BRIEFING

Requested by the ITRE Committee

European Parliament

Innovative technologies in the development of geothermal energy in Europe

KEY FINDINGS

Innovative technologies in the field of geothermal energy focus on three areas: (i) resource assessment, (ii) resource development, and (iii) resource utilisation and management for electricity, heat supply and mineral extraction (lithium). They include increased electric power system efficiency, novel and optimised drilling technologies, underground thermal energy storage, new exploration methods, closed loops, smart systems, and 3D models.

Advanced plants and technologies include ultra-deep geothermal systems, enhanced geothermal systems, advanced geothermal systems, supercritical geothermal systems. They allow access to vast geothermal resources, which would otherwise remain largely unexploited. Advanced geothermal systems have ongoing commercially viable projects in the US and Europe.

Ground source geothermal heating and cooling is a well-established technology, which is currently experiencing the opening of new markets and continuous growth. Geothermal heat pumps are among the most-performant energy-efficient technologies to transfer heat from/to the ground for heating and cooling buildings. Innovation focus here is on new materials and investment costs reduction.

State of play of geothermal technology in Europe

Art 2(3) of the Renewable Energy Directive defines geothermal energy as an 'energy source stored in the form of heat beneath the surface of the solid Earth'.

In both geothermal heat and power production, a heat pump transforms the heat stored under the surface of the earth into heating, cooling and hot water. Depending on its size, the drilling of one to several boreholes allow the exchange of geothermal energy between the ground and the heating system or power plant. In large geothermal heating systems, heat from an underground reservoir of water and hot rocks is directly transported through a distribution network into buildings, or is processed by industries. In geothermal power plants, hot water or steam is used to power a turbine, generating electricity. Geothermal power plants require high temperatures from deep reservoirs to produce electricity.

Temperatures and depths vary considerably according to the different regions and characteristics of the site. Traditionally, the sources of deep geothermal energy were found in favourable geological areas (near to volcanic activity, sedimentary basins). The most widely developed resources are found close to hydrothermal resources, which consist of hot water or steam circulating in deep-seated permeable rocks.

Innovative technologies allow the exploitation of geothermal heat from previously unsuitable areas, such as too deep or shallow reservoirs, sites with low rock permeability, or lacking fluids for heat exchange.

Policy Department for Economic, Scientific and Quality of Life Policies
Author: Matteo CIUCCI
Directorate-General for Internal Policies
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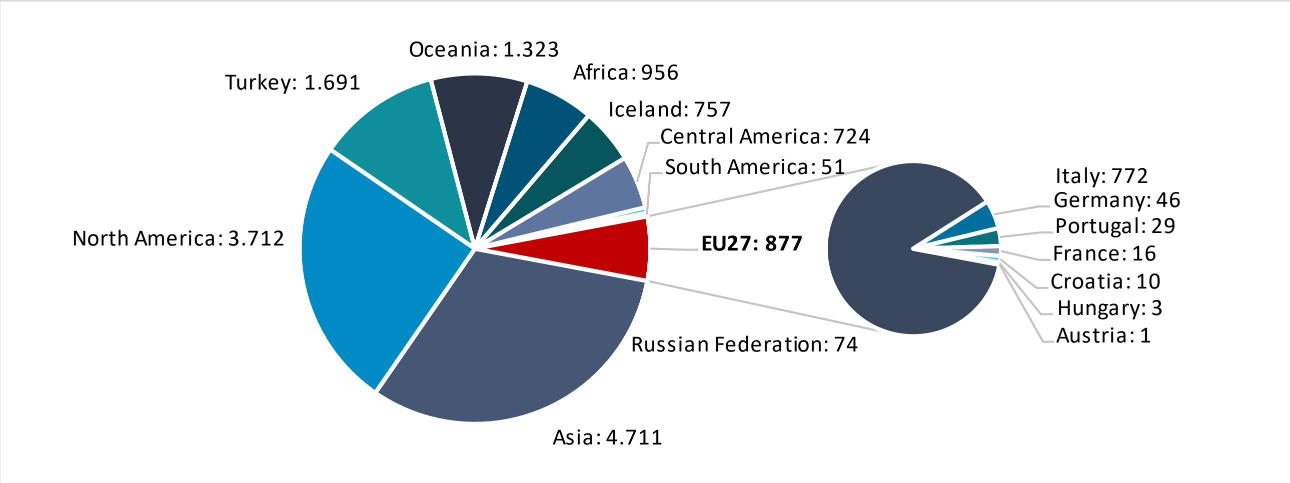
Installed global geothermal capacity has always been limited to favourable areas. In 2022, the global net geothermal installed capacity for electricity generation[1] amounted to 14.9 GW_e, accounting for only 0.5% of global renewable power capacity. In 2021, the EU27 net geothermal capacity for electricity, heating and cooling (H&C) and heat pumps (GHP) was respectively 877 MW_e, 2.15 GW_{th}, and 35.6 GW_{th}, which generated 6.5 GWh of electricity, 3.9 GWh of derived heat and 78 TWh of GHP. The global geothermal employment sector employs 152.000 professionals, representing 1.1% of all renewable energy jobs.

Forecasts on geothermal energy production foresee a strong increase in this sector. According to the IEA Sustainable Development scenario, global geothermal power is expected to triple from 92 TWh in 2019 to 1 282 TWh in 2030, but still remaining less than 1% of global energy demand in 2030. According to EGEC, there are 395 geothermal district heating systems in operation in Europe, of which 261 in the EU27, with 14 new systems in 2022. The capacity under development will double the number of systems before 2030. In 2022, a record of 141,300 new GHP were installed in Europe, out of a total of more than 2.19 million.

Figure 1: Global geothermal installed and connected capacity in 2022 (MW)



Source: Author's own elaboration, based on: Renewable Capacity Statistics 2023, IRENA, 2023; Eurostat [nrg_inf_epcrw].

The Geothermal Implementation Working Group is one of the designated working groups supporting the implementation of the SET Plan, Europe's Strategic Energy Technology Plan. The SET Plan - Geothermal IWG Vision for 2050 envisages a net-zero Europe in 2050, where:

- Geothermal heat supplies more than 25% of EU demand for space H&C, more than 25% in the agricultural sector (greenhouses) and 5% in industrial sectors in the low/medium temperature range.
- 10% of the power production in SET Plan countries is from geothermal power.
- Underground thermal energy storage supplies more than 10% of Europe's demand for space heating mainly for district heating, thus requiring collective systems.
- Co-production of minerals and critical raw materials such as lithium for resilient transportation sector and strategic autonomy is established in at least 10 European regions.

In line with the EU goals on resilience, the IWG aims to increase the resilience of the geothermal energy supply chain and to have 40% of its supply chain 'made in Europe' by 2030.

Geothermal energy by resource temperatures

The temperature and the depth of a geothermal resource define its utilisation mode. While for medium to deep geothermal resources, the temperature of the earth increases with depth at an average rate of 25–30°C per km, for shallow geothermal resources it can be assumed to be approximately constant[2]. Three standard temperature ranges[3] can be identified: low (<90°C), medium (90-150°C) and high (>150°C).

- **Low temperature** (<90°C) geothermal resources are widely distributed geographically. They can be found anywhere in the EU at shallow depth, typically below 300m, to generate low temperature H&C assisted by a heat pump system. Due to their stable temperatures, their heat is mainly extracted using geothermal heat pumps (GHP) for space H&C. In medium to deep sedimentary reservoirs, GHP systems and heat storage (HS) exploit geothermal resources from approximately 300m to 2km at typically overlooked depths, located beyond the usual range of application of GHP and below the usual depth of low enthalpy[4] geothermal systems. Even if mostly used in heat extraction, the high range of low temperature applications (70°C) still allows the production of large-scale H&C systems with existing technology. In deep sedimentary basement reservoirs, geothermal resources at depths of 2–6km are found along fractures and faults in tectonically active areas, or close to sedimentary basins, which can be accessed using drilling techniques of several kilometres, typically 1 to 3km;
- **Medium temperature** (90-150°C) geothermal resources are used for generating electricity and heat for space H&C, industrial processes, and agri-food applications. For electricity, a minimum range of temperatures of 100°C -180°C is usually required, depending on the outdoor air temperature. Combined heat and power installations allow for H&C applications, as well as electricity generation. Utilisation techniques include the use of heat pumps to increase the heat content of low-temperature resources, as well as cascaded applications, where the energy stream in output of an application is used as lower-temperature input in the next energy production step. Deep (>0.5 km) closed loop technologies allow heat extraction by using fluids, which circulate within deep boreholes. These technologies allow access to vast geothermal resources, stored in impermeable deep and compact sediments and hot crystalline rock, which would otherwise remain largely unexploited. The technology can also be applied in non-productive geothermal wells, or for repurposing oil & gas wells; and
- **High-temperature (**>150°C) geothermal resources are mostly found in tectonically and volcanically active areas at depths of a few hundred metres to several kilometres. Unconventional geothermal resources such as super-hot geothermal systems (SHGS>400°C), deep geopressured resources (>200°C) and offshore magmatic resources can contribute to the future growth of geothermal energy.

Geothermal Technologies for energy generation and storage

Table 1: Existing geothermal technologies for energy generation and storage

Technology	Type	Output	Description
Dry Steam power Plant	Generation	Electricity	Wide-spread use
Flash Steam power Plant	Generation	Electricity	Wide-spread use
Binary Cycle power Plant	Generation	Electricity	Low temperature; Closed loop system
Combined Cycle power Plant	Generation	Electricity	Similar to binary cycle; Captures waste heat
Wellhead Generator	Generation	Electricity	Small-scale application
Large scale medium to high temperature	Generation	Heat	Wide-spread use
Geothermal Heat Pumps (GHP)	Generation	Heat	Wide-spread use; Low temperature
Low temperature storage	Storage	Heat	Wide-spread use
High temperature storage	Storage	Heat	Juvenile market

Standard geothermal heat and power installations make use of several existing technologies, which include:

- **Dry steam geothermal power plants** - the oldest type of power plants. They use steam directly coming from the earth to run a turbine and are usually associated with rare natural resources like geysers or steam outbursts. Direct dry steam plants range in size from 8–140 MW;
- **Flash steam geothermal power plants** - the most common type of geothermal power plants globally. In flash steam plants, high temperature and pressure fluids (180°C) are pumped deep underground and forced to return into a low-pressure tank at earth's surface. The sudden drop in pressure causes some of the fluid to evaporate or 'flash' into steam, which is used to run a turbine. Flash plants range in size from 0.2-80 MW (single flash), 2-110 MW (double flash) or 60-150 MW (triple flash);
- **Binary cycle geothermal plants** - which transfer heat from a primary fluid (water/steam of the heat reservoir) to a secondary or binary fluid with a lower boiling point (e.g., ammonia/water mixtures in Kalina cycles, or hydrocarbons in organic Rankine cycles) in a heat exchanger. The two fluids never come into contact. These plants operate in a temperature range of 100 - 180°C, which, by carefully selecting the secondary fluid, can reach 70 -180 °C. Frequently installed in the EU, binary plants range in size from 0.1-50 MW;
- **Combined cycle or hybrid plants** - which combine power generation with direct uses of waste heat generated by geothermal power production to increase the overall plant efficiency. The temperature cascading of the two stages of a combined plant is the main feature of these plants;
- **Wellhead generator plants** - small (up to 15 MW) modular geothermal power plant units often using steam from a single well. Due to their higher specific heat consumption, they are generally less efficient than standard geothermal power plants. Their quicker return on investment, early electricity generation and lower financial risks make them financially attractive;
- **Large scale H&C plants** - which cover a wide range of applications and scales, such as building heat pumps and district heating (80 - 50°C), bathing and swimming, space, greenhouse (40 - 100°C), aquaculture (20 - 30°C), agri-food (60 - 140°C), industrial (food processing, laundry, pulp and paper, textile, etc.) and other heating. For a review of applications, see Lund and Toth, 2021; and
- **Geothermal heat pumps (GHPs)** - among the most-performant energy-efficient technologies to transfer heat from or to the ground for H&C buildings. As an average GHP transfers 3-6 units of heat for unit of electricity it consumes, its net thermal efficiency is greater than 300%, to be compared with combustion and electric heaters never exceeding 100%.

New Geothermal Energy Technologies

Table 2: Innovative geothermal technologies for energy production and storage

Technology	Type	Output	Description
Ultra Deep Geothermal	Generation	Heat	Potential for higher temperatures (>150 °C)
Enhanced Geothermal System (EGS)	Generation	Heat	Significant energy increase per borehole
Advanced Geothermal System (AGS)	Generation	Heat	Closed-loop system; Low environmental impact
Supercritical Geothermal System	Generation	Heat	Potential for very high temperatures (>350 °C)
Increased electric power system (EPS) efficiency	Generation	Heat	Increased efficiency and reduced cost
Innovative drilling technologies	Generation	All	Lower drilling costs
Underground Thermal Energy Storage (UTES)	Storage	Heat	Seasonal storage of high temperature

Novel technologies, not yet commercially available, allow for the production of geothermal energy from deep-seated or low permeability resources. They include, among others:

- **Ultra deep geothermal systems** - characterised by typical drill depths of more than 5km and extremely high temperatures reaching 500 °C. Under such conditions, water becomes supercritical;
- **Enhanced or engineered geothermal systems (EGS)** - which stimulate geothermal permeability, usually by pumping water or other fluids, such as carbon dioxide, to fracture rock and create an artificial reservoir in geological settings lacking transport fluids or adequate rock permeability;
- **Advanced geothermal systems (AGS)** - which drill well bores with wide areas to create artificial closed-loop circuits where a working fluid is heated by sub-surface rocks. They do not require pre-existing good conditions, such as a natural water reservoir with good permeability, but usually have high drilling costs;
- **Supercritical geothermal systems** - characterised by very high temperatures and water (or other fluids) in supercritical state (at least 374°C and 221 bar). Due to their operating temperatures, they have very high productivity and their operation is technologically challenging (corrosive fluids, etc.);
- **Increased electric power systems** - characterised by optimised designs which take into account the specifics of their energy production cycle with the aim to increase their overall efficiency as an alternative to the development of further resources;
- **Innovative drilling technologies** - characterised by increased drilling and economic efficiency through specific techniques, such as: rotary casing, rock spallation and fusion, water jet erosion, plasma, laser, electron beam, pallets, electric, ultrasonic, chemical, induction, nuclear, forced flame explosive, turbine, high frequency, microwave, heating/cooling stress rock cutting; and
- **Underground thermal energy storage systems (UTES)** - which seasonally store heat and cold into the ground in boreholes, aquifers, caverns or pits, using water as storage medium. These systems are usually for low temperature building applications, i.e., below water boiling temperature. While borehole and aquifer heat storage is commercial, cavern energy storage is rarely applied.

In addition to the previous techniques, novel geothermal technologies also include new approaches for resource development, enhanced energy integration in energy systems, new materials and equipment for smart plant operation, demonstrations of mineral (lithium) production and exploitation.

Benefits of geothermal energy

The benefits of geothermal energy are several. Geothermal power plants produce steady baseload power, which is independent from weather and fuel costs and can contribute to the stabilisation of the European power grid. They have the highest capacity factor among renewables (80%), and can provide electricity, heat, and mineral extraction. In power production, they produce low greenhouse gas emissions (11.3 g of CO_2/kWh)[5]; in heat production, geothermal systems are scalable, have low operating costs, and allow direct use of heat. Geothermal power plants have low resource utilisation, with lower land (around 7.5 km^2/TWh) and water consumption (0.66 litres/kWh) than solar and wind. If properly managed, they have long lifetimes of more than 50 years. The potential of geothermal energy is untapped, with ample room for market growth, even using existing technologies. Synergies can be obtained from the intervention of the oil and gas industry, where existing wells can be adapted to extract geothermal energy at reduced costs. Demonstration projects for mineral (i.e. lithium, silica) recovery from geothermal brines have intensified in recent years. Synergies with green hydrogen production already exist in Iceland and New Zealand. Potential benefits of geothermal energy include the expansion and interconnection of regional electricity grids, the increase of synergies with green hydrogen production, efficiency improvements in electricity production from medium-temperature resources, acceleration in the use of geothermal heat pumps and advanced district heating technology, and expansion of geothermal heat in agriculture, food processing and industry.

Ways to expand the sector include leveraging oil and gas expertise and technology to improve geothermal development and R&D improvements in enhanced, advanced and supercritical geothermal systems.

Challenges in geothermal technology

The challenges of geothermal plants are mostly linked to their intrinsic thermodynamic limitations[6], high exploration and long development costs. In addition, geothermal electricity is still a niche market: with a global geothermal capacity of only 0.5% of all renewable capacity, its contribution to power grid stabilisation can be mainly complementary or local.

Geothermal large scale projects have long project development timelines, require high upfront capital expenditures, face risks during their initial exploration phases, and lack sufficient data and tools for mapping geothermal resources for H&C, electricity, storage and minerals extraction, such as lithium. Challenges include accessing and securing financing via long-term heat and/or power purchase agreements (PPAs) between the developer and the utilities or parties[7], complex and fragmented regulatory frameworks, long permitting procedures, special technical challenges (remaining geothermal sources being high-hanging fruits), and lack of a qualified workforce. Another challenge is public awareness and acceptance due to limited information on the new technology, and concerns about land use, environmental (i.e. cracks after drilling and pumping water, touristic areas) and social impacts.

Geothermal projects are also in competition with other renewables. The levelised cost of electricity (LCOE) of geothermal plants depends on the specific conditions of the power plant site. In the period 2010-2020, the LCOE of US geothermal generated electricity remained in the range of USD 0.05-0.07/kWh. In 2022, the global LCOE of geothermal ranked third after solar and on-shore wind[8].

Recent global developments in geothermal energy

A 2019 report disseminated by the US Department of Energy (DOE) forecasts geothermal energy generation in the US to reach 60 GW_e of installed capacity by 2050, with the greatest growth potential provided by deep EGSs. Released in June 2022, China's 14th Five-Year Plan for Renewable Energy promotes geothermal energy and highlights the optimisation of geothermal H&C deployment. In Africa, Kenya[9], one of the global top ten geothermal electricity-producing countries, foresees to almost double its geothermal electricity capacity to 1.6 GW_e, by 2030.

In Europe, the International Energy Agency (IEA) highlighted geothermal heat pumps (GHPs) as the most cost-effective renewable solution for heating[10]. In April 2022, 150 economic operators in geothermal energy called on the European Commission to prepare a European strategy for the development of geothermal energy and mineral extraction.

The EU supports research and development in geothermal technologies, funding projects on direct use of heat and electricity generation via several EU funds, including Horizon Europe, the Innovation Fund, and Interreg 2021-2027. The European Parliament's ITRE Committee is currently drafting an own-initiative report on geothermal energy (2023/2111(INI)) to be voted in December 2023. Several EU countries (Poland, France, the Netherlands, Ireland and Germany) published national geothermal roadmaps.

Enhanced geothermal systems

The main goal of both enhanced geothermal systems (EGS) and advanced geothermal systems (AGS) is an increase in productivity, and energy extraction of low permeability rocks.

EGS systems, which are based on production stimulation, inject water and small amounts of chemicals at high pressure to create or re-open fractures in the deep rock. To prevent the closing of fractures when the pressure is reduced, special solid materials, such as sand and ceramics, are added. Several EGS projects have been developed in Germany, France, Iceland, Austria, Switzerland and Italy. In 2009, as a result of hydraulic stimulation (fracking), a magnitude 3.4 earthquake in Basel, Switzerland led to the closure of the EGS plant. In November 2017, as a result of a geothermal hydraulic stimulation (fracking), a magnitude 5.5 earthquake, the largest caused by an EGS, occurred in the vicinity of the EGS plant in Pohang, Korea, highlighting the challenge of induced seismicity from EGS projects. In 2022, the EGEC Geothermal Market Report 2021 found the scale-up of EGS technology difficult in Europe.

Advanced geothermal systems

AGS systems, on the other hand, create an underground heat exchanger by only using drilling techniques (without fracking). According to IRENA, AGS systems are '*deep, large, artificial closed-loop circuits in which a working fluid is circulated and heated by sub-surface rocks through conductive heat transfer*'. Advanced reservoirs allow the development of high enthalpy resources, including super-critical geothermal systems, offshore magmatic resources, and abandoned or end-of-life time hydrocarbon reservoirs. The closed-loop solutions primarily aim to extract heat through heat conduction at the borehole-rock interface. In 2019, a large-scale closed-loop demonstrator prototype was built in Alberta, Canada. In 2022, two commercial AGS projects were under development in the US and Europe and one was being considered in the Eastern Caribbean.

Geothermal heating and cooling: district heating and heat pumps

Geothermal H&C is a form of direct utilisation of geothermal heat. Its major applications are in space H&C, agriculture and food processing, industrial process heat, health, recreation and tourism. Iceland is a world leader in the use of heat for H&C applications, with 85% of the buildings heated with geothermal energy.

The global top countries for installed geothermal energy capacity for H&C, including GHP are: China (40.6 GW_{th}), the US (20.7 GW_{th}), Germany (4.8 GW_{th}), Turkey, (3.5 GW_{th}), France (2.6 GW_{th}), Japan (2.5 GW_{th}), Iceland (2.4 GW_{th}), Finland (2.3 GW_{th}) and Switzerland (2.2 GW_{th}). GHPs represent a large share of H&C installed capacity in Finland and Sweden (100%), Switzerland (99%), the US (98%), Germany (92%), France (78%), China (65%), Lund and Toth, 2021. More than 50% of the new 2021 projects were in the H&C sector.

District heating networks supply hot water to residential and commercial buildings on a large scale. Technological advances have enabled the use of natural or artificial low-temperature (less than 50°C) heat sources, including with the support of large heat pumps.

Recent technological developments include fourth generation district heating systems, which supply heat to low-energy buildings via low-energy losses networks from low-temperature heat sources. Geothermal district heating is largest in Iceland (1.7 GW_{th}), Turkey (1.0 GW_{th}), France (0.5 GW_{th}) and Germany (0.35 GW_{th}). In southern Europe, Turkey (3.5 GW_{th}) is the leader in geothermal H&C (3.5 GW_{th}), Lund and Toth, 2021.

Geothermal heat pumps use is the largest in the US, China, Sweden (shallow closed-loop systems), Germany (deeper wells) and Finland. The largest growth in the installation of geothermal heat pumps in 2021 happened in France (+73%), Austria (+59%), Belgium (+35%) and Germany (+10%). More than 2.19 million geothermal heat pumps are in operation in Europe. Heat pumps can also be used to create geothermal batteries, where heat or cold is artificially stored in the shallow sub-surface in underground thermal energy storage (UTES) systems.

Potential of innovative geothermal technologies

Enhanced geothermal systems (EGS) has yet to be demonstrated as a commercially viable technology. Most of these projects are located in Australia, Europe, Japan, the Philippines and the US. Developments focus on improving permeability via hydraulic, chemical and thermal stimulation. Technical challenges includes well architectures, stimulation techniques, use of 3D numerical models, sustainability assurance of fracture opening with respect to unwanted effects.

Advanced geothermal systems (AGS) have yet to be demonstrated as a commercially viable technology. The first commercial-scale implementation is the EAVOR-LOOP project in Germany.

AGS can be applied to geothermal reservoirs with sufficient temperatures and low permeability. It carries low risks of leaks into surrounding aquifers, as wellbores are sealed, and produces no carbon emissions, as its closed-loop by design. AGS developments include reduction of drilling costs and research in innovative working fluids.

Supercritical geothermal resources, with temperatures above 374°C under high pressure, exist in volcanic areas: Iceland, Italy, Japan, Kenya, Mexico and the US. The use of these resources has higher thermodynamic efficiency, but they face corrosion, technical, permeability, drilling and well completion challenges.

Faster rollout of existing technologies

Direct utilisation of geothermal fluids for geothermal H&C, especially from shallow heat and low/medium temperature sources, is a well-established technology that is currently experiencing increasing growth, with the opening of new markets. This trend is particularly strong for low temperature geothermal sources. More than 25% of Europe's population lives in areas suitable for geothermal district heating.

Geothermal heat pumps experienced a yearly growth of the global GHP market of 10 to 11% between 2010 and 2020. In 2020, 72% of geothermal H&C was from geothermal heat pumps, with an installed capacity of 77.5 GW_{th} Lund and Toth, 2021 . EU top countries by installed capacity were: Sweden (6.7 GW_{th}), Germany (4.4 GW_{th}) and Finland (2.3 GW_{th}). In Europe, the GHP industry is expected to continue growing (IRENA, 2023).

The EAVOR-LOOP project

In November 2023, the EU's Innovation Fund awarded a grant of EUR 91.6 million to the EAVOR-LOOP project, realised by the company Eavor Erdwärme Geretsried GmbH in Geretsried, Germany.

The AGS project, the first commercial-scale implementation of the innovative EAVOR-LOOP geothermal technology, aims to create a large underground radiator at a depth of 4.5km consisting of four closed loops. In 2019, a proof-of-concept demonstrator, EAVOR-LITE, was constructed at a depth of 2.5km, in Alberta, Canada. In 2022, two commercial projects were under development in the US and Europe.

The EAVOR-LOOP technology is scalable and can be operated in dispatchable or load-following mode: energy can be stored in the sub-surface and strategically extracted to produce peak energy when required. The new innovative system does not require an external aquifer and operates via the thermosiphon effect, where temperature differences between the upper and lower parts of the working fluid induce circulation without pumps. In the radiator loops, fresh water will circulate carrying the heat to surface. The thermal energy produced will be converted to electrical energy with a conventional Organic Rankine Cycle and to heat for direct use in district heating.

The total installed capacity of 60 MW_{th} or 8.2 MW_e, will result in a reduction of 44,000 tCO_2e GHG emissions per year. The 30-year life cycle project is subsidised under German EEG law by a fixed power price of EUR 227/MWh until 2042 and the plan is to complete it in late 2026. For more information, see the evidence submitted by Eavor Technologies, Inc. to the UK Parliament, 2022.

Source: author's own elaboration based on European Innovation Fund, Eavor and UK Parliament, 2023.

The HUNOSA Project

The HUNOSA project repurposes an old coal mine into a geothermal heat network using water from the Barredo well in the coal region in transition of Asturia, Spain. The project, which was initially proposed to tackle the economic costs derived from the maintenance of water-pumping activities in non-active wells, has transformed an old coal colliery into the largest geothermal district heating in Spain.

The project, realised by the company HUNOSA, was developed in two phases. In the first phase (2006-2016), three geothermal facilities with a capacity of 4 MW_t have been installed to supply H&C to a hospital, three university buildings, a secondary school, two residential buildings and the headquarter of a foundation. The second phase, which started at the end of 2018, will add 2 MW_t to supply three additional large buildings for a total capacity of 6 MW_t. The project was awarded a grant from the European Regional Development Fund (ERDF) of around EUR 0.5 million for an estimated investment of over EUR 1.4 million.

The ITRE Committee draft own-initiative report on geothermal energy (2023/2111(INI)) highlights the role of geothermal projects for the repurposing of decommissioned fossil fuel infrastructure (coal mines, gas and oil wells, and oil reservoirs), where applied cavern thermal energy storage technology is able to provide heating or cooling.

Source: author's own elaboration based on European Commission, 2021.

Annex: Deep Geothermal Power and Heat SWOT analysis

Strengths	Weaknesses
• Large potential resource in the EU Dispatchable power and high capacity factor (80%) • Sector coupling with large-scale underground thermal storage • Extensive EU manufacturing base for below-ground and above ground equipment • Can supply the DHC networks • Established EU R&I • Positive trade balance in services and equipment • Significant local employment	• High CAPEX persists • Licensing delays • Seismic concerns • High-quality resources only available in some EU countries • Availability of drilling expertise and equipment dependent on the oil/gas industry and oil/gas prices

Opportunities	Threats
• Enhanced geothermal systems with higher temperatures and efficiencies • Recovery of lithium and other critical materials from geothermal brines • Export of services and equipment • More exploitable resources with better technology and expertise • Emergence of the EU heat market (as opposed to a gas market) • EC policies for accelerated licencing for renewables	• Low/subsidised fossil fuel prices • Low social acceptance • Competition from other technologies investments in the EU, in particular wind and solar for power generation • Shortage of expertise and skills at all levels • Reduced R&I funding

Source: European Commission - DG JRC, October 2023.

Main References

- EGEC, Geothermal Market Report 2021, Brussels, June 2022.
- EGEC, Geothermal Market Report 2022, Brussels, June 2023.
- EC, JRC, Deep Geothermal Heat and Power in the European Union, Luxembourg, October 2023.
- IRENA, Global Geothermal Market and Technology Assessment, Abu Dhabi, February 2023.
- IRENA , Geothermal Power Technology Brief, September 2017.
- IRENA, Renewable Capacity Statistics 2023, Abu Dhabi, April 2023.
- IRENA, Renewable Energy Statistics 2023, Abu Dhabi, July 2023.
- J. W. Lund and A. N. Toth, Direct Utilization of Geothermal Energy 2020 Worldwide Review, Geothermics, Vol 90, February 2021.
- M. J. B. Kabeyi, O. A. Olanrewaju, Central versus wellhead power plants in geothermal grid electricity generation, Energy, Sustainability and Society, 11, 7, 2021.
- GeoVision, Harnessing the Heat Beneath Our Feet, Department of Energy, United States, 2019.

[1] Geothermal capacity for electricity generation is net capacity, i.e. the maximum generating capacity of power plants and installations, which produce electricity from geothermal sources. For most countries and technologies, it is the capacity installed and connected at the end of the calendar year.

[2] In central Europe, the temperature at a depth of 20 metres is approximately constant and equal to 10 °C.

[3] All temperature thresholds are somehow the result of a schematic convention; the medium/high temperature threshold is in the interval 135-150 °C, depending on chosen reference. In this document, a medium/high temperature threshold of 150°C is assumed.

[4] The enthalpy of a system (H) is the sum of its internal energy (U) and of the product of its pressure (P) and volume (V): H = U + PV.

[5] Values estimated for geothermal binary electricity plants with 100% reinjection; for a complete review, see T. Fridriksson et al., World Bank, 2017.

[6] As a result of to their lower working temperatures, geothermal power plants with source temperatures in the range 90-300 °C are less efficient than conventional (gas-fired) power plants with steam temperatures around 550 °C (Lund, Chiasson, 2007). This argument, which is thermodynamically undisputable (see Carnot's theoretical maximum efficiency of heat engines), becomes less constraining for all systems where the ultimate aim is the extraction of heat for standard applications (H&C), rather than the most-efficient way of heat extraction.

[7] In countries with deregulated electricity markets, geothermal energy PPAs cannot compete against lower-cost solar and wind PPAs.

[8] An approach exclusively based on LCOE doesn't take into account all non-price system benefits of a baseload technology such as geothermal.

[9] In 2019, installed geothermal electricity capacity and consumption in Kenya were 29% and 47% of the total, respectively.

[10] The conclusions of the analysis applied to both geothermal heat pumps and fossil gas boilers. As only data up to 2019 was used, the consequences of the extremely high gas prices were not taken into account.

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Administrator responsible: Matteo CIUCCI Editorial assistant: Irene VERNACOTOLA

Contact: Poldep-Economy-Science@ep.europa.eu

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