.1 Projects Commissioned

The following projects for direct use or power productions are in the planning and execution phase in 2021:

| Project name / Project developer | Project developer | Technology /planned energy use | Project duration and status |
|---|---|---|---|
| Services Industriels de Genève (SIG) | | Hydrothermal heat production, 200 $GWH_{th}$ for district heating, 25 $GWH_{th}$ for greenhouse heating | 2020 – 2023, 3D seismic campaign finished in 2021 |
| EnergeÔ Vinzel and La Côte (VD) by EnergeÔ SA | | Hydrothermal heat production for district heating, 30 – 40 $GWh_{th}$ from two 2500 m deep boreholes, seismic prospection campaign 3 additional boreholes | 2020 – 2022, drilling in Vinzel planned for second half of 2022, seismic campaign finished in 2021 |
| Lavey-les-Bains (VD) by AGEPP SA | | Hydrothermal production from a 2300 or 3000 m deep borehole. Power production 5 $GWh_{el}$, 15 $GWh_{th}$ heating of thermal baths. | 2020 – 2023, drilling started early 2022 |
| Forsthaus Bern (BE) by Energie Wasser Bern (ewb) | Energie Wasser Bern (ewb) | Aquifer thermal heat storage project through array of 6 boreholes in Molasse units. Waste heat produced a waste-to-energy plant is stored and produced for district heating | 2019-2023, drilling set to start in second half of 2022 |
| Haute Sorne (JU) by Geo-Energie Suisse AG | | Petrothermal (EGS) project for power, 25 – 40 $GWH_{el}$, and heat 160 – 200 $GWH_{th}$ | 2020-2029, permit in force after delays, drilling activities planned for 2023. |
| geo2riehen by Wärmeverbund Riehen AG | | Hydrothermal project, direct heat use for district heating 5 $GWh_{th}$ | Surface exploration program completed in first half of 2022. |

### 19.3.2 Projects Operational

In 2020, the total installed capacity of geothermal-based heating facilities was 2390 MW, which is made up of ground-sourced heat pumps (83.4%) shallow ground water use (13.9%), geo-structures (1.2%), deep aquifers with heat pumps (0.3%), direct use (0.1%), tunnel water use with heat pumps (0.2%), direct use (unknown), and thermal baths (0.9%). In total, this is an increase of 4.5% since 2019. The total produced heat energy is 4016 GWh, of which 3006 GWh (ca. 75%) is geothermal energy (i.e. energy produced before the heat pump). The evolution of the geothermal energy production since 1990 is shown in Figure 19.1. Heating facilities based on deep aquifers and tunnel water as well as thermal baths are listed below (numbers from 2020). Currently, there are no operational geothermal power plants.

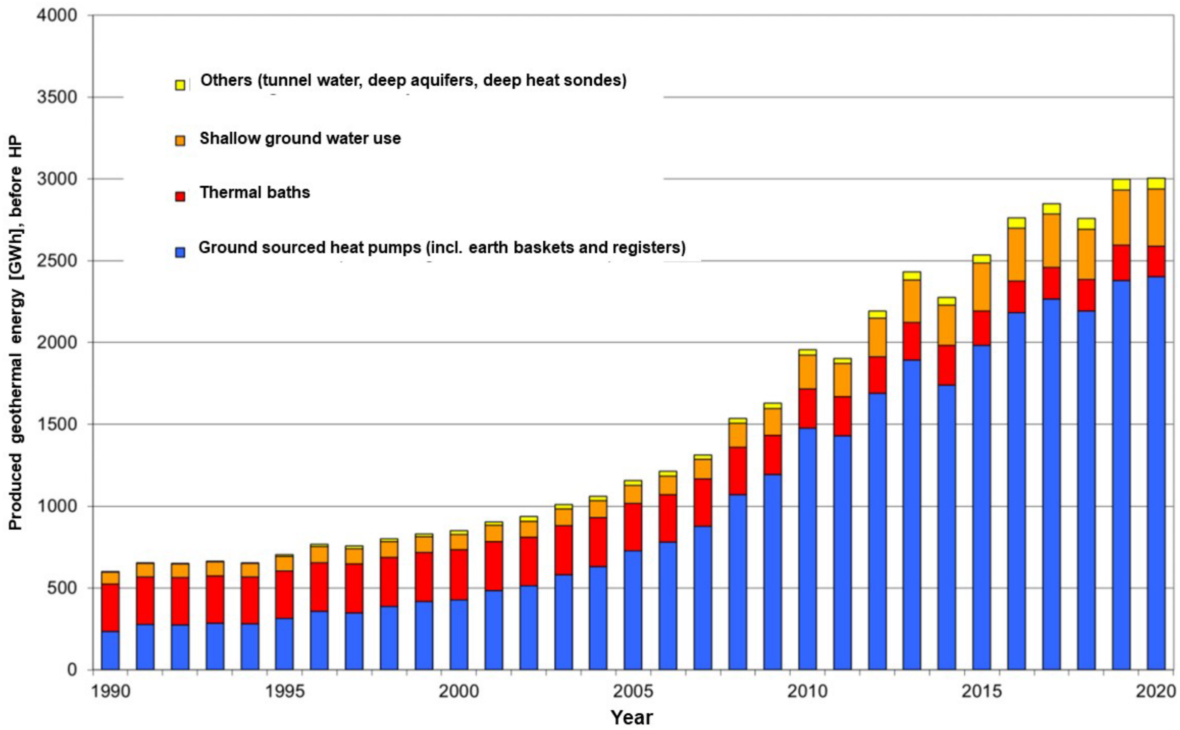


Figure 19.1: Annual geothermal energy production of all geothermal systems (both with and without heat pump) between 1990 and 2020 (based on Link, 2021)

### 19.3.2.1 Deep Aquifer

| Heating project direct use DU/ heat pump HP | Capacity [MW]*) | Heat energy [GWh/yr] | Geothermal energy (without HP) |
|---|---|---|---|
| Riehen (BS), DU | 1.5 | 5.2 | 5.2 |
| Riehen (BS), HP | 3.5 | 13.15 | 10.20 |
| Bassersdorf (ZH), HP | 0.24 | 0.47 | 0.24 |
| Davos Arkaden (GR), HP | 0.88 | 0.37 | 0.20 |
| Itingen (BL), HP | 0.08 | 0.18 | 0.13 |
| Kloten (ZH), HP | 0.24 | 0.98 | 0.6 |
| Seon (AG), HP | 1.35 | 2.36 | 1.76 |
| Schlattingen, (TG), DU | N/A | N/A | N/A |

### 19.3.2.2 Tunnel water

| Heating project (Heat pump, unless indicated) | Flow rate [l/s] | Temperature [°C] | Capacity [MW]*) | Heat energy [GWh/yr] | Geothermal energy (without HP) |
|---|---|---|---|---|---|
| Lötschberg base tunnel, direct use of tunnel water for fish farm, Frutigen | 100 (used ca. 85) | 19 | 6.83 | 2.00 | See left |
| Lötschberg base tunnel, Frutigen (BE/VS) | 11.3 | 16-18 | 1.08 | 1.38 | 1.01 |
| Furka Railway tunnel, Oberwald (VS) | 70 | 116 | 1.43 | 2.87 | 2.11 |

| Heating project (Heat pump, unless indicated) | Flow rate [l/s] | Temperature [°C] | Capacity [MW]*) | Heat energy [GWh/yr] | Geothermal energy (without HP) |
|---|---|---|---|---|---|
| Gotthard road tunnel, Airolo (TI) | 111 (used 33-40) | 12-17 | 0.72 | 0.86 | 0.65 |
| Ricken railway tunnel, Kaltbrunn (SG) | 11.5 | 12.3 | 0.16 | 0.25 | 0.17 |
| Hauenstein railway tunnel, Trimbach (SO) | 42 (used 22) | 19 | 0.37 | 0.38 | 0.20 |
| Mappo Morettina, road tunnel, Minusio/Tenero (TI) | 4.2 | 16-18 | 0.09 | 0.08 | 0.03 |

### 19.3.2.3 Thermal spas

| Thermal spa Location (Canton) | Flow rate [l/s] | Temperature [°C] | Capacity [MW]*) | Heating energy [GWh/yr] |
|---|---|---|---|---|
| Andeer (GR) | 0.67 | 19 | 0.03 | 0.21 |
| Bad Ragaz (SG) | 23.8 | 36.5 | 2.65 | 22.01 |
| Bad Schinznach S3 (AG) | 7.44 | 41 | 0.97 | 8.07 |
| Brigerbad (VS) | 33.3 | 36.5 | 3.71 | 30.85 |
| Kreuzlingen (TG) | 0.76 | 28.5 | 0.06 | 0.49 |
| Lavey-les-Bains (VD) | 18.9 | 50.3-64.3 | 3.72 | 30.95 |
| Leukerbad (VS) | 46.1 | 47 | 7.17 | 59.69 |
| Ovronnaz (VS) | 2.66 | 24 | 0.16 | 1.30 |
| Saillon (VS) | 58.3 | 18-24 | 2.51 | 20.86 |
| Stabio (TI) | 0.67 | 13 | 0.01 | 0.07 |
| Vals (GR) | 4.11 | 27 | 0.29 | 2.44 |
| Yverdon-les-Bains (VD) | 3.0 | 28 | 0.23 | 1.89 |
| Bad Zurzach (AG) | 6.97 | 39.7 | 0.78 | 6.45 |
| **Total** | | | **22.26** | **185.25** |

## 19.4 Research Highlights

The federal government finances the energy research and innovation projects developing technologies that make geothermal more cost effective, safer, more efficient and more reliable as an energy source for electricity and heat. Improvements in geothermal drilling and exploration technologies are expected to eventually result in a decrease in the costs and risks associated with geothermal development by; increasing drilling efficiency, and making resource evaluation more accurate.

Research and innovation is funded by the Swiss National Science Foundation (fundamental research), the Swiss Federal Office of Energy (applied research, piloting and demonstration) and Innosuisse (market-driven research). Some of the federally funded Swiss Federal Institutes of Technology have allocated funds to be used for geothermal energy research and innovation. Of the five institutes, ETH Zurich, EPF Lausanne and the Paul Scherrer Institute engage in geothermal research and innovation.

Although Switzerland is not an associated state in the EU research framework program, Horizon Europe, the Swiss Federal Office of Energy (SFOE) cooperates with European funding agents through the European Research Network GEOTHERMICA and via its dedicated funding programs for geothermal energy research and innovation. Switzerland will also participate in the Clean Energy Transition Partnership (CETP) – the new European Research Network funded by Horizon Europe – as a third country member.

In 2020, funding of geothermal research and development, including pilot and demonstration projects was at a level of CHF 20 million (Figure 19-2).

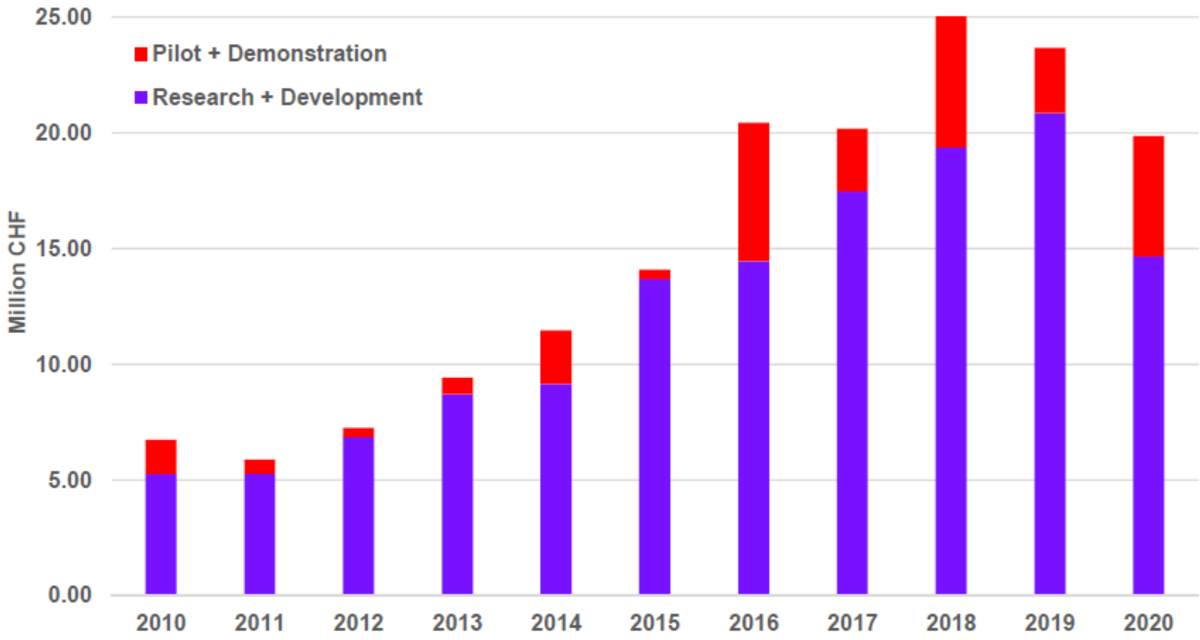


Figure 19.2: Annual funds spend on Geothermal research and development as well as pilot and demonstration projects in Switzerland between 2010 and 2020.

Some research highlights are described in the following sections. The list of projects is not exhaustive.

### 19.4.1 Hydraulic stimulation experiments in underground laboratories

Between 2014 and 2020, eight Swiss Competence Centers for Energy Research (SCCER) were running to develop competences and initiate research and innovation in fields critical for Switzerland's Energy Strategy 2050. One of them focussing on Supply of Electricity (SCCER-SoE), dealt with geothermal energy primarily focussed on Engineered Geothermal Systems but also on direct use geothermal energy and heat storage. A synthesis report (Giardini et al, 2021) highlighting the major achievements of the SCCER-SoE was published in September 2021.

A primary focus of the initiatives where insitu underground laboratory experiments on hydraulic stimulation in crystalline rock, first at the Grimsel Test Site (GTS, 450 m below surface, between 2014 – 2017) and then in the newly established "Bedretto Underground Laboratory for Geoenergy and Geosciences (BULGG. 1 km below surface, since 2019)". These hydraulic stimulation experiments were downscaled by roughly one (BULGG) and two (GTS) orders of magnitude in size and aimed at exploring stimulation concepts (multi-stage stimulations, zonal isolation) that are adapted from unconventional oil and gas industry seeking to unlock the potential of engineered geothermal systems in a safe, efficient and reproducible manner. Thus, another important topic was to improve the management of induced seismic hazard through enhanced process understanding and the development of a-priori and near-real time hazards and risk analysis schemes. The experiments at the GTS demonstrated that in principle that multi-stage stimulations are superior to conventional open-hole stimulations in that permeability can be increased in a more precise, efficient and safe (in terms of induced seismicity) way.

In the BULGG, hydraulic stimulations were performed at scales close to actual EGS scale in the pilot and demonstration project VALTER and the Horizon EU project DESTRESS. Thus, also the equipment for full-scale EGS projects (pumps, borehole completions, monitoring instruments, etc.) could be tested. More efficient drilling techniques (percussion drilling), and different ways to complete boreholes for zonal isolation (sliding sleeves, multi-packers, small-diameter lateral holes, etc.) were explored in the GEOTHERMICA project ZoDrEx which concluded in 2021.

### 19.4.2 Research and innovation for engineered geothermal systems

Several additional projects aim at supporting the development of EGS. The GEOTHERMICA project COSEISMIQ, finished in 2021, improved and validated advanced technologies for monitoring and controlling induced seismicity at the Hengill geothermal area demonstration site in Iceland. The GEOTHERMICA project DEEPEN uses experience and data from Iceland acquired through COSEISMIQ to further develop ambient noise based subsurface imaging techniques. Similarly as a continuation of COSEISMIQ, the GEOTHERMICA project DEEP will focus on innovative seismic processing, seismicity forecast modelling and adaptive risk assessment as part of so-called advanced traffic light systems. The developments can readily be tested in the unique FORGE field laboratory in Utah. The project SPINE (also GEOTHERMICA) aims at developing new tools for characterizing the stress field along boreholes, which supports the design of reservoir creation procedures. The design of reservoir stimulation will further be facilitated by a novel high-end reservoir simulator developed within the project EMOD. This series of projects are to some degree targeted on the up-coming EGS project in Haut-Sorne (see Section 3.1) and other future EGS projects, where many of the developed concepts are to be put into practise. The projects DEEPEN, DEEP, SPINE and EMOD are ongoing at the end of 2021.

### 19.4.3 Heat storage and drilling technologies

Further research and innovation efforts included the GEOTHERMICA project HEATSTORE (concluded in 2021) with the goal of promoting underground thermal heat storage (UTES) in Europe. The two project sites; SIG in Geneva, and Forsthaus in Bern (see Section 3.1) have been part of the project, with work at these sites ongoing. The Swiss part of the project VESTA (with partners in the EU and USA) continues to focus on the Forsthaus site investigating geochemical issues arising from cyclic production and injection in higher temperature storage situations.

Alternative drilling technologies were explored in the research projects SPALL-APP looking at thermal-spallation drilling in laboratory experiments and PLASMA looking into plasma-pulse drilling using numerical modelling.

### 19.4.4 SWEET: a new funding instrument

With the SCCERs coming to an end in 2020, a new funding instrument was launched in 2021 to accelerate innovation for implementing the Swiss Energy Strategy 2050. The funding program is based on calls on specific research challenges addressed to consortia with partners from different universities, and the public and private sector. Currently funded consortia dealing with "integration of renewables" (first call) also include the integration of geothermal energy.

## 19.5 Other National Activities

### 19.5.1 Geothermal Education

An overview of education and training courses related to geothermal energy can be found through this web address: https://geothermie-schweiz.ch/formation-continue-geoth . The University of Neuchâtel runs a successful and popular Certificate for Advanced Studies on Exploration & Development of Deep Geothermal Systems (CAS DEEGEOSYS).

### 19.5.2 Conferences

In the last few years, a number of national and international geothermal conferences with significant geothermal interest took place in Switzerland, albeit fewer through the period of the pandemic:

- Journées romandes de la géothermie 2020, Montreux (VD), 5 February 2020
- Gurten Symposium: Geothermie – Quo Vadis, Bern /BE), 4 November 2020
- Geothermie Forum 2021, Fribourg (FR), 21 September 2021

### 19.5.3 Publications

See the publication websites of the Swiss Federal Office of Energy (Geothermal energy (admin.ch)) and of the SCCER-SoE (http://www.sccer-soe.ch/publications/).

### 19.5.4 Useful Websites

| | |
|---|---|
| Geothermie-Schweiz (Swiss Geothermal Association) | http://geothermie-schweiz.ch |
| Fachvereinigung Wärmepumpen Schweiz FWS (Swiss Heat Pump Association) | http://www.fws.ch |
| Swiss Competence Center for Energy Research – Supply of Energy (SCCER SoE) | http://www.sccer-soe.ch<br>http://www.sccer-soe.ch/research/geo-energy/ |
| Bedretto Underground Laboratory for Geoenergies | http://www.bedrettolab.ethz.ch/home/ |
| Grimsel Test Site (Grimsel rock laboratory) | http://www.grimsel.com |

## 19.6 Future Activity

The geothermal sector is benefiting from the first set of measures from the Energy Strategy 2050 with a total subsidy of about 114 mio CHF and 65 mio CHF awarded to specific geothermal power and direct use heat production projects. While the focus remains on subsurface exploration activities, drilling activities have been increasing since the beginning of 2021. In addition, whilst the uptake of the subsidy programs supporting the development of direct use of geothermal heat projects is ongoing, a noticeable increase in interest has been observed in geothermal power production projects in the last 12 months.

## 19.7 References

Giardini, D., Guidati, G. (eds.), Amann, F., Driesner, T., Gischig, V., Guglielmetti, L., Hertrich, M., Holliger, K., Krause, R., Laloui, L., Lateltin, O., Lecampion, B., Löw, S., Maurer, H., Mazzotti, M., Meier, P., Moscariello, A., Saar, M. O., Spada, M., Valley, B., Wiemer, S., Zappone, A. (2021): Swiss Potential for Geothermal Energy and CO2 Storage, Synthesis Report, ETH Zurich, 2021. doi.org/10.3929/ethz-b-000518184.

Link, Katharina: Statistik der geothermischen Nutzung in der Schweiz – Ausgabe 2020. Schlussbericht, 30. August 2021.

# 20. United Kingdom

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Figure 20.1 Drilling at Eden Geothermal Limited's site at the Eden Project in Cornwall (part funded by the European Regional Development Fund). Photo credit: Corinna Abesser

## 20.1 Introduction

This report summarises the national activities surrounding the development of geothermal energy systems between October 2020 and October 2021. The installed capacity of 787 MWth is from the estimated 43,700 installed ground source heat pumps. The total installed capacity in the UK from deep and mine water geothermal systems is ~8.1 MWth and 0 Mwe respectively. There are two geothermal power schemes currently being developed. Mine water geothermal systems are of increasing interest to the UK for their potential societal, economic and environmental benefits.

**Table 1. Status of geothermal energy use for electric power generation, direct uses (excl. GSHP) and GSHP in the UK in October 2021.**

| **Electricity** | |
|---|---|
| New capacity installed in 2021 (MWe) | 0 |
| Total Installed Capacity (MWe) | 0 |
| **Direct Use (incl. Mine energy schemes)** | |
| New capacity installed in 2021 (MWth) | 0 |
| Total Installed Direct Use (MWth) | 8.1 |
| **Ground source heat pumps** | |
| New capacity installed in 2021 (MW) | 35# |

| | |
|---|---|
| Total Installed Capacity for Heat Pumps (MW) | 787# |
| Total Net Heat Pump Use [GWh/yr] | 1316* |

# These data are forecasted based on market trends, expecting growth in GHSP sales of 18% in 2021

* In calculating the net GSHP use it has been assumed that the hrs/year heating equivalent full load is 1800 hrs/year for domestic systems and 1500 hrs/year for commercial systems.

The structure of the report is as follows. In section 2, the new and ongoing geothermal projects are presented, from deep geothermal, to district heating networks with mine water geothermal and large open/closed loop systems. In section 3, changes to policy supporting geothermal energy are reviewed. Research highlights, which include a new research centre and various research programmes are presented in Section 4. Various other activities are presented in section 5.

## 20.2 New and ongoing geothermal projects

### 20.2.1 Deep geothermal projects

The ***United Downs Deep Geothermal Power project*** (UDDGPP), led by Geothermal Engineering Ltd (GEL), is the first commercial project in the UK to develop deep geothermal for power generation. The project utilises the natural permeability of the Porthtowan Fault in the Carnmenellis granite in Cornwall. Drilling of two deviated wells started in November 2018 and was completed in 2019. The wells intersect the fault at two different depths in order to create a closed loop circulation system vertically along the fault. The first well, UD1, has a drilled depth of 5275 m (5057 m total vertical depth), encountering temperatures of nearly 200°C, and is the production well. The second well, UD2, has a drilled depth of 2393 m (2214 m total vertical depth) and will act as the injection well. Hydrotesting of the wells took place in July 2021. Production and injection of geothermal fluids was reported to be successful. Installation of the power plant is expected to be complete in 2022. The project plans to supply electricity for 6,000 homes and distribute 55MW heat to local users (including a Tropical Rum Distillery and a new housing estate). GEL has announced plans to develop four more projects in Cornwall by 2026.

In addition, GEL is planning a trial of a lithium extraction plant at the United Downs geothermal site, which was reported to have significant lithium concentrations (averaging around 220 mg/L) in the produced geothermal fluids. The pilot plant will use Direct Lithium Extraction (DLE) technology to recover lithium from the geothermal water and will be developed in collaboration with Cornish Lithium Ltd.

The second, deep geothermal project has started at the ***Eden project in Cornwall***. It is situated on the St Austell granite. The project is being developed by Eden Geothermal Ltd., which has shareholders comprising Eden Project Ltd., EGS Energy Ltd. and BESTEC (UK) Ltd. The project has funding of £9.9m from the European Regional Development Fund, £1.4m from Cornwall Council and £5.5m from institutional investors. The project is targeting a deep crustal fracture. Drilling of the well into the granite began in mid-May this year, and was completed ijn November 2021. The well, EG-1, has a vertical depth of 4,871m and its measured depth (actual drilled depth) is 5,277m, making it the longest geothermal well in the UK. The well has found its target fault structure and the early signs of high temperatures and good permeability at depth are promising. The well will be used to heat the Biomes, greenhouses and offices at the Eden Project. A second phase is planned to start next year, drilling a second well for power generation.

The only operating deep geothermal project is in the **City of Southampton** which contributes approximately 40 GWh heat to an inner-city district heating network. This scheme was under maintenance in 2020 but is understood to be back operating in 2021.

No further deep geothermal projects have been commissioned this year.

### 20.2.2 Mine water geothermal projects

Development of disused mine systems for utilisation of their waters for geothermal heating is progressing in the UK . Although in many cases the temperature of the water will be at normal ground water temperatures, the very high abstraction rates possible make disused mine systems ideal for large-scale open loop ground source heat pumps. Abandoned mines fall under the jurisdiction of The Coal Authority (CA) who are developing geothermal heating schemes at several of their sites. The CA estimated around 25% of UK homes are situated in the former coalfields, with potentially sufficient geothermal water to heat all the homes. The most advanced projects are:

- **Seaham Garden Village :** This is a new development of housing, a school, shops and medical and innovation centres that will have district heating supplied from the Dawdon treatment scheme. The pumped mine water is at a temperature of 18-20 °C and has a potential heating capacity of 6 MWth, supporting a district heat network of 1,500 new homes. The Dawdon green energy project will cost between £12 million and £15 million. It received £3.8m government support from the Heat Networks Investment Project (HNIP). It is hoped that the scheme will be a commercially viable sustainable energy demonstrator project that can be duplicated across UK coalfields.[46]
- **Hebburn Minewater District Network:** This development involves drilling into the former Hebburn colliery to extract heat for council owned buildings in the town. The Hebburn site, run by Dunelm Geotechnical, is currently drilling two 300-400 m deep boreholes, one abstraction well and one re-injection well, into the mine workings. Drilling is expected to complete in December, with pumping tests scheduled after Christmas.
- **Gateshead District Heat Network:** In Gateshead, an existing heat network is to be expanded and supplied from the groundwaters within disused mine workings beneath the town. A 6MW water source heat pump will recover heat and distribute via the heat network to up to 1,250 new private homes, a care home, Gateshead International Stadium and other Council-owned buildings. The development is being funded from a grant of £6M from the UK government's Heat Networks Investment Project (HNIP).

### 20.2.3 District heating networks using geothermal energy

District heating networks are not as common in the UK as in other European countries. However, there is an increasing recognition in the role these can play in reaching net zero targets. Consequently, government funding has been directed to these projects.

- **Swaffham Prior Community Heat Network**: Funded with a £3.268m grant, sponsored by Cambridgeshire County Council in partnership with Swaffham Prior Community Land Trust, it is intended to help a village of some 300 homes to transition from oil to low carbon heating and serve as a model for other rural communities. The network will combine ground source heat and air source heat pumps to provide heating to

[46] Press release: https://tp-heatnetworks.org/innovative-low-carbon-projects-in-north-east-secure-hnip-funding/

homes within the village. Construction will consist of 130 boreholes drilled into the ground to a depth of around 200m to extract heat. The ground source pump will be supplemented by air source and both will be powered by solar panels.[47]

- In South Wales, Rhondda Cynon Taf County Borough Council has announced ***the Taff's Well Thermal Spring Heat Network Project***. The project plans to utilise Wales' only natural thermal spring, Taff's Well, as a source of low-carbon heat for the heating systems of the new school block and nearby pavilion. The spring emerges from the south Wales Coalfield and discharges to the river Taff at temperatures of 21-22C. The wider development is supported by a £1m investment from the Welsh Government.

## 20.3 Changes to Policy Supporting Geothermal Development

### 20.3.1 Interest in government

A Parliamentary Debate on ***Opportunities for geothermal energy extraction in the UK***[48] took place in the House of Commons on 15 September 2021.

In **Northern Ireland**, interest in geothermal energy saw a noticeable rise over the past year. Following on from a successful international conference in December 2020, the Geological Survey of Northern Ireland (GSNI), the Centre for Sustainability, Equality and Climate Action (SECA) at Queen's University Belfast and the Geothermal Association of Ireland have run a monthly webinar series that has been attended by over 1000 people to date.

A new ***Geothermal Advisory Committee (GAC)*** for Northern Ireland, chaired by the Geological Survey of Northern Ireland, was established in July (2021) which brings together a group of experts from industry, academia, public sector and professional organisations based in UK and Ireland. This group will provide independent advice to the DfE aimed at informing, supporting and developing public policy on geothermal energy as part of the new Energy Strategy for Northern Ireland.

The UK government's "Heat and Buildings strategy" was released in October 2021, which outlines "electrification of heat for buildings using hydronic (air-to-water or ground-to-water) heat pumps, heat networks and potentially switching the natural gas in the grid to low-carbon hydrogen" as the likely future for heating in the UK. The strategy targets at least 600,000 hydronic heat pumps per year by 2028. (Deep) geothermal energy has been recognised in the strategy as a low-carbon source for heat networks that the government "will continue to monitor … (to) assess whether the technology provides a cost-effective option to help decarbonise heat."

The new Energy Strategy for Northern Ireland was released in December 2021 following public consultation on policy options by the Department for Energy earlier that year.

The Electrification of Heat Demonstration Project (£14.6m) installed 750 innovative heat pump systems across a range of different housing types. The project will monitor these systems to demonstrate the feasibility of a large-scale roll-out of heat pumps in GB. The system installation phase was completed in 2021, monitoring will be undertaken for one year, finishing in 2022.

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[47] Press release: https://tp-heatnetworks.org/hnip-funding-awarded-to-first-community-renewable-heating-project/

[48] Debate pack. Number CDP 2021/0143: https://commonslibrary.parliament.uk/research-briefings/cdp-2021-0143/

### 20.3.2 Government support & funding programmes

The Renewable Heat Incentive (RHI) is currently the principal mechanism to support geothermal heat installations in the UK. It provides a subsidy to applicants for every unit of renewable heat they produce. The scheme closed to non-domestic applicants in March 2021 but has been extended to March 2022 for domestic schemes.

A number of support schemes are available for heat networks. The Heat Network Delivery Unit (HNDU) provides support for local authorities in England and Wales for carrying out techno-economic feasibility studies and specialist consultancy work around provision of heat (including from geothermal sources) to heat networks. This fund was set up in 2013 and a total of £25.6m has been awarded to date.

A new scheme, the Boiler Upgrade Scheme (£450 million over three years), has been announced in the Government's Heat and Building Strategy for domestic and small non-domestic installations, starting in April 2022. The scheme offers capital grants of £5,000 for air source heat pumps and biomass boilers, and £6,000 for GSHPs for schemes up to 45kW, including shared ground loops for non-social housing projects. Separate funding will be made available for social housing schemes, but details have yet to emerge.

A £270m Green Heat Network Fund (GHNF) scheme was announced in the budget of March 2020 and is currently being developed for England. The scheme supports all networks that meet its core eligibility criteria (which includes metrics on technology carbon intensity and minimum heat demand supplied by the network) irrespective of technology. Core eligibility metrics have yet to be confirmed for the GHNF full scheme which is planned to open in 2022 and close in 2025. The GHNF will be a capital grant support scheme which will provide targeted financial support for the decarbonisation of existing and development of new low carbon heat networks across England.

A £10 Million transition scheme was launched on 21$^{st}$ June (Green Heat Network Fund Transition Scheme), for networks with heat demands > 2GWh/year (urban) or > 100 connected dwellings (rural) which are more likely to be served by deep geothermal or mine energy sources instead of GSHPs. The Transition Scheme will provide grant funding to support projects through the commercialisation phase of development. This will enable them to be in a position to apply to the GHNF for construction funding when it opens.

Finally, in England and Wales, BEIS's Heat Network Invest Project (HNIP) is investing £320m up to April 2022 to support the construction of heat networks and accelerate the growth of the market across England and Wales. This fund was mentioned previously in this report, as it includes the grants to the North East mine water pump technology schemes.

In Scotland, several additional funding streams are available for geothermal energy technologies, including the Low Carbon Infrastructure Transition Programme (LCIPT) and the Community and Renewable Energy Scheme (CARES).

Geothermal energy continued to be eligible to compete in the Contracts for Difference under pot2 (less established technologies), though no projects have so far been successful. Contracts for Difference is a mechanism by which the government buys power from renewable technologies with 15-year contracts.

## 20.4 Research Highlights

### 20.4.1 Research centres

A second research site is currently being developed by the ***UK Geoenergy Observatories***, a £31m project funded by the 2014 UK Government Plan for Growth of Science and Innovation. The new site, UKGEOS Cheshire, will include infrastructure for research on GSHP systems, thermal storage in the Triassic Sherwood Sandstone and investigation of environmental impacts. The first research site, UKGEOS Glasgow, is now operational and available to third party researchers. The infrastructure comprises 12 wells drilled into an abandoned mine system equipped with high resolution monitoring technology. It will enable the UK science community to study the low temperature mine water geothermal environment at shallow depth.

### 20.4.2 Research programmes

UK geothermal research is broadening out, with an increasing number of funding calls supporting geothermal research. Overall, funding for geothermal research remains sparse with much research undertaken within / led by the Higher Education sector. A number of new projects have started in 2021.

***NetZero Geothermal Research for District Infrastructure Engineering (NetZero GeoRDIE)*** project, led by Newcastle University, is a £1.6m academia/industry consortium which was launched earlier this year. The project will develop Newcastle 1.6km deep Helix's borehole into a state-of-the-art research facility. It is funded by the £8 Mill EPSRC[49] Programme to Decarbonise Heating and Cooling to support the UK's goal of achieving Net Zero emissions by 2050

A second call for an **£14.6 NERC[50]/EPSRC Programme to Decarbonise Heating and Cooling** was issued in 2020. Eleven projects were funded under this call, including three geothermal projects:

- Geothermal Energy from Mines and Solar-geothermal heat (GEMS) (£1.4 M), led by Durham University
- Sustainable, Flexible and Efficient Ground-source heating and cooling systems (SaFEGround) (£1.5 M), led by Imperial College
- Aquifer thermal energy storage for decarbonisation of heating and cooling: Overcoming technical, economic and societal barriers to UK deployment (1.5 M), led by Imperial College

The £8M ***UK Unconventional Hydrocarbons (UKUH) research programme*** (funded by NERC and ESRC[51]) made £400K funding available to fund a series of projects that address new research themes, which have emerged as the result of the changes to the shale gas landscape in the UK. Projects that received funding included

- Underground energy on-the-ground: risk perception, community engagement and lessons learned for geothermal energy in a post-shale energy landscape (£70K), led by Anglia Ruskin University which started in May 2021.
- Testing the limitations of empirical traffic light systems used to manage the hazard of fluid induced seismicity (£25K), led by Durham University

[49] EPSRC – Environmental and Physical Sciences Research Council
[50] NERC – Natural Environment Research Council
[51] ESRC - Economic and Social Research Council

- Baseline seismic monitoring survey for UKGEOS Glasgow geothermal production using Distributed Acoustic Sensing (DAS) (£25K), led by University of Bristol
- Public engagements with induced seismicity: lessons for geothermal energy in the UK's net-zero transition(£25K), led by University of Birmingham
- Effective monitoring of the environment before, during and after sub-surface activities(£25K), led by the British Geological Survey

In Northern Ireland, funding announced for an innovative new partnership between academia and industry will harness Northern Ireland's natural geothermal resources, thermal energy that comes from the sub-surface of the earth to encourage the most efficient use of energy by industrial users, such as for data centres. It is funded through Invest NI's Competence Centre Programme and the Centre for Advanced Sustainable Energy (CASE).

### 20.4.3 Education

At COP26, a new education platform was launched: the UK Centre for Masters' Training in Energy Transition (CMT). The platform brings together UK universities with leading energy companies and industry training providers to facilitate access to resources and training for the next generation of geoscientists and engineers. Its remit covers a range of energy and renewable technologies, including geothermal energy and carbon capture and storage. Further details are available on the CMT website at https://www.energy-transition.ac.uk/ .

### 20.4.4 Selected publications

**Abesser & Walker (2022)** Geothermal Energy, *Parliamentary Office for Science and Technology (POST) researching briefing*, POSTbrief 46, https://post.parliament.uk/research-briefings/post-pb-0046/

**Hinson & Sutherland (2021)** Opportunities for geothermal energy extraction. *House of Commons Research Briefing*, September 2021. https://commonslibrary.parliament.uk/research-briefings/cdp-2021-0143/

**Jones, D (2021)** Unlocking the deep geothermal energy potential of the Carboniferous Limestone Supergroup, *BGS Research Highlight*, https://www.bgs.ac.uk/news/unlocking-the-deep-geothermal-energy-potential-of-the-carboniferous-limestone-supergroup/

**Narayan et al., (2021)** Karstified and fractured Lower Carboniferous (Mississippian) limestones of the UK – A cryptic geothermal reservoir, *Zeitschrift der Deutschen Gesellschaft für Geo-wissenschaften*; DOI: 10.1127/zdgg/2021/0288

**Pharaoh et al., (2021)** Early Carboniferous limestones of southern and central Britain: Characterisation and preliminary assessment of deep geothermal prospectivity; *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften;* DOI: 10.1127/zdgg/2021/0282

**Raine & Reay (2021)** Geothermal energy potential in Northern Ireland : summary and recommendations for the Geothermal Advisory Committee. Geological Survey of Northern Ireland, 27pp. http://nora.nerc.ac.uk/id/eprint/530934/

**REA & ARUP (2021)** Deep Geothermal Energy – Economic Decarbonisation Opportunities for the United Kingdon, Report by the Association for Renewable Energy and Clean Technology (REA) and Arup, May 2021. https://www.r-e-a.net/wp-content/uploads/2021/05/Deep-Geothermal-Energy-Opportunities-for-the-UK.pdf

## 20.5 Other National Activities

### 20.5.1 Geothermal Education

There are no specific higher education courses devoted to the exploration and utilisation of geothermal energy in the UK. However, earth science and renewable energy university courses increasingly offer modules on aspects of geothermal energy. There is also increased interest in renewable energy topics, including Geothermal Energy, in secondary school education. The

2021 Environmental Science Teacher Associations Annual General Meeting hosted a keynote lecture on Geothermal Energy in the UK (delivered by BGS).

### 20.5.2 Conferences

Build Back Better: Geothermal Energy for Norther Ireland virtual conference (virtual) 11th December 2020: Conference-Agenda-Building-Back-Better-A-future-for-Geothermal-Energy-in-Northern-Ireland.pdf (qub.ac.uk)

2021 Mine Water Geothermal Energy Symposium: Mine Water Heating and Cooling – A 21st Century Resource for Decarbonisation (virtual), organised by the BGS, BEIS and IEA Geothermal, 12 -13 April 2021. https://iea-gia.org/workshop-presentations/2021-mine-water-geothermal-energy-symposium/

8th London Geothermal Symposium (hybrid), 17th November 2021, https://www.geolsoc.org.uk/11-EG-Geothermal

### 20.5.3 Useful Websites

Contracts for Difference

https://www.gov.uk/government/policies/maintaining-uk-energy-security--2/supporting-pages/electricity-market-reform

Renewable Heat Incentive

www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/incentive/incentive.aspx

http://www.energysavingtrust.org.uk/scotland/Generating-energy/Getting-money-back/Renewable-Heat-Incentive-RHI2

Renewable Energy Association Deep Geothermal Group

www.r-e-a.net/member/deep-geothermal

Ground Source Heat Pump Association

www.gshp.org.uk/

## 20.6 Future Activity

Interest and awareness in geothermal continue to increase, but obtaining funding to develop projects remains challenging.

## 20.7 References

BSRIA 2021. Heat pumps market analysis 2021 - United Kingdom. Report number 102184/ 17

# 21. United States of America

Geothermal Technologies Office

Geothermal Technologies Office, Energy Efficiency and Renewable Energy, U.S. Department of Energy.
Email: Lauren.Boyd@ee.doe.gov

## 21.1 Introduction

In 2021, the United States (U.S.) remained the leader in installed geothermal capacity with 3.692 gigawatts (GW), representing close to 25% of the world's total online capacity. Ninety-five percent of U.S. capacity is in California and Nevada. Geothermal resources in the United States are found primarily in the western states, where broad volcanic and mountain-building activity have occurred. Eminent geothermal provinces include portions of the San Andreas Fault running through California from the Imperial Valley to the Golden Bay; the Basin and Range system in Nevada and Utah; and the Cascade Range volcanism in Oregon and Washington.

As of 2021, there are 23 geothermal district heating (GDH) systems in the United States. The oldest installation dates from 1892 (Boise, Idaho), and the most recent installation was completed in 2017 (Alturas, California).[52]

Geothermal heat pumps maintain approximately 3 percent annual growth, with current installations exceeding 1.7 million (equivalent 12 kW) units. About 40 percent of installations are residential; the other 60 percent are commercial or institutional. Most growth continues to occur in the central and eastern states.

The lead federal agency in charge of advancing the U.S. geothermal sector is the U.S. Department of Energy's (DOE) Geothermal Technologies Office (GTO), which is committed to supporting a portfolio of innovative technologies that address critical geothermal exploration and development challenges. GTO and its partners research, develop, and validate cost-competitive technologies and tools to help make geothermal energy more affordable, and to locate, access, and develop geothermal resources within the United States. Other federal agencies are also involved in helping to expand U.S. geothermal, such as the Federal Energy Management Program and the Advanced Manufacturing Office.

## 21.2 *GeoVision* Analysis and Report

GTO's *GeoVision* analysis, released in May 2019, continued to serve as a guiding document for GTO's programmatic R&D planning in 2021.

The *GeoVision* analysis includes the following conclusions:

- Optimized permitting could cut geothermal development timelines in half, leading to a doubling of geothermal (13 GWe by 2050) versus business-as-usual.
- By 2050, direct use could increase from 21 geothermal district heating installations to as many as 17,500 nationwide. Geothermal heat pumps could increase to 28 million.
- Geothermal power deployment could reach 60 GWe by 2050—more than 8 percent of national capacity—with aggressive technology improvements.

[52] National Renewable Energy Laboratory, 2021 U.S. Geothermal Power Production and District Heating Market Report (July 2021). https://www.nrel.gov/docs/fy21osti/78291.pdf.

## 21.3 2021 U.S. Electricity and Direct-Use Figures

| Electricity | | Direct Use | |
|---|---|---|---|
| Total Installed Capacity ($MW_e$) | 3,692 MWe | Total Installed Capacity ($MW_{th}$) | 485 $MW_{th}$ [53,54] |
| New Installed Capacity ($MW_e$) | 186 MWe (since 2015) | New Installed Capacity ($MW_{th}$) | N/A |
| Total Running Capacity ($MW_e$) | Net Summer = 2,555 MWe<br><br>Net Winter = 2,963 MWe | Total Heat Used (PJ/yr) [GWh/yr] | 2,120.3 GWh |
| Contribution to National Capacity (%) | 0.26 (winter) 0.24 (summer) [55] | Total Installed Capacity Heat Pumps ($GW_{th}$) | 20.7 $GW_{th}$ [56] (2020) |
| Total Generation (GWh) | 15.89 TWh[57] | Total Net Heat Pump Use [GWh/yr] | 32,493 GWh_th/year[5] |
| Contribution to National Generation (%) | 0.37[6] | Target (PJ/yr) | N/A |
| Target ($MW_e$ or % national generation) | N/A | Estimated Country Potential ($GW_{th}$) | 231 $GW_{th}$ by 2050[58] |
| Estimated Country Potential ($GW_e$) | ~530 GWe [59] | | |

(N/A = data not available)

## 21.4 Geothermal Project Development

GTO works in partnership with other federal agencies, industry, academia, DOE's national laboratories, and other stakeholders to increase deployment of geothermal energy resources through research, development, and demonstration (RD&D) targeting geothermal exploration and production. GTO focuses on accelerating innovation and expanding opportunities across the geothermal resource spectrum, with work in four program areas: enhanced geothermal systems (EGS); hydrothermal resources; low temperature and coproduced resources; and data, modeling, and analysis.

## 21.5 Projects Commissioned and Continued in 2021

### 21.5.1 Frontier Observatory for Research in Geothermal Energy (FORGE)

GTO's Frontier Observatory for Research in Geothermal Energy (FORGE) outside Milford, Utah, continued its history of ground-braking work in 2021. Led by the University of Utah, FORGE is a dedicated underground field laboratory for developing, testing, and accelerating breakthroughs in Enhanced Geothermal Systems technologies to advance the uptake of geothermal resources.

[53] United States Direct Utilization Update 2019; Lund, et al., World Geothermal Congress 2020.
[54] U.S. Geothermal Direct-Use Installations Database: https://gdr.openei.org/submissions/911
[55] U.S. Energy Information Administration 2020. "Electric Power Annual 2020." U.S. Energy Information Administration.
[56] Calculated based on the 2019 IEA data and the incremental data of geothermal heat pump shipments in 2020.
[57] U.S. Energy Information Administration2019b. "Electric Power Annual 2020." U.S. Energy Information Administration. .
[58] Estimated Country Potential, Oak Ridge National Laboratory presented March 28, 2018 at International Ground Source Heat Pump Association Conference, Orlando, FL
[59] Estimated total for 30 GWe undiscovered hydrothermal resources per the United States Geologic Survey plus an estimated 500 GWe EGS potential per the Massachusetts Institute of Technology.

The FORGE site focuses on EGS, or humanmade geothermal reservoirs. A recent video on FORGE Utah is available here.

FORGE supports GTO's vision for widespread EGS deployment by serving as a laboratory where scientists and researchers can learn how to reproducibly engineer these humanmade systems. Through work performed at FORGE, the geothermal community is gaining a fundamental understanding of the key mechanisms to enable EGS.

In 2021, the Utah FORGE team successfully completed drilling of its first highly deviated deep well—60 days ahead of schedule. The team drilled the upper part of the well vertically through approximately 4,700 feet of sediments before penetrating high-strength, crystalline granite. At 6,000 ft, the well was deviated at a 65° angle from vertical. The angle was maintained for the remainder of the trajectory, through the well's true vertical depth of 8,559 feet. With this well successfully completed, Utah FORGE can run tests to determine stress conditions and monitor microseismicity, as well as tests to interpret the orientation and distribution of the existing and induced fractures in the granite, which will form the pathways for water to circulate and heat up in the newly created EGS reservoir.

In 2021, FORGE also announced selections for its initial research and development (R&D) solicitation (2020-1), funding up to $46 million for new and innovative EGS tools and techniques that support reservoir characterization, creation, and sustainability. FORGE selected 17 projects to research five topic areas:

- Topic 1: Devices suitable for sectional (zonal) isolation along both cased and open-hole wellbores under geothermal conditions
- Topic 2: Estimation of stress parameters
- Topic 3: Field-scale characterization of reservoir stimulation and evolution over time, including thermal, hydrological mechanical, and chemical (THMC) effects
- Topic 4: Stimulation and configuration of the well(s) at Utah FORGE
- Topic 5: Integrated laboratory and modeling studies of the interactions among THMC processes.

### 21.5.2 EGS Collab

Launched in 2017, EGS Collab is a multi-national-laboratory initiative that serves as an intermediate-scale field site where geothermal reservoir modelling and research is validating against controlled, small-scale, *in-situ* experiments on rock fracture behavior and permeability enhancement. Led by Lawrence Berkeley National Laboratory, the project focuses on subsurface process modelling, geophysical monitoring, and experimentation. Collab research acts as a bridge between small laboratory-scale mechanics studies and the large field-scale research at FORGE.

GTO continued funding the EGS Collab effort through 2021. The team worked on experiment 2 throughout 2021, with a focus on further design, execution, and monitoring of hydraulic shearing of fractures and associated predictive modelling.

The location for Experiment 2, which targets the stimulation of existing fractures, was moved in 2020 to a location at the 4,100-foot level. Working with the Sanford Underground Research Facility (South Dakota), the Collab team refurbished this location and modified it with a small amount of additional excavation.

The Collab project has been prolific in disseminating information. An informative and up-to-date Wiki has been developed, and more than 120 papers, reports, and presentations have originated via Collab (URL to Wiki).

### 21.5.3 Wells of Opportunity

In June 2021, GTO released a new Funding Opportunity Announcement (FOA) for up to $14.5 million to support active field testing of enhanced geothermal systems (EGS) technologies and techniques within existing wells. EGS, like all geothermal resources, supplies secure, resilient renewable electricity and heating and cooling that is always-available regardless of weather, and with a small environmental footprint.

The Wells of Opportunity 2021 FOA, solicited the partnership of well owners or operators to help cost-effectively bring more geothermal power online using their existing wells.: The Wells of Opportunity 2021 FOA builds upon the progress of the initial Wells of Opportunity FOA, released in February 2020, by focusing on two topic areas:

- Topic Area 1 – Amplify: EGS Near-Field RD&D: This field validation effort will result in new power production, making existing geothermal fields more economical to operate. The goal of Amplify is to illustrate that near-field and in-field enhanced geothermal systems can be successfully deployed now.
- Topic Area 2 – ReAmplify: Geothermal Production from Hydrocarbon Wells: This effort seeks to establish the commercial viability of geothermal energy production from hydrocarbon wells that might provide access to otherwise untapped geothermal potential.

### 21.5.4 Zonal Isolation

In 2018, GTO awarded funding to four projects seeking to improve zonal isolation, which—if successful—could dramatically improve the performance and economics of EGS. Zonal isolation technologies create extensive and optimized fracture networks by targeting stimulation activities to specific zones efficiently and predictably. This targeting reduces costs and risks associated with EGS development and operation, and facilitates increased power generation from fewer wellbores.

In 2021, the projects continued to develop prototypes and prepare for field testing, with aims to reduce risk to wellbore integrity and fracture conductivity and to develop tools that can operate extensively at high temperatures and in varying pressures and corrosive, hard rock environments.

### 21.5.5 Hidden Geothermal Systems

GTO's work in hidden systems exploration seeks to accelerate discoveries of new, commercially viable hidden geothermal systems, particularly in the Great Basin Region (GBR) of the western United States. Work in this effort spans multiple methods, including play fairway analysis, machine learning, advanced geostatistics, and conductive surveys. This work is intended to create a comprehensive guide and predictive geothermal maps that can ultimately reduce the costs and risks associated with geothermal exploration.

Hidden systems projects include GTO's INnovative Geothermal Exploration through Novel Investigations Of Undiscovered Systems (INGENIOUS) and Basin & Range Investigations for Developing Geothermal Energy (BRIDGE). In 2021, research teams gathered data, conducting HeliTEM surveys, and started work on conceptual models.

In 2020, GTO launched its Geoscience Data Acquisition for Western Nevada initiative (GeoDAWN), which acquired datasets in the Walker Lane geologic zone in Nevada and applied innovative machine learning to find ways to characterize the subsurface. Building on the success of GeoDAWN, in 2021, GTO initiated GeoFlight—a partnership with the U.S. Geological Survey that is using specially equipped, low-flying aircraft to survey the Salton Sea region in California. The surface and near-surface geologic data collected in GeoFlight will help identify new geothermal energy prospects and areas of highest potential for mineral recovery, especially lithium

### 21.5.6 Deep Direct-Use and Thermal Energy Storage

Deep direct-use (DDU) systems are an emerging technology area in the geothermal sector that draw on lower temperature geothermal resources for direct use applications. In 2017, GTO launched feasibility studies at six sites across the country. These comprehensive studies included initial site selection, resource assessment, and feasibility analysis of DDU geothermal technology, in hopes of identifying locations where DDU installations could help address net-zero energy demand. The projects were completed in 2020. In 2021 (at the end of fiscal year 2020), the National Renewable Energy Laboratory completed a retrospective report of the studies.

In 2021, work on two feasibility study sites continued—Cornell University, which is proceeding with a drilling and stimulation coupled with existing surface infrastructure to directly test the concepts from their DDU study on campus; and West Virginia University, where plans are to drill an exploratory well with a full logging and coring program to develop the low-temperature geothermal resource beneath the campus and evaluate shallow reservoirs for energy storage.

## 21.6 Research Priorities

Using the *GeoVision* roadmap as a guide, GTO has established a key priority for the next 8–10 years: To demonstrate geothermal energy's value as the baseload renewable of the future in the United States. This overarching priority is supported by three objectives:

1) **Unlock the potential of enhanced geothermal systems**: Ensure that engineered reservoirs—created where there is hot rock but little to no natural permeability or fluid saturation present in the subsurface—become commercially viable.

2) **Increase geothermal energy on the U.S. electricity grid**: Reduce risks and costs of all aspects of geothermal energy, including exploration, drilling, and deployment, to make geothermal energy an ever-more attractive piece of the energy portfolio.

3) **Expand geothermal energy opportunities throughout the United States:** Increase deployable technology and awareness of deep EGS, geothermal heat pumps, district heating, and thermal energy storage across the entire country.

## 21.7 Other National Activities

### 21.7.1 Geothermal Education

GTO's 2021 Geothermal Collegiate Competition (GCC) focused on community geothermal, specifically addressing the question on how direct-use geothermal can benefit the local community. The competition drew outstanding entries from student teams across the United States. These entries directly support geothermal R&D and are valuable in gauging and developing future R&D initiatives. The goal of the GCC is to provide students with an on-ramp to the renewable energy field and opportunities to engage with established industry professionals as well as their local communities.

The Spring 2021 GCC challenged students from across the United States to design direct-use concepts leveraging geothermal energy to heat and cool buildings, campuses, districts, or entire communities. Participating students gained valuable project development, design, and communications skills while increasing public understanding of geothermal power as a direct, renewable source of energy. Students conceived a use case, performed a resource assessment and usage evaluation, and created a plan and materials for engaging community stakeholders.

Students from the University of North Dakota and Reykjavik University won the first-place prize for their prospectus on gas well recompletion for geothermal district energy in Mandaree, North Dakota. The project generates heat, food, and jobs through integration of a direct-heated greenhouse. The second-place prize went to the University of Oklahoma Sooners Geothermal Team, and the third-place winners were the Earth Source Heat team from Cornell University.

### 21.7.2 Conferences

GTO Acting Director Lauren Boyd and GTO-funded principal investigators participated in Stanford University's 46$^{th}$ geothermal workshop. This annual conference convenes engineers, scientists, and industry involved in geothermal reservoir studies and developments; provides a forum for exchanging ideas on the exploration, development, and use of geothermal resources; and enables timely and open reporting of progress. Stanford made the 46$^{th}$ conference entirely virtual because of the COVID-19 pandemic.

GTO provided a keynote plenary and led or participated in multiple technical sessions at the Geothermal Rising 2021 Conference. The conference is the largest annual gathering of the geothermal community, convening industry, academia, government, and the public.

GTO continues to expand outreach and stakeholder engagement by presenting R&D overviews or participating in various events. In 2021, this included the National Academies of Science Committee on Earth Resources Career Forum, the Strategic Environmental Research and Development Program and Environmental Security Technology Certification Program Symposium, the Symposium on the Application of Geophysics to Engineering and Environmental Problems, the American Rock Mechanics Association Symposium, and the 10$^{th}$ International Congress on Sustainability Science and Engineering.

### 21.7.3 Useful Websites

***Department of Energy Sites***

DOE: energy.gov

DOE's EERE (Office of Energy Efficiency and Renewable Energy): energy.gov/eere/office-energy-efficiency-renewable-energy

DOE's Grid Modernization Initiative: energy.gov/grid-modernization-initiative

FORGE: energy.gov/forge

GTO: energy.gov/eere/geothermal

GTO's Lithium StoryMap: https://www.energy.gov/eere/geothermal/lithium-storymap

*GeoVision* analysis and report: energy.gov/geovision

***Useful External Sites***

American Geophysical Union: www.agu.org

Geothermal Rising: www.geothermal.org

Stanford University Geothermal: geothermal.stanford.edu

U.S. Geological Survey - Geothermal Publications:
energy.usgs.gov/OtherEnergy/Geothermal.aspx

## 21.8 Future Activity

**Community Geothermal** – GTO intends to open an initiative to fund competitively selected geographic coalitions to implement geothermal district energy systems through installation of geothermal heat pumps and/or direct use.

**Drilling Demonstrations** – In 2022, GTO anticipates a drilling technology demonstration initiative to enable field demonstration that can quantifiably demonstrate technology driven drilling cost reductions in geothermal well development.

**EGS Collab** – Work will continue on stimulation and flow experiments in highly monitored and well characterized intermediate-scale (~10-20 m) field test beds.

**Energy Storage** – GTO will continue funding geothermal advanced energy storage research. The office will fund research into geothermal applications and conditions suitable for subsurface storage.

**Federal Geothermal Partnerships** – GTO and the Federal Energy Management Program will launch a new initiative to make it possible for federal agencies to consider geothermal energy to heat/cool (and in some limited cases, potentially power) their installations. The initiative will fund feasibility, research, and characterization activities in FY 2022.

**FORGE** – In 2022, GTO will continue its support for the next R&D solicitation to take advantage of the momentum at the FORGE site and provide additional technological progress toward ensuring EGS viability in the commercial space FORGE is expected to release Solicitation 2022-2 (see previous section for details).

**GeoDAWN** – Continue to gather data in the Walker Lane region of Nevada, with ongoing updates and results announced during the year.

**Geothermal Energy from Demonstrated Oil and gas Engineering** – GTO's 2022 activities will include work to support a new consortium designed to leverage oil & gas subsurface assets, technologies, and expertise to help address barriers to expanding geothermal energy deployment.

**Geothermal Lithium Extraction Prize** – Launched in early 2021, this $4 million prize competition seeks to advance technologies that improve the economics and lessen environmental impacts of lithium mining from geothermal brines. GTO expects to announce Phase 2 winners in 2022, opening the third and final phase of the prize.

**Geothermal Manufacturing Prize** – Supported by the GTO in conjunction with EERE's Advanced Manufacturing Office, the Geothermal Manufacturing Prize is a series of four progressive competitions to harness the rapid advances that additive manufacturing can provide in tool design and functionality. In 2022, GTO expects to announce finalists in Stage 3 of the prize—the Make! stage—as they progress to the final stage, called Geo! GTO anticipates selecting final winners in mid- to late 2022.

**Machine Learning** – GTO will continue research to apply machine learning techniques to geological, geophysical, geochemical, borehole, and other relevant datasets, with the goal of finding new resources and improving operations. Machine learning R&D includes datasets gathered through GeoDAWN.

**Wells of Opportunity** – GTO will continue to invest in near-field EGS demonstration projects and is expected to also invest in projects to help establish commercial viability of geothermal energy production from existing hydrocarbon fields.

# Appendix 1 – IEA Geothermal Executive Committee

**Chair**

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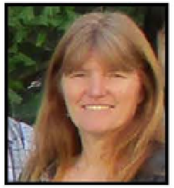
**Vice-Chair**



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# Appendix 2 - IEA Geothermal Members and Alternates

| Country / Name | Delegate | Organization / address | e-mail and phone | | Alternate | Address, etc. (where different) | |
|---|---|---|---|---|---|---|---|
| AUSTRALIA | Barry Goldstein | **Director**<br>**Energy Resources Division**<br>**Department of Premier and Cabinet South Australia (DPC)**<br>Government of South Australia<br>GPO Box 1264<br>Adelaide SA 5001<br>AUSTRALIA | barry.goldstein@sa.gov.au<br>Tel: +61-8-8463-3200 | | Betina Bendall<br>*Vice-Chair* | **Energy Resources Division**<br>**Department of Department of Energy and Mining**<br>Betina.Bendall@sa.gov.au<br>Tel: +61-8-8463-3243 |  |
| EUROPEAN COMMISSION | Matthijs Soede | **Policy Officer**<br>**European Commission**<br>DG Research and Innovation<br>Directorate for Energy<br>Unit G.3 – Renewable Energy Sources<br>Rue du Champs de Mars, 21 (CDMA 00/060)<br>1049 Brussels<br>Belgium | matthijs.soede@ec.europa.eu<br>Tel +32 2 29 58201 |  | Samuel Carrara | **European Commission – Joint Research Centre**<br>Directorate for Energy, Transport and Climate<br>Unit C7 'Knowledge for the Energy Union'<br>Westerduinweg 3, 1755 LE Petten / The Netherlands<br>samuel.carrara@ec.europa.eu<br>Tel: +31 224 56 5118 |  |
| FRANCE | Virginie Schmidle-Bloch | Secretary General<br>French Geothermal Association of Professionals (AFPG)<br>77 rue Claude Bernard<br>750005 Paris<br>France | virginie.schmidle@afpg.asso.fr<br>Tel. +33(0)7 86 58 67 17 |  | Christian Boissavy | **GEODEEP**<br>77 rue Claude Bernard<br>75005 Paris<br>France<br>christian.boissavy@orange.fr<br>Tel: +33 (0)6 38 83 93 52- |  |
| GERMANY | Lothar Wissing<br>*Chair* | **Forschungszentrum Jülich GmbH**<br>Project Management Organization<br>D-52425 Jülich<br>GERMANY | l.wissing@fz-juelich.de<br>Tel: +49-2461-61-48-43 |  | Andreas Koch | **Forschungszentrum Jülich GmbH**<br>an.koch@fz-juelich.de<br>Tel: +49-2461-61-2196 |  |
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| Country / Name | Delegate | Organization / address | e-mail and phone | | Alternate | Address, etc. (where different) | |
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| **NORWAY** | **Jiri Muller**<br>***Vice-Chair*** | **Institute for Energy Technology**<br>P.O. Box 40<br>NO-2027 Kjeller<br>NORWAY | Jiri.Muller@ife.no<br>Tel: +47-6380-6185 |  | Carsten F. Sørlie | **Equinor ASA**<br>Arkitekt Ebbells veg 10, 7053 Ranheim, NORWAY<br>cso@equinor.com<br>(+47) 90961827 |  |
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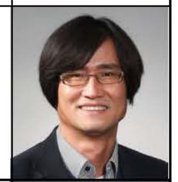
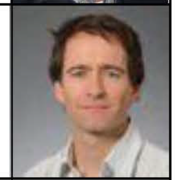
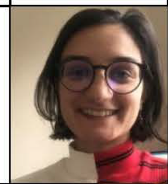
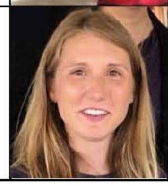
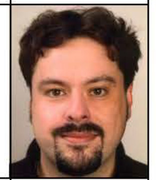
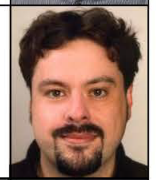
| **REPUBLIC of KOREA** | **Yoonho Song** | **Geothermal Resources Department**<br>**Korea Institute of Geoscience & Mineral Resources (KIGAM)**<br>92 Gwahang-no<br>Yuseong-gu<br>Daejeon 305-350<br>KOREA | song@kigam.re.kr<br>Tel: +82-42-868-3175 |  | Tae Jong Lee | **KIGAM**<br>megi@kigam.re.kr<br>Tel: +82-42-868-3051 |  |
| **SWITZERLAND** | **Valentin Gischig** | **Swiss Federal Office of Energy**<br>3003 Bern,<br>Switzerland. | valentin.gischig@bfe.admin.ch<br>+41 | | Christian Minnig | **Swiss Federal Office of Energy**<br>3003 Bern,<br>Switzerland.<br>email: christian.minnig@bfe.admin.ch<br>Tel. +41 58 467 44 51 |  |
| **UNITED KINGDOM** | **Melanie Jans-Singh** | **Department for Business, Energy & Industrial Strategy**<br>1 Victoria Street, London SW1H 0ET<br>United Kingdom | Melanie.JansSingh@beis.gov.uk<br>Tel: + 44 02072150245 |  | Corinna Abesser | **British Geological Survey**<br>Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK<br>e-mail: cabe@bgs.ac.uk<br>Tel +44 (0)1491 692296 |  |
| **UNITED STATES OF AMERICA** | **Lauren Boyd** | **Program Manager**<br>**Enhanced Geothermal Systems (EGS)**<br>**Office of Energy Efficiency and Renewable Energy**<br>**US Department of Energy**<br>1000 Independence Ave, SW<br>Washington, DC 20585<br>UNITED STATES of AMERICA | Lauren.Boyd@ee.doe.gov<br>Tel: +1- 202-287-1818 |  | To be appointed | - | |

# Appendix 3 - IEA Geothermal Working Group Leaders

| Annex | Descriptive Title | Leader | e-mail and phone | Photo |
|---|---|---|---|---|
| 1 | **Environmental Aspects** | Chris Bromley | c.bromley@gns.cri.nz<br>Tel: +64 7 374-8211 |  |
| 8 | **Direct Use** | Vacant since end July 2020. | | |
| 10 | **Data and Information** | Josef Weber, | Josef.Weber@liag-hannover.de<br>Tel: +49 511 643-3442 |  |
| 12 | **Deep Roots of Geothermal Systems** | Guðni Axelsson | gax@grogtp.is<br>Tel: +35 4 528-1500 |  |
| 13 | **Emerging Geothermal Technologies** | Josef Weber | Josef.Weber@liag-hannover.de<br>Tel: +49 511 643-3442 |  |
| | | Christian Minnig | christian.minnig@bfe.admin.ch<br>Tel. +41 58 467 44 51 |  |

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