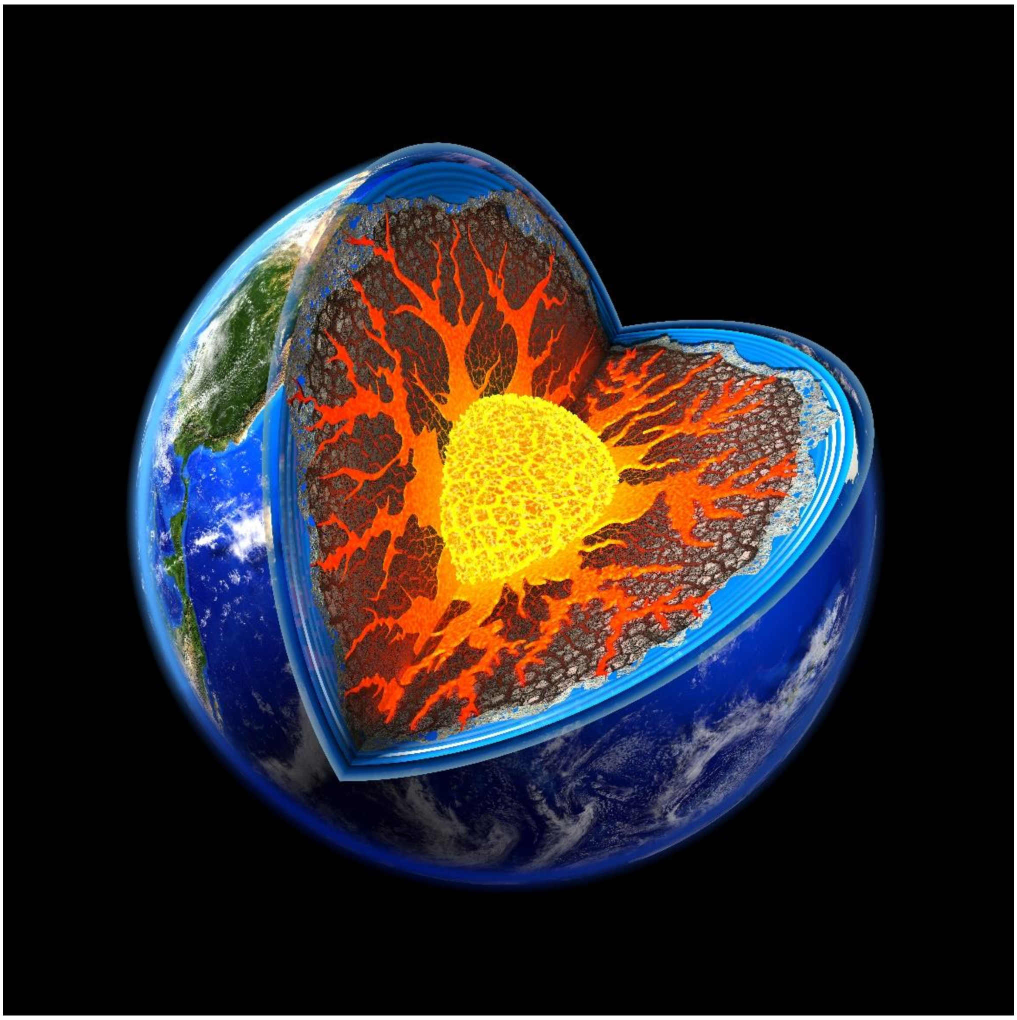
Geothermal Energy: Heating Up

A Renewed Interest in Energy from the Earth

Industry Background From Longspur Research



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GEOTHERMAL ENERGY

Industry background research available to all professional investors under MiFID II as a minor non-monetary benefit

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Enel Spa

Contact Energy Ltd

First Gen Corporation

Kenya Electricity Generating

Nextera Energy Inc

Polaris Renewable Energy

**Longspur Research client*

GEOTHERMAL ENERGY: HEATING UP

Geothermal energy is beginning to attract new investors to the space with a combination of emerging technologies and an increasing recognition of the ability of geothermal energy to provide predictably priced, long-term, low-carbon heating and power. Investors have historically been put off by the high upfront capital cost of geothermal projects relative to the perceived risks of development, however, with an improved understanding of the risks (combined with improvements in mitigation available), attention is now turning to the sector. There have been steps to increase policy support, notably in the EU, and more targeted support, commensurate with other renewable technologies would accelerate the next stage of growth for the sector.

A Competitive, Low Carbon Energy Solution

From a levelized cost of electricity perspective, geothermal energy can compare favourably with other renewable energy technologies in given scenarios whilst also having the upside of being dispatchable. Geothermal heating applications are perhaps even more attractive, with geothermal heating having higher coefficient of performance than many low-carbon alternatives, making this an energy-efficient and potentially low-priced solution for decarbonising heating, which remains a complex area of decarbonisation. This is combined with low lifecycle emissions, making geothermal energy attractive from, both, an economics and emissions perspective against both its renewable peers and fossil fuels.

Significant Increases in Investment Volumes

Geothermal energy features in all net zero scenarios, however, there needs to be a material increase in overall investment into the sector. WoodMac estimates $60bn of annual investments could be needed by 2050 under a net zero scenario for geothermal power and heat. 2023 saw record inflows into the sector, with nearly $8bn of investments, primarily funding new and developing technologies in the space and 2024 is believed to have continued the trend of elevated investment. This is combined with continued growth in conventional geothermal deployments as recognition grows that geothermal can help to decarbonise heating and power whilst delivering positive returns for investors.

Policy Changes Proven to Stimulate Growth

In general, the sector has been overlooked from a policy perspective, however, examples in Europe have shown that with the right kind of targeted support (both from a financial and regulatory perspective) that rapid development can be made to drive the industry forward.

Where to Find Exposure

There remains limited pure-play geothermal public equity exposure globally, with Ormat (ORA US) only truly fitting the bill, with most other geothermal operators being diversified utilities with a smaller geothermal exposure. We hope to see an increasing number of publicly listed equities with geothermal exposure moving forward, particularly as initiatives from existing oil and gas companies, such as Star Energy (STAR LN), look to leverage their existing skill sets into geothermal energy as part of the energy transition.

Industry background from Longspur Research

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GEOTHERMAL ENERGY: HEATING UP

The Holy Grail of Low Carbon AND, Baseload Energy

Geothermal energy can be used to provide clean, consistent dispatchable power when high-temperature aquifers can be accessed. High-temperature resources (140C+) are more geographically sparse, however when found and developed, they can provide a significant source of clean power. Given the increased focus on energy security globally and growing demand from data centre operators, we expect geothermal power generation demand will increase significantly. We see emerging jurisdictions like Poland, Croatia and Hungary, where there is both resource and a demand for clean power and increased energy security, as potential growth regions for geothermal power developments.

Geothermal Now Recognised as a Heating Decarbonising Tool

We see geothermal as having an important role to play in decarbonising heating. Whilst electrification will likely play a leading role in this space, there will be a need for alternative solutions where electrified solutions like heat pumps are not feasible or where grid constraints make this difficult. There is already an extensive history of district heating networks powered by geothermal energy in the EU and renewed policy is supporting a second wave of growth in the industry. The UK has been slower to follow due to the historic availability of cheap fossil fuels, but with a new focus on net zero under the Labour government, growth in this space could be strong. Rystad estimates the UK could see a cumulative growth of 13% in geothermal heating towards 2030 and with ARUP estimating £1.5bn of annual investment in UK geothermal required for the UK to meet its geothermal potential. The Green Heat Network Fund and Market Framework from 2022 combined with the expected Heat Network zoning in 2025 ought to drive this in the short term.

Record Investments into the Geothermal Sector

The volume of investments in both absolute and nominal terms for geothermal energy has increased significantly in 2023 and we expect to see that continue moving forwards as more attention is placed on the sector. In our view, utility level returns are possible for investors. The continued sticking point for investment into the sector will likely be the high upfront cost required to prove up a resource and the geological risk that comes with this. However, we are seeing progress on this front and developments in hydrothermal resource modelling combined with more geothermal developments across the globe continue to aid in reducing the risk. If combined with reductions in the cost of drilling, as witnessed with shale gas, there could be scope for material improvements to returns for investors. There is demand for long-term heat and power purchase agreements from consumers and if a geothermal project is able to match its power or heat to an offtaker, this can mark an attractive entry point for investors looking for exposure to long-term predictable cash flows. The introduction of additional policy support and guarantees, as has been witnessed in some European countries (discussed further below) could help to materially de-risk the proposition for investors further. The IEA estimates that annual geothermal investment could reach $140bn per annum if cost reductions for existing and next generation geothermal developments can be delivered.

Environmental and Economic Benefits

Whilst there is a clear environmental case for the development of geothermal energy, with its ability to decarbonise heating and power, there is also a wider economic case. From an economic perspective, there are a number of second order economic benefits from geothermal development. Job creation in this sector will directly support the energy transition, with highly skilled workers from the oil and gas industry able to move into this sector. Geothermal energy could also contribute to the wider levelling up agenda in the UK, with there being a high correlation between geothermal potential and economically disadvantaged areas, meaning the development of cheap, low carbon sources of heat and power could support lower living costs in these areas and attract more industry from predictably priced energy.

Economics that Can Deliver Returns for Investors

Beyond the wider economic good, there is a strong investment case for geothermal energy in the UK in its current form. Whilst we see policy support as necessary to turbocharge the sector and improve returns thus making more projects viable, that does not mean that the current landscape makes geothermal developments uneconomic: quite the contrary in fact. Our modelled project economics in this note, show there are attractive returns available for investors today. Unsubsidised returns, where there is cornerstone demand in a heat project are in the low double digits and with the addition of potential subsidies, such as grant funding, these can increase to 20%+ based on our estimates. The development of more support schemes, as we highlight in our policy section below, and falling capex costs over time could increase returns even beyond this.

New Technologies May Further Improve Returns

A number of new technologies, whether that is in well design, drilling techniques or more advanced resource mapping ought to support the deployment of geothermal energy moving forwards, and if leveraged with the existing skills in the oil and gas sector could lead to reductions in upfront capital costs and support improved returns for investors, potentially bringing levelised costs closer to wind and solar. Start-ups in the space have attracted increasing levels of investment over the past year with investors recognising the role that geothermal energy has to play in a net zero outcome and supporting companies that can help enable that. This has been combined with an increase in demand for clean power, particularly data centre derived demand, which is again attracting more capital and interest into the geothermal sector. The IEA in its recently released Future of Geothermal publication has estimated that technology improvements could see geothermal meeting 15% of global electricity demand growth to 2050.

Listed Geothermal Companies

Company	Market Cap (£m)	EV (£m)	Ticker	Description
Star Energy Group Plc*	10	10	STAR LN	Oil and gas transitioning to geothermal
Ormat Technologies Inc	3,314	3,314	ORA US	Pure play geothermal
Enel Spa	58,142	122,851	ENEL IM	Utility with geothermal assets
Contact Energy Ltd	3,449	4,223	CEN NZ	Utility with geothermal assets
First Gen Corporation	872	45	FGEN PM	Utility with geothermal assets
Kenya Electricity Generating	173	765	KEGC KN	Utility with geothermal assets
Nextera Energy Inc	118,843	192,341	NEE US	Utility with geothermal assets
Polaris Renewable Energy	156	179	PIF CN	Renewable developer with geothermal assets
Vulcan Energy Resources Ltd	616	570	VUL AU	Geothermal and lithium extraction

Source: Bloomberg, Longspur Research, *Longspur Research client

GEOTHERMAL INTRODUCTION

Coming from the Greek gê and thermòs, which literally means Heat of the Earth, Geothermal energy is one of the oldest energy sources available in the world today. Heat is constantly transferred from the centre of the earth outwards. Accordingly, the deeper into the earth's crust, the hotter it becomes. For instance in the UK on average the rock temperature increases by about 30°C for every kilometre of depth, whereas in other countries it can be (significantly) higher, e.g. as a result of volcanism. The rate at which the temperature increases with depth is known as the geothermal gradient. This heat can be utilised in a number of ways to generate either heat or electricity.

Conventional Geothermal

Also referred to as "hot wet rock" or hydrothermal. Over time water has and continues to percolate downwards, through natural fractures and fissures. It is trapped underground, captured in porous rocks, forming aquifers, where it is heated by the flow of heat from the Earth's core, or it can proceed to return back to the surface through faults and fractures, appearing at the surface in the form of hot springs and geysers. These reservoirs can also form the energy source for hydrothermal systems with drilled wells taking the place of the faults and fissures, bringing hot water to the surface in direct routes where it may be utilised for geothermal energy production, either for heat or for power.

A geothermal development can be broadly grouped into three stages, these being the pre-drilling works (exploration, pre-feasibility and feasibility stages), drilling and then ongoing operations.

We visit each of these stages in greater detail later in this note but to summarise:

- **Exploration, Pre-Feasibility and Feasibility Stages:**
    - The steps in the process aim to identify geothermal reservoirs for possible exploitation, select the best sites for drilling production and then determine the commercial and technical feasibility of advancing to production.
    - Exploration typically begins with gathering data from existing nearby wells (where available) and other subsurface data, and goes on to surface and sub-surface surveying using geological, geochemical, and geophysical methods.
    - Not every identified project will make it through each of these stages prior to drilling commencing and while this can result in sunk costs generating EBITDA losses in the early stages of development or where capitalised potentially requiring impairment (with both having an impact on earnings volatility), it is critical, however, that these steps are followed to develop a robust, commercially feasible project.

- **Drilling**
    - Geothermal energy relies on the recognised skills and technology developed in the oil and gas industry to drill wells to varying depths to exploit fluid reservoirs.
    - This is the typically most expensive part of the development and the stage with the highest perceived risk, however advances in drilling technologies and skills have increased the ability of developers to mitigate many of the issues that could be experienced.
    - Additional wells drilled on a project with a successful first well have a considerably lower cost and risk profile, significantly lowering the marginal cost of energy supplied when used to meet additional demand.

- **Ongoing Operations**
  - After drilling, a small surface footprint is required for heat projects, typically requiring a space not much larger than a garage to house the well heads and a heat exchanger and, consequently, highly suitable for urban environments. Power projects will be larger than this and vary depending on targeted output but will still have a significantly smaller footprint than other renewable electricity technologies.
  - Water or steam flows up through the well to the surface operation where it is passed through the heat exchanger in a heat project (or powers a turbine in a power application) before the working fluid is distributed across the heat network or power exported to the grid.
  - In many cases, the heat exchanger can be directly connected to a building's existing internal heat distribution networks or a district heating scheme thereby reducing conversion costs and disruption during installation.
  - In almost all modern conventional geothermal developments water that is extracted is re-injected elsewhere in the reservoir.
  - Once constructed, geothermal projects typically operate for 25+ years and in many cases longer, providing low-carbon heat or electricity, with existing geothermal schemes in Germany and France (discussed further below) having been in operation for over 60 years in some cases.

Geothermal energy is a baseload, dispatchable source of energy and therefore does not have the disadvantage of intermittent generation as with other renewables.

Emerging Geothermal Systems (EGS), Advanced Geothermal Systems (AGS) and Alternative Geothermal Applications

We include a discussion on the emerging technologies of EGS, AGS and alternative geothermal applications in Appendix A. These areas are attracting investor attention and will likely continue to generate news flow and ongoing investment but given their relative infancy compared to conventional geothermal developments we do not expect to see widespread deployment of these technologies until they reach nth of a kind deployment readiness, whereas progress on conventional geothermal developments have the potential to meaningfully contribute to the decarbonisation of heat and power in the shorter term. As such the majority of this paper focuses on mainstream geothermal applications in heat and power, predominantly focused on the UK and Europe. Similarly, whilst we discuss the technologies below, deployment of these technologies is still highly dependent on the successful application of skills and knowledge developed by existing geothermal developers and onshore oil and gas operators, with new technologies still reliant on (amongst others) a deep knowledge of the subsurface, drilling skills and the ability to deliver complex projects whilst meeting stringent regulatory requirements.

EGS- whilst there is no set definition for enhanced geothermal systems, MIT have stated it is defined as 'engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or permeability resources'. This can broadly be achieved through the use of chemical, thermal, mechanical or hydraulic stimulation.

AGS- AGS systems create an underground heat exchanger by only using drilling techniques without stimulation. These are typically in the large closed-loop circuits where a working fluid is circulated and heated through conductive heat transfer.

Alternative geothermal applications- there are a number of other geothermal applications that are being looked at, including Underground Thermal Energy Storage and looking at co-producing lithium along with geothermal energy.

GEOTHERMAL ENERGY TODAY

Geothermal energy is typically used for power and generation and heat generation. Both uses have an extensive history, with the first geothermal district heating deployment at Warm Springs in Idaho in 1892 and the first modern geothermal power plant in Italy at Lardarello in 1904. The Warm Springs development is still in use today after initially heating 200 homes and a swimming pool. The deployment of the first geothermal electricity generator which was able to produce 10kW of energy and power five lightbulbs. This was extended and the world's first geothermal power plant was completed in 1913. With a capacity of 250kW, this plant was used to power the Italian railway system and the nearby villages of Lardarello and Volterra. Incremental additions saw the site increase to 34 plants and a total capacity of 800MW where the site continues to operate, displaying the remarkable longevity of the reserve.

In a global context, geothermal power production has traditionally been led by countries such as the USA, the Philippines and Indonesia whilst geothermal heat production has been more the preserve of Europe and China, predominantly driven by the nature of the geothermal resources available for exploitation and the energy and heating demand needs of individual countries.

Geothermal district heating and cooling systems in Europe saw 395 systems operating in 2022, an increase of 14 on the prior year, adding 105MWth of capacity to Europe's renewable heating and cooling tally. At the time of the European Geothermal Energy Council's report, there were a further 316 district heating and cooling projects under active investigation. Germany, France, the Netherlands and Italy represent more developed district heating and cooling markets, with upwards of 50 projects in operation or development in each. Progress is being made in Romania, Austria, Croatia and the UK where there are a number of identified projects for development that will significantly add to existing capacity, which is in the low double to single digits.

As of 2022, there are approximately 142 geothermal power plants in operation in Europe with an installed capacity of approximately 3.5GWe and generating more than 22TWh. The average capacity factor for 2022 was 79%. Turkey, Italy and Iceland maintain a significant lead on the remainder of Europe in terms of geothermal energy production.

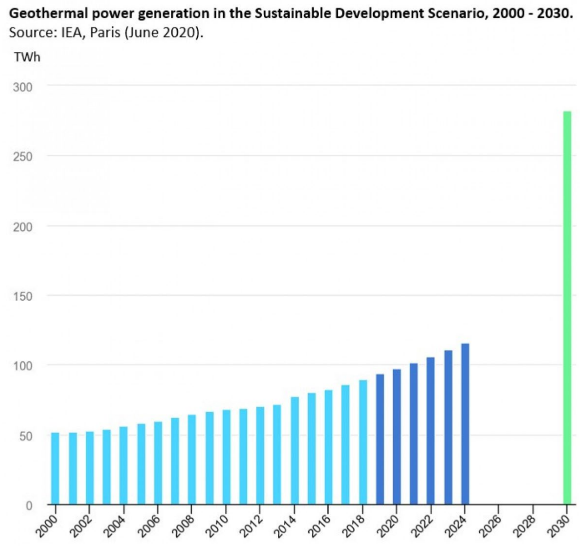
Historic projects have been developed in a non-systematic manner, with no clear guidelines or extensive experience to draw upon in order to derive an exploration and production guide to best practice. Over time this has markedly improved with the number of geothermal systems deployed, although not quite to the stage of reaching a cookie-cutter project model due to the variations driven by geology and demand. We discuss the policy landscape and project economics further in this paper.

Geothermal Plays a Role in All Net Zero Scenarios

Geothermal electricity and heating projects are considered as a contributor in all major net-zero roadmaps, albeit as a resource they are dwarfed by the deployment of more conventional renewable energy sources.

In the IEA net-zero roadmap geothermal energy is expected to contribute 1% of total renewable power, providing dispatchable electricity to maintain electricity security along with hydropower, bioenergy and batteries. This equates to over 126GW of electrical capacity from geothermal electricity, up from the current 16GW of capacity. Whilst not quite a tenfold increase, this is still a substantial increase on the existing installed capacity and highlights that there is a role for this technology in achieving a net zero outcome and the significant amount of investment and development that is still required into the space.

IEA Sustainable Development Scenario



Source: Irena 2022, ThinkGeoEnerg, 2022 (b): Huttrer, 2021.

Whilst the current approaches to the exploitation of geothermal energy are likely to remain driven by location, resource and proximity to demand (amongst other factors), that does not indicate that the market is small. There are (as indicated earlier and discussed in greater depth in Appendix A) technologies and approaches that will remove some of the geographical/geological dependencies and open up a greater degree of ubiquity for geothermal energy.

Geothermal can make material gains as an energy source where there is suitable policy and regional-level support to enable this, despite competition from other sources. We can look to the development of geothermal district heating in China, where the joint venture between Sinopec and Arctic Green has resulted in a significant uptake of geothermal district heating, with around over 1000 wells drilled to date. This represents nearly third of geothermal wells in the world ever having now been drilled by the JV, despite this being a nascent industry in China a decade ago. And whilst planning and construction processes in China and Europe differ vastly, this does indicate how with the combination of the right skills and the right policy framework, rapid deployment of geothermal energy at scale can occur. This brings with it all the benefits of job creation, cost reduction as well as delivering predictably priced, low carbon dispatchable energy. Countries such as the UK, the Netherlands and others with an oil and gas legacy can, with the right policy initiatives, mirror the experience of China, delivering material inroads for geothermal energy deployment in a highly competitive energy market.

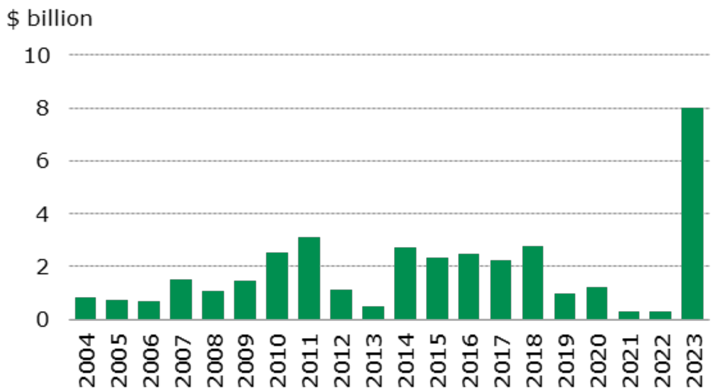
BNEF estimate that in their Economic Transition Scenario (a scenario in which the energy transition is driven by historical efficiency trends and using economically and commercially competitive scalable technologies, reliant on no additional support beyond that in existence), a total of $58bn could be spent annually on the technology in decarbonising heat and electricity by 2050. In BNEF's higher Net Zero Scenario this rises to $156bn by 2050 (this scenario is significantly more aggressive and aims to limit global warming to 1.75C).

Geothermal Investment Backdrop

2023 saw record investment into geothermal power assets as investors and policymakers looked to alternative solutions to support decarbonisation. This was predominantly through private market transactions with a significant amount of PE and VC money flowing into next-generation geothermal technology startups combined with ongoing conventional geothermal deployments. Whilst there is a chance the volume of funds deployed in 2023 will mark a one-off year with a return to more normalised volumes moving forwards, we remain optimistic that 2023 may have marked an inflection point for the sector.

Geothermal power is poised to benefit from the AI data centre energy demand mega-trend and we believe that increased deployments of geothermal energy in this specific use case could both spur investment and lift the geothermal sector more broadly, potentially leading to improved returns for developers and new investors into the space.

Annual Geothermal Investments



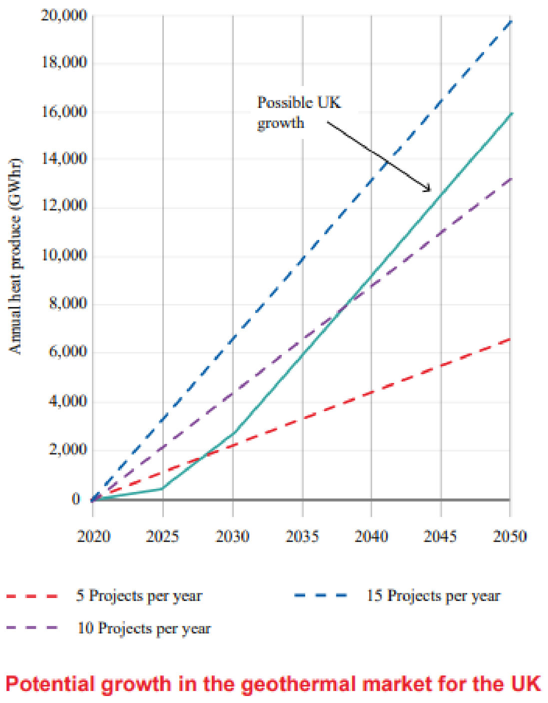
Source: Bloomberg New Energy Finance (BNEF)

With the addition of suitable policy and financial support, we see considerable scope for the volume of investment to increase and a number of new geothermal projects to advance in the UK and Europe in particular.

UK Investment Potential

In the UK specifically, we see potential for a significant increase in investment. Currently, there are 32 deep geothermal projects at different stages of development in the UK, from 4 operational developments to more than 20 which are at the pre-feasibility/feasibility stage. ARUP have estimated there is scope for up to 360 deep geothermal projects in operation by 2050 in the UK if national targets and policies similar to those adopted in the Netherlands (discussed further below) are adopted in the UK. This is a significant increase on the handful of operational projects in the UK now and would require a notable uptick in annual investment (approximately £1.5bn) to come to fruition. Whilst a portion of these projects would be likely to deliver electricity, the bulk of these developments would likely be focused on heat, meaning that the growth and success of the geothermal industry in the UK are likely to be reliant on the ability to develop commercially successful deep geothermal heat projects.

UK Geothermal Development Potential



Source: ARUP

GEOTHERMAL PROJECT ECONOMICS

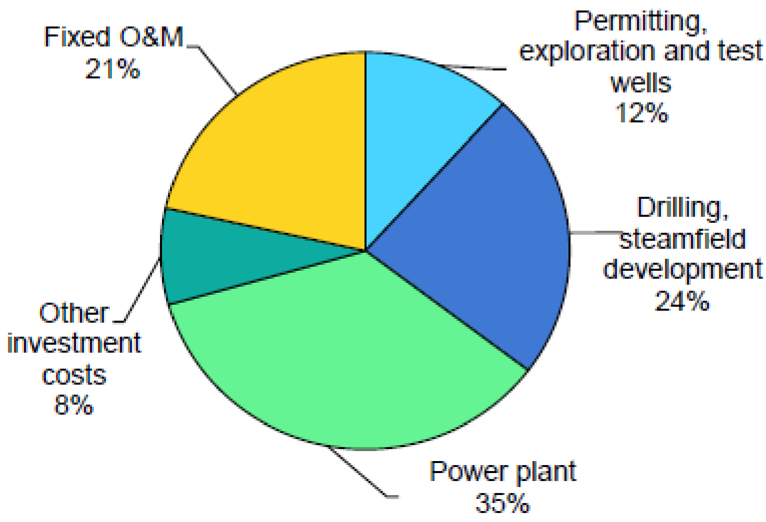
We discuss the steps involved in developing a geothermal project further below, but the bulk of the cost incurred is prior to operations commencing. Feasibility studies, exploration and other initial costs can be significant and projects can fail at this stage if early work determines that a project or resources are not commercially attractive.

Moving into the capex phase, this is where the bulk of the pre-revenue spend on a project is incurred. Whilst the drilling process typically only lasts for a few months in a geothermal development, this is the most expensive part of the process (in a heat development). Mobilisation and demobilisation costs are incurred to get the drilling rig to and from a site and a day rate is typically charged in the intervening period. Costs then include the relevant materials like cement and drill bits for the well and general staff costs.

The remaining capex cost will then be the above ground installation. Costs here will vary depending on whether this is a district heat network or a power project, and if a power project what the plant technology selection is. The above ground installation in a heat network is considerably cheaper than in a power project, where the plant makes up a significant amount of the total cost of the project (up to 40% in some instances). The plant/heat exchanger design will have been designed with the end user in mind. The absence of costly electricity-generating equipment in a geothermal heat development allows for a significantly lower total capex cost compared to a power development, something which investors should be aware of when assessing two relative projects. Given the nature of geothermal energy, this will likely have been pre-agreed, any additional transmission infrastructure or heat network capex is generally borne by the end user or grid operator and is not included in the overall capex of the geothermal development. Revenues are typically driven by a long-term PPA guaranteed for either heat or electricity, typically under a take or pay framework, guaranteeing long-term stable revenues. Some projects like the United Downs project in Cornwall are targeting heat and power production, with additional revenue streams potentially delivering improved economics depending on the capex profile, however delivery of combined heat and power will not be the case across the bulk of projects delivered in the UK.

Ongoing opex, particularly in a heat network, is generally low and fairly steady with the exception of the pump, which is a more substantial piece of replacement expenditure, relative to other operation costs. This is mainly for ongoing maintenance and reviews of the well and the heat exchanger. Any pumps and seals etc will typically need examining and replacing on a regular basis and procedures may be required to prevent scaling or the build-up of other solids coming from the hydrothermal fluids.

Breakdown of Typical Geothermal Power Development Costs



Source: IEA, Future of Geothermal

All in all, we think that this provides investors with the opportunity to earn strong returns if investing prior to the commencement of capex, or to generate more utility style returns derived from consistent and regular cashflows if investing once the project capex has been incurred. We discuss funding and bankability further below but with suitable policy or financial incentives to risk share the upfront costs and steady returns, we can see the economics of geothermal stacking up more beneficially and increasing the number of viable projects well beyond those currently in development. If carbon credits for avoided emissions or alternative revenue streams such as lithium (see further below) can be attained then the returns can be significantly improved.

INDICATIVE UK GEOTHERMAL HEAT DEVELOPMENT MODEL

Inputs		
Location		UK
Depth		1-2km
Capacity (MW)		5
Revenue (£/MWh)		85
Availability		95%
Term		30 Years
Tax		25%
Debt		Nil
Development Expenditure		£
	Preliminary studies	65,000
	Exploration	255,000
	Development	538,000
	Development Financing Costs and Due Diligence	218,000
	Contingency	225,000
DEVEX Total		**1,301,000**
Capital Expenditure	Generic Costs	2,400,000
	Well-site and conductors	1,450,000
	Drilling Rig (mobilisation and demobilisation)	2,970,000
	Services and Consumables	3,470,000
	Materials	3,610,000
	Above Ground Installation	3,560,000
	Contingency	1,470,000
CAPEX Total		**18,930,000**
CAPEX+DEVEX		**- 20,231,000**
OPEX		
	Fixed Operating Costs	250,000
	Electricity for Heat Pump	350,000
Opex Total		**600,000**
Revenue	Heat Sales	3,537,000
	Revenue	3,537,000
	Opex	600,000
	Operating Profit	2,937,000
	Tax	734,000
	Profit Per Annum	**2,203,000**
	Post Tax Project IRR (unsubsidised)	**12%**
	Post Tax Project IRR (assuming DEVEX Grant Funded)	**13%**
	Post Tax Project IRR (DEVEX and 25% CAPEX Grant Funded)	**17%**

Source: Longspur Research, EBN

We highlight that the model development above has no debt included and that with a suitable amount of leverage included, returns could be higher than that forecast above and comfortably at 20%+ depending on the time of entry. Naturally, the level of debt will vary on a company and project basis but we believe there would be an appetite for debt in geothermal developments, particularly when this has been developed and de-risked by a suitably qualified developer such as an oil and gas company and there is free cash flow that could potentially support debt at the project company level.

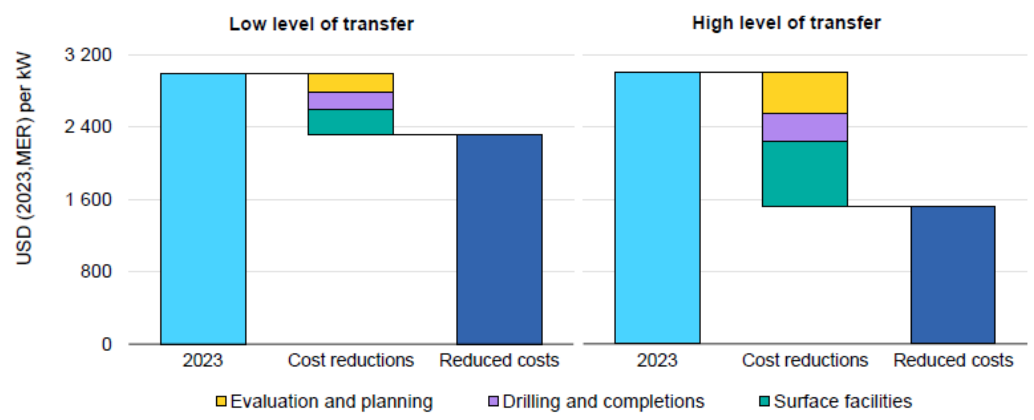
Capex costs could decrease over time

Whilst there are individual developments that can display near cost parity with other renewables, WoodMac estimate that for a more widespread uptake of geothermal power developments to occur there would need to be a 30-60% decrease in capex costs. We could see the costs of geothermal developments coming down, provided the UK can build a suitable pipeline of projects as developers build up their domestic skill base and are able to rely on a more readily available pool of talent. This also applies to supply chains, where a steady pipeline will allow for more readily available technology like onshore drill rigs, helping to reduce costs and allow for rapid mobilisation and demobilisation at the drill site. Currently, there are a limited number of geothermal developments in the UK, with drilling only taking a few months, compared to the offer of longer campaigns in a multi-well oil and gas development or longer geothermal programs in nearby EU countries. This can increase the cost of drilling in the UK, with partners preferring longer-term secured contracts and increasing the cost of mobilising and demobilising rigs. A growing pipeline would also potentially provide a degree of respite from onerous planning requirements as developers are able to more easily navigate the regulatory environment.

We could also see new and emerging technologies in the space supporting lower drill costs over time. There are numerous start-ups in the space looking to lower the cost of drilling given this remains a significant piece of the capex. GA Drilling for example has recently raised capital to fund the development of their downhole stabilisation and plasma drilling solutions, both of which aim to reduce the time and cost of drilling by reducing the number of replacement drill bits needed. Equally, advances in AI and modelling could see initial DEVEX costs come down as processing and interpretation can be sped up.

The IEA have reviewed conventional geothermal costs and estimated skill level transfers across the entire capex phase of a conventional deployment, and believe that in a high level of transfer, total costs could reduce by 50%, with a 15% reduction in planning and evaluation and a 35% decrease in drilling and design through the application of modularity and skills and technologies developed in the oil and gas industry.

Breakdown of a Typical Geothermal Power Development Costs



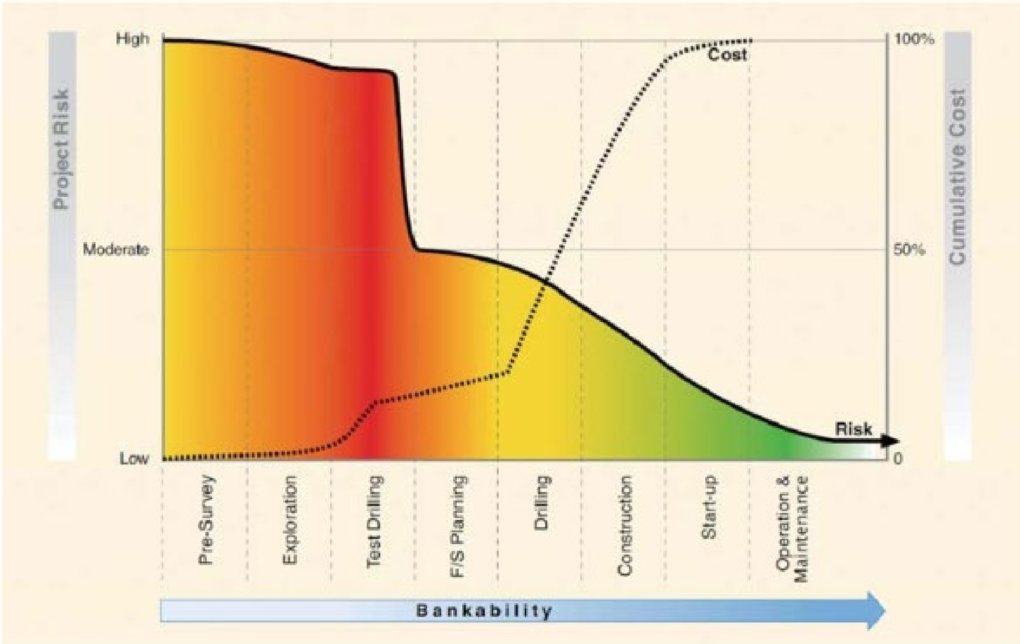
Source: IEA, Future of Geothermal

FUNDING GEOTHERMAL

In terms of financial risk, the earliest stages of a geothermal development have the highest level of risk as they require significant financial outlay when there is still uncertainty about the availability of the resource, its longevity, and the feasibility of its extraction/exploitation. This is then compounded by the long lead time required to develop a project which delays returns, making early-stage investment difficult to finance.

Returns on a single project are naturally linked to a number of factors but any potential ROI must be looked at through the prism of there not being an economic resource and probability-weighted accordingly, equally a potential lack of surface demand and a willingness to commit to the project has to be considered. This risk can be spread, however, with a portfolio approach reducing the single well exposure and by targeting projects where historic oil and gas production has proven or significantly derisked the availability of a suitable resource in a known basin. Once in production, the required level of productivity and the ability to maximise supply (meaning in heat provision, having enough connected load, or in the power production, having sufficient grid capacity to export) are key to generating a return on investment and crucial to this is appropriate pre-production work.

Bankability Through Development



Source: Gehringer and Loksha 2012

The successful completion of test drilling dramatically reduces the overall uncertainty for the project and this is typically an easier time to attract capital into a project. Following drilling and the successful establishment of a hydrothermal resource, this presents an entry or exit point for investors.

If the project has an offtake in place for the heat or electricity this can mark a potential entry point for infrastructure investors, with ongoing low maintenance costs and a steady PPA agreement, potentially on a take or pay arrangement, providing the basis for steady returns. Similarly, this can mark an exit point for investors who are willing to take a degree of exploration risk or for the developer to sell down a portion of the project to then recycle this capital into the development of further projects.

Without more government revenue support for heat, we see an offtake that can cornerstone demand as being critical for a heat network development in the UK. If the initial heat demand can be secured and allow for a commercial development of the geothermal, then any additional demand found after operations commence can be added at an extremely low marginal cost, significantly boosting project returns.

With guaranteed returns, sticky revenue coming from customers (as they typically cannot move from a fixed connection) and long project lifetimes with the potential for increasing returns over time, once in production geothermal developments can deliver utility style returns. Similarly, the returns on invested capital for investors involved at the outset can be sizeable as the project gradually de-risks through to production.

Similarly, if more comprehensive government support is available project returns can be significantly improved and growth in the sector could be turbocharged, as has been witnessed in areas like the Netherlands.

There are a number of second order economic benefits from the growth of a geothermal industry, particularly in the UK but also in other regions.

In broad terms there is scope for growth in the industry to add a significant amount of economic growth to an economy. This can be achieved through direct and indirect job creation, lower heat and power prices for industrial users- supporting lower operating costs, urban regeneration and aiding in the development of new carbon neutral town developments.

In the UK specifically, development of a strong geothermal industry can create new skilled jobs and help to support workers transitioning from the UK oil and gas industry which has entered into structural decline on account of the current UK fiscal regime and declining productivity from the North Sea basin. There is a high level of transferrable skills from the oil and gas industry and retaining these skilled workers in the UK and deploying these on geothermal developments will support the UK tax base whilst also potentially lead to improved geothermal developments over time. The Eden Geothermal project created an estimated 254 jobs throughout the project to date, showing how this could support more employment if the industry were to develop.

Secondly, geothermal heat and power can be supplied independently of UK gas and electricity prices meaning that energy supply from this source is effectively decoupled and immune to external price shocks which can impact commodity and power prices, providing energy security and potentially supporting the UK's balance of trade as the reliance on gas imports for heating in particular is reduced.

Lastly, there is a potential for geothermal energy to support levelling up and regional development, with several potential geothermal development areas also coinciding of areas with low economic resilience. A study by Durham Energy Institute identified 45 local authority locations with the highest deep geothermal potential and noted that 44% of the list is in areas qualified for the UK Community Renewal Fund, which aims to support economically disadvantaged areas. Geothermal developments in these areas could support more urban regeneration with access to low cost, low carbon predictably priced heat and electricity potentially attracting more industry to the area.

GEOTHERMAL RESOURCES

Importance of Resource Availability and Characteristics

Geology and the availability of a resource with sufficient temperature for the demand case is ultimately, critical for a development to be commercially successful. Traditional geothermal resources have relied on high-temperature aquifers (<100C) which has made the development of geothermal energy somewhat location-bound and prevented a more global scale-up of the technology. However, new technology and lower temperature requirements for applications like district heating which can use medium temperature resources, means the opportunity is much greater than previously perceived and could signal that geothermal energy is reaching an inflection point as countries progress towards their net zero goals.

Naturally, the resources available for a geothermal development varies from site to site but, in general terms, the IFC and World Bank have estimated that the highest average capacities are seen in tertiary and older volcanic/volcaniclastic systems. This is consistent with expectations that old rocks are more likely to have significant fractures, which increases the permeability of the reservoir and so increases the productivity of the wells. Conversely, granitic rock has the lowest average capacity, typically the result of the characteristically low porosity and permeability of such rock, and the low incidence of fracturing.

A geothermal resource is evaluated on three main traits in order to assess suitability for geothermal energy production: temperature, permeability and water. Temperature requirements vary depending on the use case with heating networks generally requiring lower temperatures of around 60℃ + against power applications which require significantly higher temperatures of over 120℃). Permeability refers to the ability of water or steam to flow in and out of rocks and directly affects the movement of geothermal fluids that are required to bring heat to the surface. Lastly, water is critical in a geothermal development given that it plays an essential role in the extraction and transfer of heat from the subsurface to the surface.

Hydrothermal resources are considered to be conventional in that they can be developed using existing technologies, workflows and skills (often derived from oil and gas). Conventional hydrothermal resources typically involve the tapping of a hydrothermal reservoir (aquifer) underground where trapped water and steam pools. This is typically only accessible through drilling and requires heat, water and permeable rocks to combine in suitable amounts to be economical.

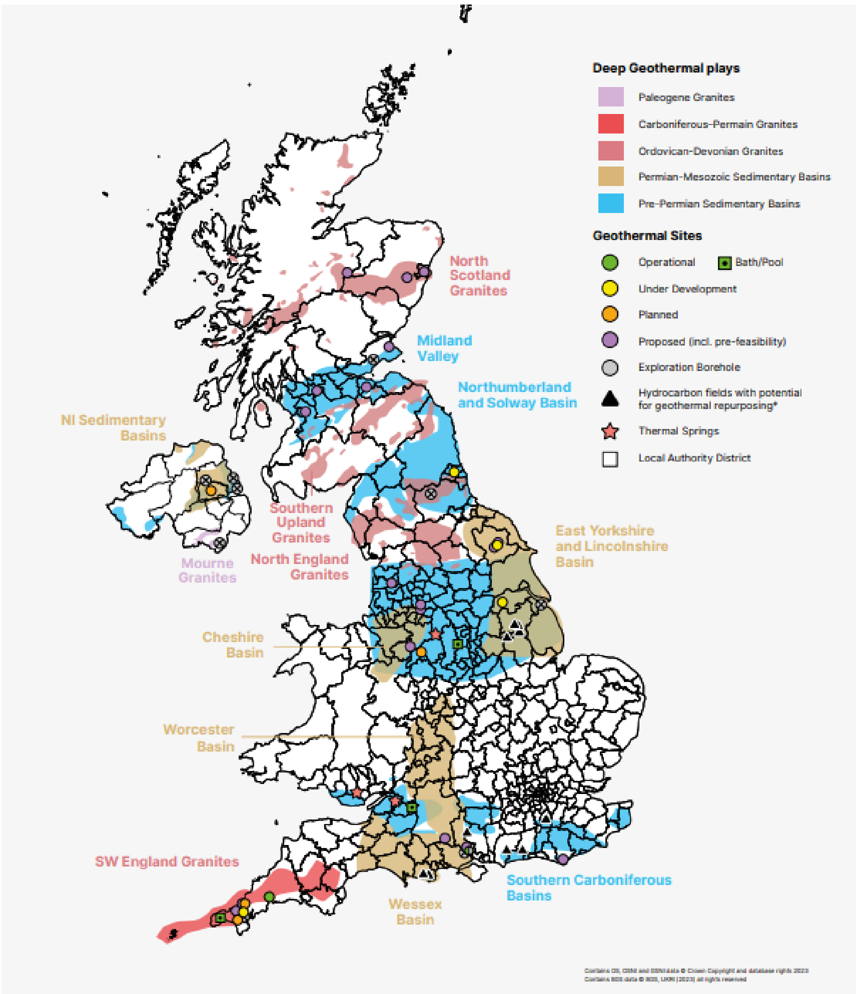
Much of Europe has temperatures (albeit at varying depths) that would be suitable for geothermal district heating networks and more limited areas with the ability to generate power where there is significantly more heat. This translates to significant scope for geothermal heat network development across much of Europe. In areas where there are existing geothermal developments, there is potential to connect in more demand in most instances, often at a lower cost and risk.

UK Geothermal Resources

In general terms, the bulk of the UK's geothermal potential is found in deeper sedimentary basins across the country, however, hybrid and shallow (<1000m) schemes driven by project demand have a much broader applicability, less limited by geology. These basins typically contain deeply buried limestones and sandstones where groundwater can circulate. Temperature ranges depend on the depth of the aquifer, however, temperatures are estimated to be around 40C-60C at depths of >500m, potentially increasing as high as 100C in some deeper aquifer locations. Sedimentary aquifers exist from shallow depths all the way to 4.5km in depth or more. This means there is a wide potential for geothermal energy, with the bulk of this being best suited to a geothermal heat development but with potential for power generation in some higher temperature locations.

Geothermal resources in granites, most notably in Cornwall but highlighted in the graphic below, are more suitable for power generation development but can also be used for heating applications. Temperatures in UK granites are expected to be in excess of 100C. This has been the primary focus of most geothermal developments in the UK to date, however, we note there are several studies going on across England, where district heating solutions in some of the sedimentary basins are being explored.

Geothermal Resources in the UK



Source: C Abesser; A Gonzalez Quiros; J Boddy

Whilst the resource is clearly important in development, of equal importance are potential grid connections, heat uses, access requirements and heritage areas etc, all of which impact on the cost and viability of a geothermal development.

Furthermore, the UK, despite having a history of onshore oil and gas development, is somewhat underexplored in subsurface terms at geothermal depths. With little incentive to deploy geothermal energy historically, primarily due to the availability of cheap gas, there is likely to be more interest going forward as attention turns to geothermal energy as a solution in the decarbonisation toolkit.

Applications for geothermal heat and electricity generation very much depend on the temperature and location of the resource (with proximity to a source of demand also being critical for heat projects) but the Heat Flow Map below details the temperatures which could support a wide range of potential applications. At the bottom of the scale is district heating and low-level heat requirements like fish farming, agricultural use and greenhouse heating, whilst moving up the scale, higher temperature industrial process heat or conversion to electricity is a possibility.

Whilst this very high-temperature heat is more rare and usually more expensive to deliver due to deeper drilling requirements and the associated costs, this does show how geothermal energy could fit into decarbonising a range of high-carbon emitting processes.

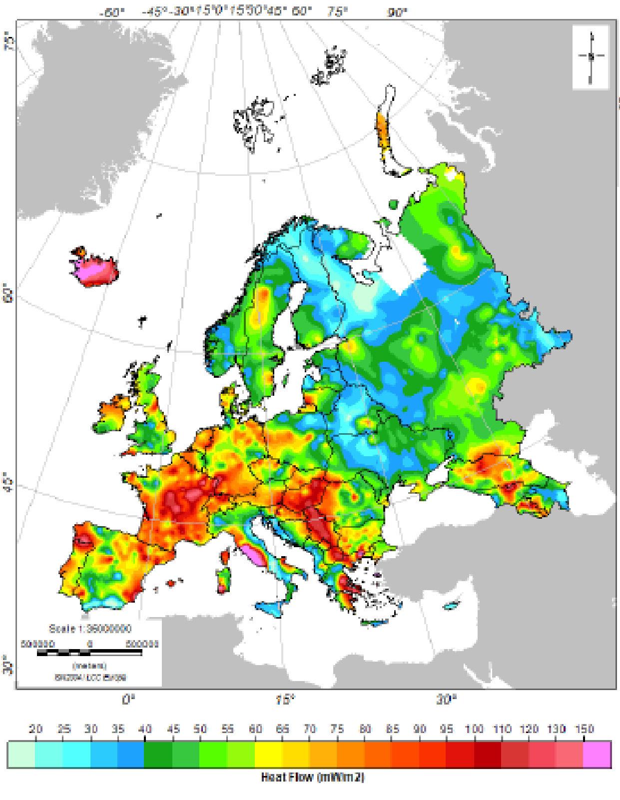
European Geothermal Resources

Europe has a more extensive history in geothermal deployments than the UK, largely on account of it having more high temperature areas which allowed for easier exploitation, combined with lower domestic oil and gas industries in a number of cases. Naturally, given the size of the area, there is a wide range of temperatures and potential resources.

Traditionally, Italy, Germany, France and Iceland have tended to have the greatest numbers of operational geothermal heating and power projects and this continues to be the case as they expand the number of both types of projects, recognising the value of low-carbon, cost-effective, geothermal energy.

We are seeing a number of emerging areas in Europe, notably in Croatia, Austria and the Netherlands, where there is good geothermal resource availability and policy support leading to increasing numbers of developments. In our view, there remains a significant untapped resource in continental Europe and, given there has been policy support to date and a resolution in the European Parliament in January 2024 calling for the European Commission to devise a Geothermal Strategy, we expect more steps to encourage companies to exploit that resource. We have discussed policy in key jurisdictions further below.

European Heat Flow Map

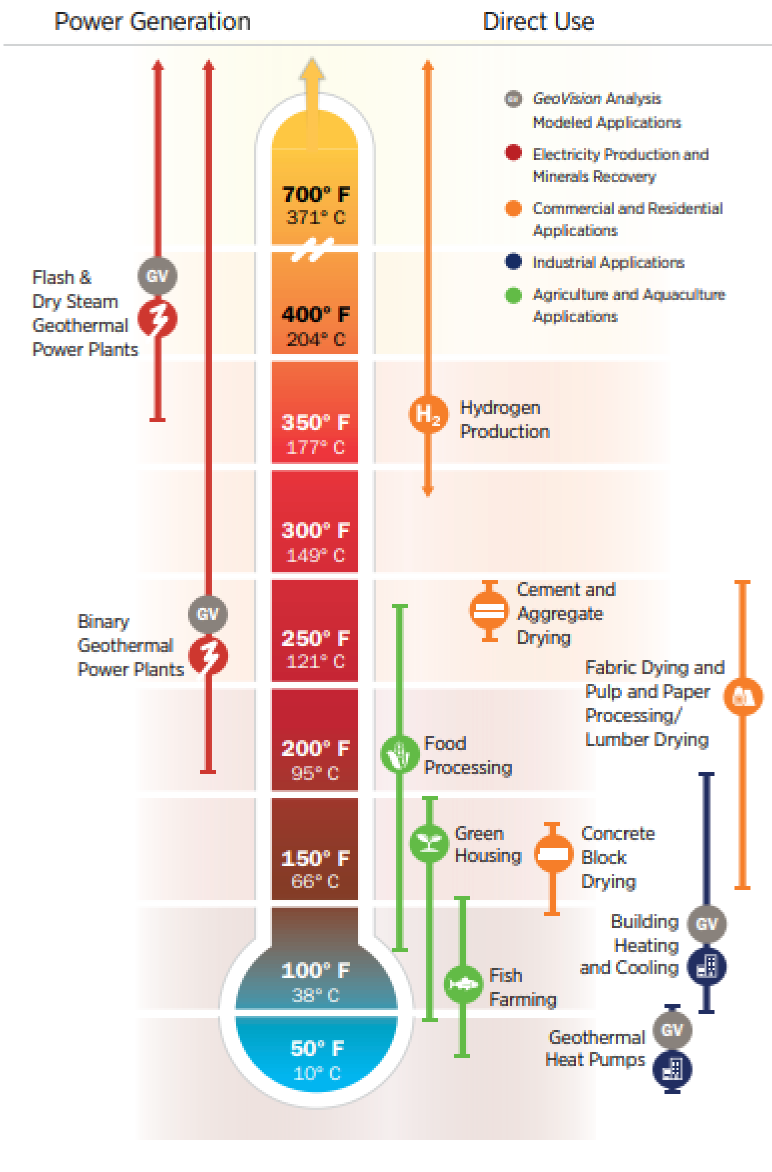


Source: Fábio Pinto Vieira, Suze Nei P. Guimarães, Jorge Luiz dos Santos Gomes and Valiya M. Hamza

THE MARKET FOR GEOTHERMAL ENERGY

As noted above, almost all Net Zero Scenarios see a larger deployment of geothermal technologies. There is scope for a wide application of geothermal energy, with this largely being driven by the temperature and quality of the geothermal resource and the proximity of this source to potential demand. We do not see geothermal energy as a one-size-fits-all solution, however, there remains a high degree of replicability across projects, where there are similar resources and demand cases, which are likely to centre around smaller geographical and geological clusters.

Geothermal technology summary



Source: US DoE

HEATING

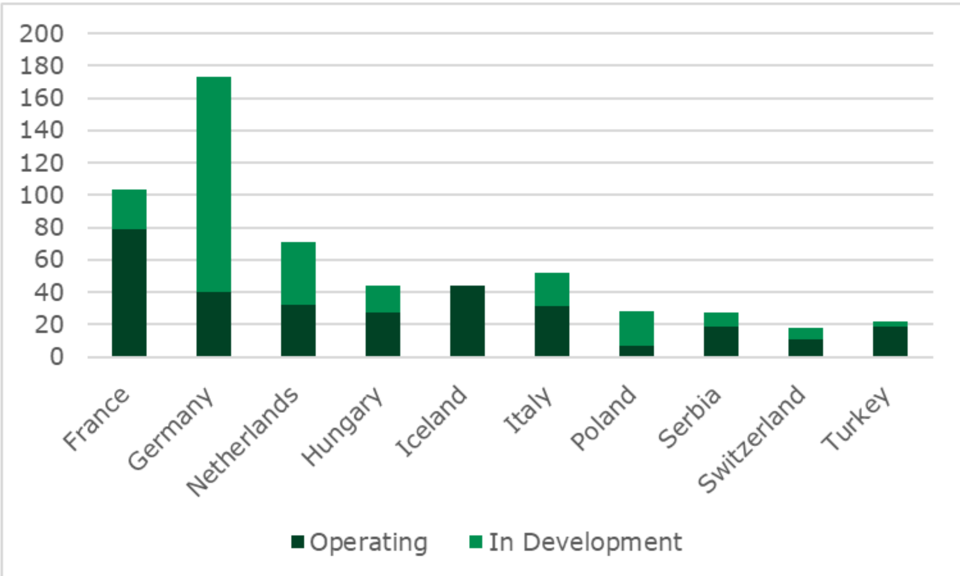
District Heating and Large Scale Users

In our view, the main potential for European geothermal energy is in heat generation, which remains a complex area to decarbonise. Under the IEA's net zero tracker, district heating progress is not on track to deliver the required decarbonisation outcomes required under a net zero scenario which reflects the lack of investment in the space to date. As of 2022, district heating met around 9% of final heating demand in buildings and industry and this needs to move to 14% under the IEA's net zero scenario, with a significant proportion of the existing district heating systems needing to move from fossil fuels to clean energy alternatives.

395 systems were in operation as of 2022, with 261 systems in operation in the EU Member States, amounting to 5,608MWth across 29 countries. The coverage of geothermal heating and cooling systems is expected to increase to 34 countries when Bosnia, Ireland, Latvia, Luxemburg and Malta complete the projects that are currently in their respective pipelines.

District heating networks are widespread and used extensively across Europe, even in colder climates, for example, Copenhagen has 98% of its buildings connected to district heating networks (albeit not heated by geothermal energy). This is not new technology but technology that can be rolled out with sufficient capital and will. District heat has been around for decades, with both geothermal energy and alternatives providing the central heat source depending on the project. This provides a significant scope of opportunity for geothermal heat networks to replace fossil fuel driven infrastructure and for new-build geothermal district heat networks.

Developed European Geothermal Market District Heating Projects



Source: EGEC

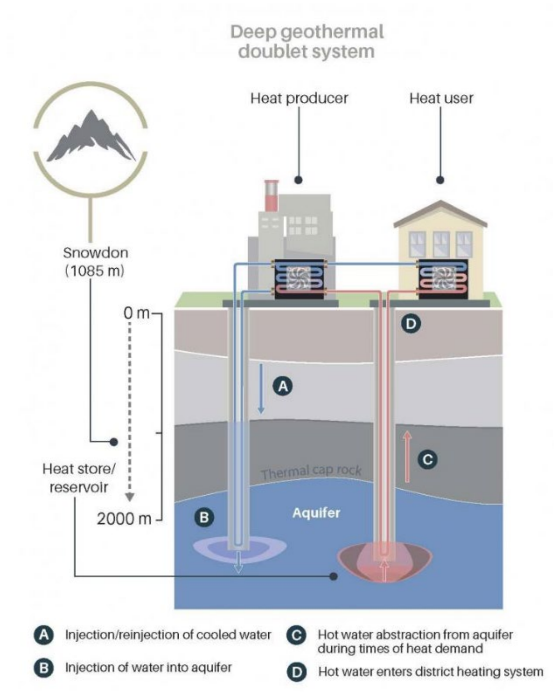
How it works

In simple terms, geothermal district heating networks take hot geothermal fluids, pass these through a heat exchanger and then distribute the secondary side fluid across the district heat network, before re-injecting the cooler water back into the existing aquifer. This is no different from an existing district heat network that generates heat in a central location before delivering this to a number of different users.

Modern heat networks and district heating systems are able to limit energy losses from networks, ensuring this is an energy-efficient and reliable means of heating homes and businesses.

The two main prerequisites for the establishment of a heat network are a well-located resource with sufficient flow rates and temperature on the supply side and sufficient heat users on the demand side. Naturally, the higher the heat demand in MWth allows for the geothermal project to increase the volume of heat dispensed and lower the cost of the distributed heat as the marginal cost of supply is very low by virtue of the high system efficiency, up until the point whereby a second production well is required to increase capacity. Heat can also be stored when not needed immediately and used when demand is high, thereby increasing the utilisation factor of the plant.

Geothermal District Heating

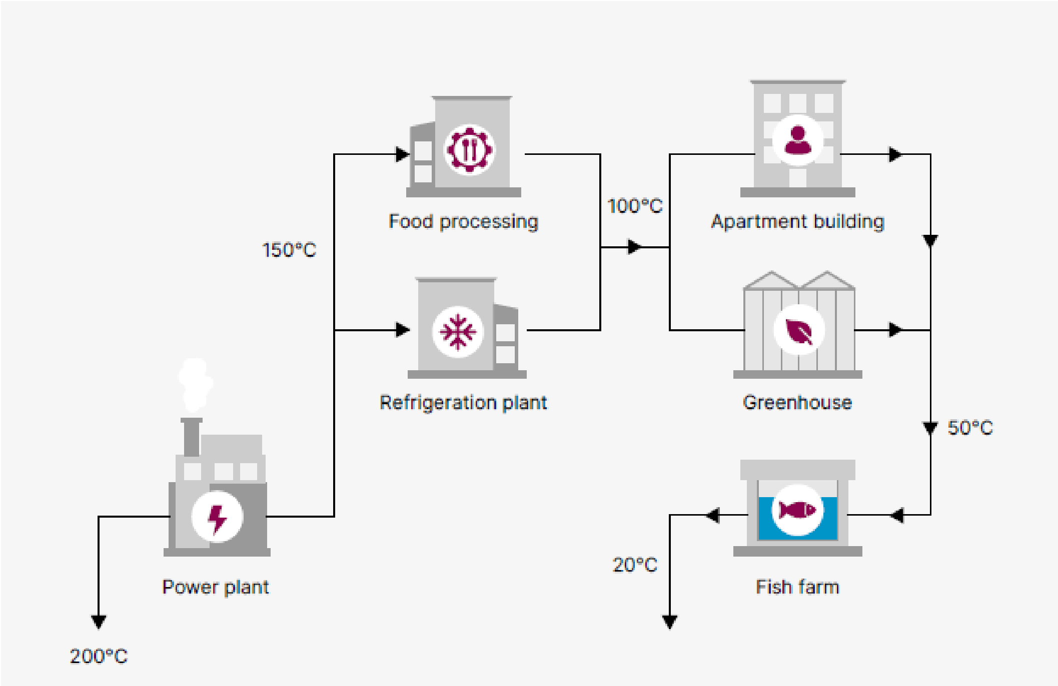


Source: British Geological Survey

Cascading Use of Heat

We also see additional demand coming from the cascading use of heat, as demonstrated below. Given the differing heat requirements for different users, there is the option for developments to disperse heat to each of these users, boosting the project returns and multiplying the carbon savings. Whilst the graphic below starts with a power plant and distributes heat through industrial users before residential heating, this could also have a geothermal development supplying residential users first and lower heat industrial users second. Once a cornerstone level of heat demand has been found, additional users can be added at the initial stage or further “down the line” where the heat demand is lower.

Cascading Use of Heat



Source: NELP, adapted from Brophy et al 2015

Potential Large Consumers of Industrial Heat

We see the potential for industrial-scale heat and cooling demand predominantly coming from distribution centres, local hospitals, new housing developments, retrofitted district heat networks and lower heat requirement developments like greenhouses and fish farms as highlighted above.

We see local hospitals as being an early source of demand for geothermal heat developments in the UK, with Star Energy currently pursuing several developments in this area, and this could potentially lead to a wider roll out of geothermal heating in public sector buildings as the need to decarbonise increases.

Distribution centres could prove to be a source of geothermal heat and power demand in future, with most warehouses requiring efficient heating and cooling, year-round and this could be served by geothermal heat, provided there is a proximity to a geothermal source. Given these developments are often multi-building units with several distributors in nearby locations there is potential to add additional users once the primary user has been identified and added to the heat network. Given the power requirements of most distribution centres, a combined geothermal heat and power development could be a very efficient way of power and heating distribution centres, however we are yet to see an announcement in this space.

Heat Networks in the UK

Deep geothermal energy deployment in the UK remains limited, not for a lack of resource, with a small number of projects either operating or in development. Government focus has typically been directed towards other energy forms given the UK's historic oil and gas strength and the more recent focus on more traditional renewable energy generation like wind and solar. However, with the economic and physics arguments stacking up against hydrogen and a slow uptake of heat pumps, there remains a significant challenge in decarbonising heating in the UK. Whilst a substantial amount of this will likely be done through electrification of the home and workplace over time, there will also be a demand for district heating networks where this is more effective and we see geothermal energy as being one of the most cost-effective, low carbon options for providing heat into a network.

There are currently over 14,000 district heat networks in the UK (with heat predominantly coming from fossil fuels from commercial gas boilers or combined heat and power engines), meeting around 2% of the UK's current heat supply. Geothermal energy currently only meets a fraction of this, however we see scope for this to increase significantly.

Heat networks represent a new approach to heating for most UK households and businesses and education about both the value of heat networks and how they will integrate into existing infrastructure is critical across the stakeholder spectrum to help drive forward projects.

We see a particular role for geothermal heating in new housing developments in the UK. The expected introduction of the Future Homes Standard in 2025, which prevents the development of new residential homes that have direct emissions heating solutions, presents a significant opportunity for geothermal heating. New housing, which the current government have committed to add 1.5m homes worth in the current parliament, will therefore require alternatives to gas boilers. Whilst there is an expectation that much of the slack will be taken up by heat pumps, geothermal district heating networks could be a very cost-effective solution with new build developments providing an anchor level of demand that could support the project economics.

One of the perceived issues with district heating networks is that it is too costly or difficult to implement in areas where there is already an existing gas network or infrastructure. This is not necessarily the case and can be engineered around. The Citigen project in the City of London has successfully connected a number of buildings and residences onto a district heating network (not geothermal powered) despite the significant urban density and aged architecture and infrastructure in the City of London with minimal disruption and using the existing infrastructure. Whilst a geothermal development may or may not have been feasible in this location, it does attest to the fact that new district heating networks can be developed and implemented and can be used as a tool to decarbonise heating, even in complex scenarios.

Where there is a large heat demand near to a source of geothermal energy and the ability to convert an existing heat network or develop a new network (either through conversion of existing buildings or in a newbuild context) we see a considerable role for geothermal heat networks. We have discussed some existing geothermal heat networks in the UK and abroad below, to give a wider context into the applicability of geothermal heat networks and frame how this could look in the UK with a wider deployment.

Southampton

Southampton has a geothermal district energy heating scheme that is owned and operated by ENGIE, now known as Bring Energy. Operational since 1986, initially this supplied only a small civic centre but over time has been gradually expanded to supply the Royal South Hants Hospital, Solent University and an enlarged district heating system connected to over 1000 properties. The network was included in the heat network zoning program which intends to develop heat networks in zones where they can provide the lowest cost low carbon heat to end users. Geothermal energy currently provides around 20% of the enlarged district heating network and there remains scope for this to increase under the heat network zoning program, potentially providing an opportunity for geothermal growth here.

Cornwall

Cornwall is currently viewed as having some of the best deep geothermal resource prospects and that is currently reflected in the increased number of projects in the area. Geothermal Engineering Limited (GEL) has constructed its first project and has had an additional two approved in the area. The three sites together can provide power for 35,000 homes and heat for a number of local homes and businesses on top of that.

The first of these, the United Downs Project deep geothermal project based in Cornwall, with the intention of producing combined heat and power. The project has an initial power capacity of 3MW with the potential to expand this to 6MW. The site also has a heat generation capacity of 24GWh per annum. Expecting to produce power in 2025, the site had two test wells drilled in 2019 and 2020 which included a 5km depth production well. The project secured £15m in funding and a further £22m in funding will be issued to develop the district heat network to connect around 4000 homes and the Royal Cornwall hospital to the development, with heat expected to be distributed in 2026/2027.

There is also the Eden Geothermal project which is a project to decarbonise the Biomes at the project as well as providing commercial greenhouses and other buildings. Drilling started in May 2021 and was completed in October of the same year, with a deviated well drilled to 4,871 metres. This project was undertaken by EGS Energy and Bestec UK. Funding for the project, which cost an estimated £22m, came from the EU (£15.7m), Cornwall Council (£1.4m) and Gravis Capital (£6.5m).

Prospective Geothermal Projects/New Developments

Star Energy Portfolio

Star Energy are currently looking at developing a portfolio of deep geothermal projects, compatible with district heating systems. The primary focus initially has been to work to provide heat to NHS hospitals, where there is a demand for significant, regular heat supply (>20GWhth/annum) and proximity to other demand centres that could then be connected into the district heat network. Star are currently progressing their geothermal developments at Wythenshawe and Salisbury hospitals where they are targeting heat production by the end of 2026 at the latter site and the end of 2027 at the former, with both now subject to appraisal. Importantly both projects have identified large sources of heat demand, who would be able to provide a cornerstone level of demand in the first instance, whilst the network operator would look to add further demand in future.

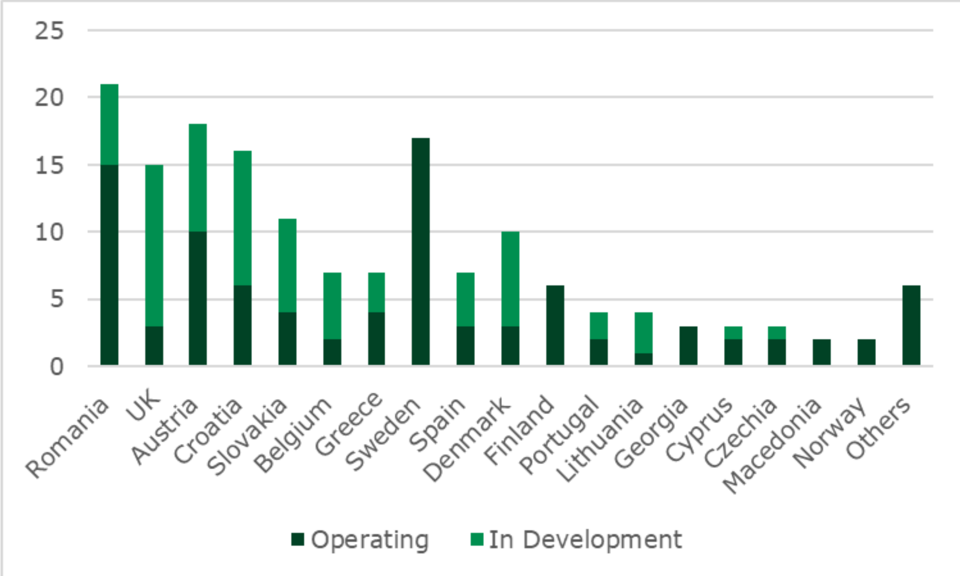
Newcastle

Newcastle is currently exploring a district heating system (NetZero GeoRDIE) project which is looking to develop the Newcastle Helix borehole. This is a 1.6km deep borehole drilled between 2011 and 2014 which allows for access to 70°C temperature rock. The project is looking to deliver heat and cooling to 10+ commercial buildings, university buildings and 450 domestic properties.

European Geothermal Heat Networks

Europe has a much longer and more developed history of utilising geothermal energy, whether that be in power or heating than the UK and there are numerous new projects in development at present.

Emerging European Geothermal District Heating Sites



Source: EGEC

Germany, France and Scope for more

Over 25% of the EU population lives in areas directly suitable for geothermal district heating. Geothermal district heating is a valuable and sustainable solution for decarbonising heating across swathes of gas or fossil fuel-dependent areas.

We can look at two population dense areas where local geothermal energy has been adopted, namely in the Paris and Munich metropolitan areas. The Paris basin for example provides a significant volume of heat in the city each year. There is a high concentration of wells in the Paris region, which are predominantly mid-depth wells at 1,500-2,000m depth (Dogger geological age). Future wells in the area are expected to target deeper aquifers (Trias). Geothermal energy in this instance can look like a multistorey house with different target aquifers stacked on top of each other which can generate heat.

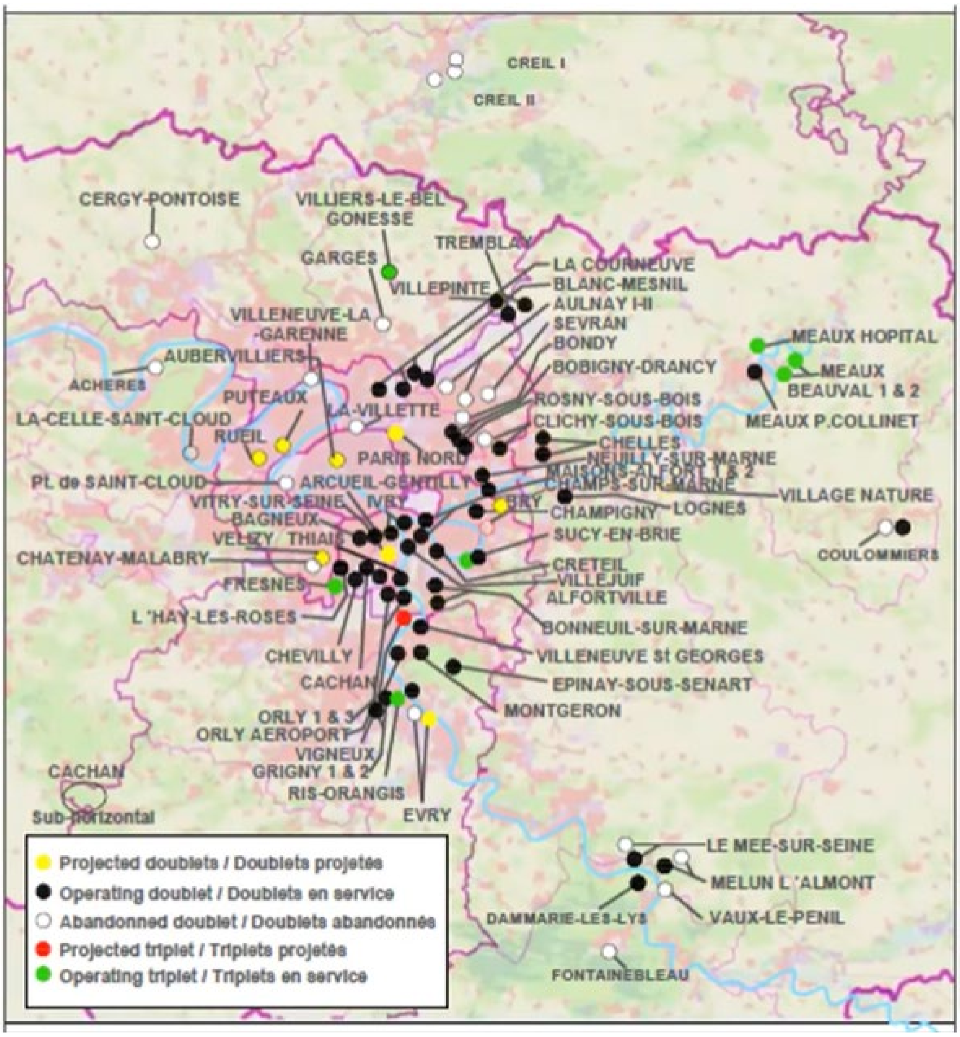
A number of development failures were learned in the Paris basin development. After early initial wells developed in the 1960s-1980 there was an extensive drilling of doublet wells, between 1980 and 1990 with over 50 doublets completed, however, this was done to a poor standard with 21 of these damaged or non-economic and subsequently abandoned. These early technological failures saw a significant drop off in the drilling of wells with nearly no drilling conducted in 1990-2008. Drilling in the basin then recommenced and has continued through to the present date with 4 wells drilled per annum on average since 2008 in the Paris area. These are done in conventional urban areas, with high traffic density or residential density.

The two latest notable projects being developed in the Paris basin are:

a) The geothermal district heating network for the city of Malakoff will be deployed in this city close to Paris between January 2025 and autumn 2026. Drilling began in the second half of 2024, and the 12.5 km long network will be commissioned in the autumn of 2026 delivering 78 GWh/year of heat distributed (to the equivalent of 8,000 homes) with 1,500 tonnes of CO_2 avoided each year. Total investment is EUR 51.4MM.
b) The drilling at Paris-Charles de Gaulle Airport for the ADP Group, a global leader in airport operations of a geothermal doublet which marks a key milestone in the decarbonization of the Paris-Charles de Gaulle platform. This geothermal doublet, which involves drilling two separate wells to extract the Earth's natural heat by

capturing water at 70°C located 1,800 meters deep, is being carried out by Arverne Drilling using state-of-the-art drilling equipment. The heat extracted will be used to supply Terminal 1 with a continuous source of renewable and locally produced energy. The planned installation will allow the production of up to 80 GWh/year of heat. The drilling work will take approximately three months.

Parisian Geothermal Basin



Source: EGEC

Munich Area

The wider Munich area has a significant geothermal presence, and ambitions to further develop this in the future. Stadtwerke Munchen (SWM) is the municipal utility company that operates in Munich. They are aiming to achieve carbon-neutral district heating in Munich by 2040, primarily through geothermal energy. SWM currently operates six geothermal plants in the city and surrounding region and is planning to build a seventh plant. SWM currently produces over 90% of the power requirements for Munich as green electricity and they see the decarbonisation of heat through geothermal energy and district heat networks as complementing this.

There are other geothermal operators in the wider Munich area including Innovative Energie Pullach which is looking to expand its North Energy Centre. The new facility ought to be open by 2025 and is receiving funding from the Federal Ministry of Economic Affairs and Climate Protection in Germany. This will add an extra 77MW of capacity at the site, which provides 48% of the area's heating requirements. This follows the conclusion of 3D seismic work which commenced in 2018. The site currently has 3 wells, two production and one injection. The first two wells were drilled in 2004/5 to 3.9km and 4.1km in depth. The third well was drilled in 2011 after completion of seismic surveys started in 2011. The third well was drilled in just 56 days and allowed for the geothermal heat supply to increase up to 48% of the demand figure above.

Scope for More

The Netherlands, since 2014, has been actively promoting geothermal energy and over the past decade, due to significant policy support (see further below) has significantly increased the number of geothermal district heating projects in the country.

There is scope for significantly more geothermal deployments in Europe as the continent looks to move away from Russian gas consumption and the historic reliance on coal. Based on the broad resource availability we see scope for increased deployments in Croatia, Hungary, Austria and Romania in particular within Europe and this is beginning to be played out with the number of potential developments highlighted in the graphic above supporting this (note that this also excludes power developments).

Industrial and Process Heating and Cooling

The potential for heat supply for industrial users is more limited (in the UK) and is equal to approximately 5% of the total heat use in industrial applications. For shallower geothermal projects where there is less access to significantly hot water, heat is more limited in industrial uses to areas like heating plant nurseries or potentially providing process heat to breweries where there is a requirement for long periods of relatively low heat.

High-temperature industrial heating (steam supplied industrial processes for example) is more suited to deep geothermal where there is significant access to extremely hot hydrothermal resources. For example, the Hellisheidi Geothermal Power Plant in Iceland has access to water reservoirs with temperatures exceeding 300°C.

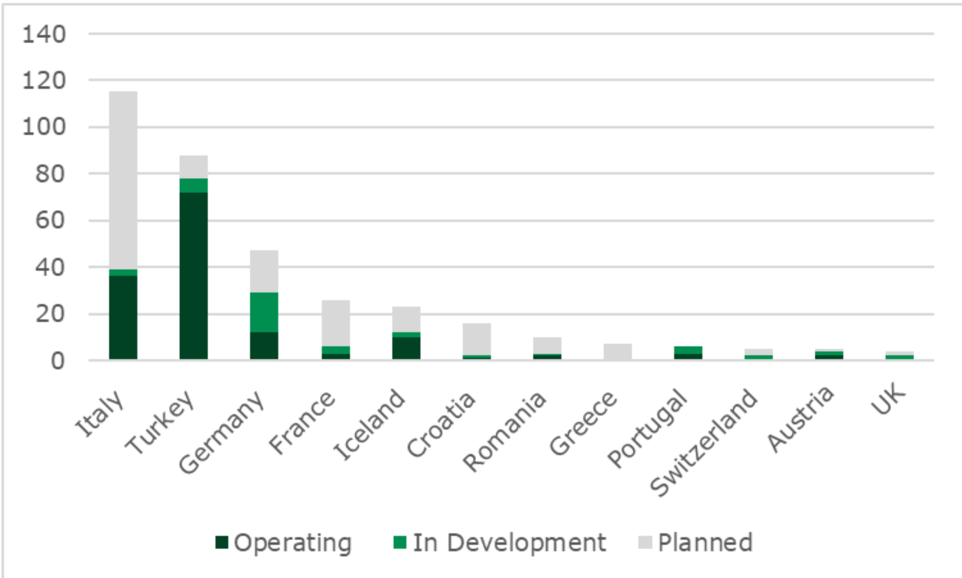
For the most part, unless there are breakthroughs in deep geothermal drilling, most geothermal heat generated in the UK and across much of Europe will likely be too low for a significant manufacturing impact. However, this will not be the case across the globe, and studies are ongoing as to how best to incorporate geothermal energy into hard to abate, high-temperature industrial applications. Given the nascent level of the technology required and the specific geographies where this will be successful, we do not view this as a significant area of growth for the geothermal market in the short term.

GEOTHERMAL POWER GENERATION

Geothermal energy can play a significant role in decarbonised energy markets, providing balancing power to complement non-dispatchable renewables such as wind and solar. Traditional geothermal has an approximate 95% utilisation rate with minimal annual maintenance and downtime required for turbines, pumps and heat exchangers. This gives geothermal energy the option to be “always on” and dispatching power to the grid, an important option in the grids of the future where balancing will not be provided by coal or gas turbines. Grid stability and inertia will become increasingly vital and there could be a role for geothermal power plants in the energy mix to support this. Importantly the nature of geothermal energy also avoids the cost of storage, with no oil or gas storage required as part of a development.

Given the nature of power generation requiring a higher temperature resource, power developments are more limited in their geographies, with the bulk of new developments in planning below, in relatively established geothermal power markets such as Italy. We also note the emerging demand in Croatia where there is significant potential for geothermal power generation and a policy impetus to support this, as discussed further below.

Number of European Geothermal Power Deployments



Source: EGEC

We see geothermal power generation as continuing to play a role in providing baseload power to the grid where the resource is available and see potential technological developments in deep geothermal, allowing for more high-temperature resources to be accessed, as contributing to the decarbonisation of power grids in the longer term.

AI Demand to Drive Growth in Power Developments

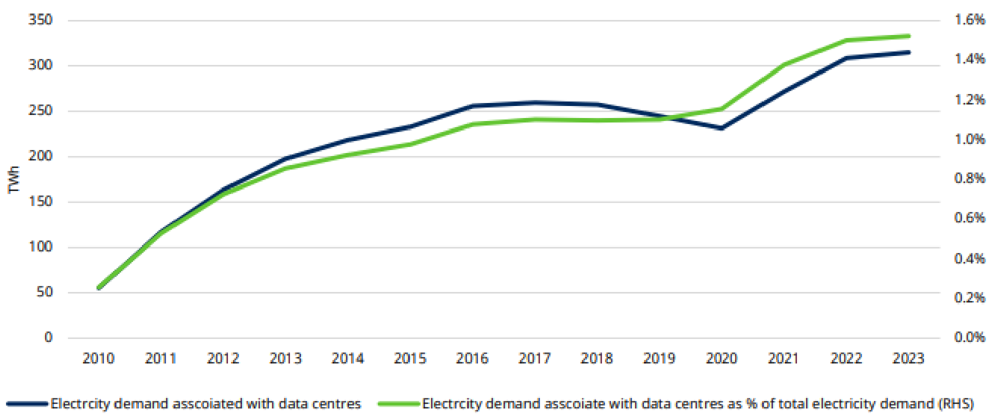
We also note the continued demand for clean baseload power in the data centre space. Meta has agreed a deal with Sage Geosystems to purchase geothermal power for its US data centres. This will be a 150MW project, with the first phase operational by 2027. This was followed by an announcement from Google who have entered into an agreement with Berkshire Hathaway subsidiary NV Energy to power a Nevada data centre with a 115MW geothermal development.

There has been an active drive from the US government to ensure that companies with large data centre power requirements are using clean baseload power and there is a clear demand for geothermal power as a solution in this scenario, providing low-cost, low-carbon, consistent power to meet data centre demand. Data centres alone are forecast to consume 9% of the US electricity supply and with no new nuclear plants currently being built geothermal power could very conceivably step into this space and deliver meaningful amounts of clean energy.

There will likely be an equivalent demand surge as global data centre demand is expected to increase toward 1000TWh of annual energy consumption by 2026 according to the IEA. We have already seen an example of this with Microsoft and G42 announcing a data centre in Kenya to be constructed and powered by geothermal energy in the country. Whilst we see geothermal energy demand being more heat-driven in the UK and EU markets, more geothermal activity across the board, whether in power or heat, ought to deliver industry-wide benefits through data sharing, process and technology advances, improved resource identification globally and a higher profile with policy makers and investors.

Forecast Electricity Demand Associate with Data Centres

Figure 1: Global electricity demand associated with datacentres in absolute terms (TWh) and as a % of total electricity demand

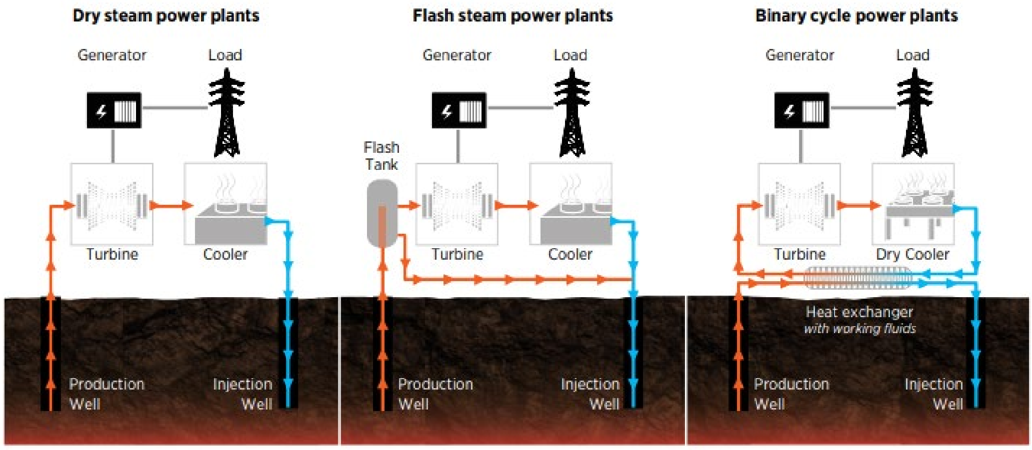


Source: Thunder Said Energy

Geothermal Power Technology Overview

Geothermal energy in power generation typically uses three main technologies: dry steam, flash steam and binary cycle. Each system has different characteristics and efficiencies and is generally used based on the nature of the resource. It is commonly assumed that around 10% of the energy from produced geothermal fluid can be converted to electricity. This can vary upwards towards 20% however the energy efficiency generally depends on the individual plant design and geothermal resource and temperature.

Geothermal Power Plants Summary



Source: US DoE

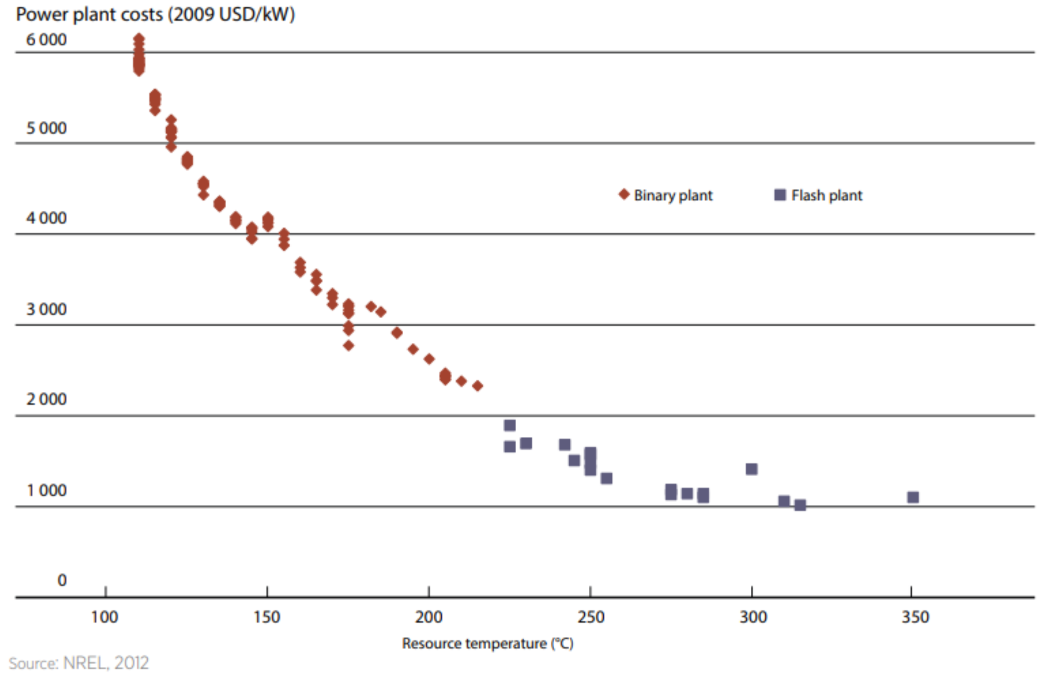
Dry steam power plants are the oldest type of geothermal power plant and use steam directly from the geothermal development to drive turbines and generate electricity, requiring high-temperature steam (over 180°C) and a high-quality resource. Dry steam plants in Europe typically range from 8-140MW.

Flash steam plants "flash" the steam (as the hot water rises to the surface, the pressure drops, causing some of the water to rapidly vaporize, or "flash," into steam) to drive the turbines, making it suitable for high-temperature reservoirs over 180°C. Flash steam plants vary in size depending on whether they are single (0.8-80MW), double (2-110MW) or triple flash plants (60-150MW).

Binary cycle power plants power plants use two fluids: geothermal water/steam and a secondary working fluid with a lower boiling point. The geothermal fluid heats the secondary fluid through a heat exchanger causing the secondary fluid to vaporise. This vapor drives the turbine to generate electricity. These are suitable for moderate to lower-temperature geothermal resources (85-150°C).

Each plant will have a different capital cost and the design will be driven by the temperature of the resource and the nature of the demand. In general terms dry steam power plants are typically cheaper to build, with an approximate capital cost of C£1.9m/MW-c.£4m/MW of capacity. Flash steam and binary cycle plants are broadly equivalent in cost but both have a higher range than binary cycle plants at c.£2.2m/MW up to c£7.5m/MW.

Indicative Power Plant Only Costs for Projects by Reservoir Temperature



Source: NREL

GEOTHERMAL SOLUTIONS COMPARED

In comparing geothermal energy solutions to existing renewable energy solutions, it is worth considering the emissions profiles, levelized cost of electricity, coefficient performance of heat and the availability of alternatives for the stated objectives. As noted above, there are hard-to-abate areas and projects (notably in domestic heating) where electrification will not be the optimum solution and whilst technological solutions may emerge over time, geothermal can provide a clear pathway towards decarbonisation now.

LIFE CYCLE EMISSIONS

In general terms, the production of geothermal energy results in a significantly reduced GHG emissions profile compared to traditional baseload and heating technologies, whether compared to fossil fuel or renewable technologies.

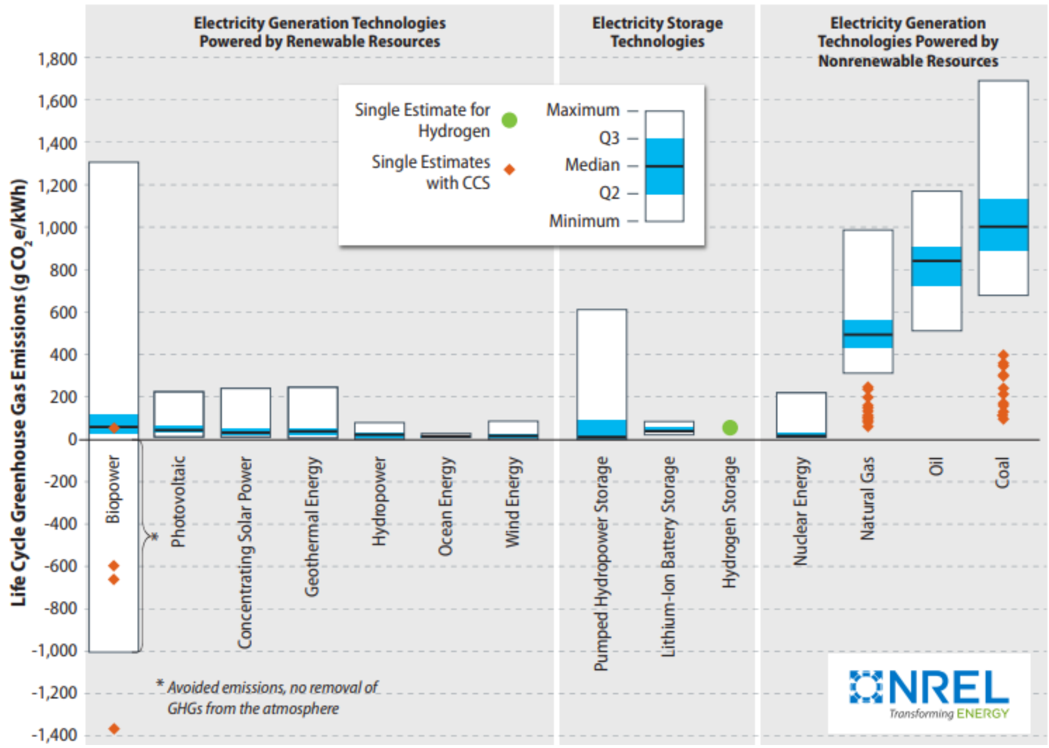
The emissions profile of a conventional geothermal project is highly contingent on the nature of the reservoir, the use of the geothermal network and the plant design selected if producing power rather than heat.

Whilst there can be significant amounts of GHGs in geothermal fluids (predominantly CO_2 and some methane), in most cases this fluid is re-circulated and returned to the formation and not released into the atmosphere resulting in very low emissions profiles from the geothermal energy itself.

A study by the National Renewable Energy Laboratory (NREL) in the USA has established that the major contributing factor to lifecycle emissions in geothermal electricity development is the selection of the power plant design. Emissions from a conventional hydrothermal flash plant are dominated by the operations phase due to the flash cycle being on an open loop whereby CO_2 contained in the geothermal fluids is released into the atmosphere. The lifecycle emissions from an EGS system are expected to be 32g CO_2e/kWh with emissions of 47 CO_2e/kWh for a hydrothermal flash plant and 11.3g CO_2e/kWh for a hydrothermal binary plant. Binary plants, using either EGS or hydrothermal resources predominantly emit during the construction phase owing to the closed-loop design process.

Geothermal energy compares very favourably with most renewable energy sources and is clearly a better alternative to conventional fossil fuel based sources.

Lifecycle Emissions Compared



Source: NREL

As noted in a closed-loop system there is a limited ongoing energy requirement to maintain production. Any emissions generated will be done during the construction phase, with embedded carbon in plant construction and likely emissions from a diesel-fuelled drill. The emissions per MWh generated post-construction will then theoretically be effectively nil and given the length of time in which geothermal plants can run this results in an extremely low life cycle emissions profile.

COEFFICIENT OF PERFORMANCE

The coefficient of performance refers to a ratio that measures the efficiency of a heating or cooling system. Specifically, it is the ratio of useful heating (or cooling) output to the amount of energy input required to produce that output.

$$COP = \frac{\text{Heat Output (useful energy)}}{\text{Energy Input (work or energy consumed)}}$$

The higher the COP, the more efficient the system is. For example, a COP of 4 means the system produces 4 units of heat for every 1 unit of energy it consumes. Whilst factors like losses and efficiency in the heat network and external conditions (e.g., weather) can reduce the effective COP, the measure remains a good indicator of the potential efficiency of heating or cooling systems.

Analysing the COP of a network is critical for comparing different system designs, optimising system performance and maximising the economic return for a project.

Geothermal compares very favourably from a heat perspective when looking at COPs as we can see below:

Coefficients of Performance Compared

Technology	COP
Geothermal Heating	Up to 20
Shallow Geothermal- GSHP or array	3.1-5.0
Air Source Heat Pump	2.0
Direct Electric Heating	1.0
Gas Boiler	0.7-0.9
Hydrogen	0.5

Source: NREL

Higher COPs equate to higher efficiency, lower energy consumption and generally lower operating costs.

Geothermal district heat networks present a large opportunity to disperse cheap low-carbon heat in one of the most effective manners currently available.

LEVELISED COSTS OF ELECTRICITY

The International Renewable Energy Agency (IRENA) has calculated that electricity generated from geothermal energy in 2021 was approximately £42/MWh ($56MWh), putting it in the lower band of the cost of electricity generated from fossil fuels. The report uses a global weighted average levelized cost of all projects commissioned in the year- given the low deployment rate for geothermal this can mean that the weighted average costs and performance figures are being determined by a limited number of plants each year. The cost of geothermal however varies significantly in practice due to the site-specific conditions required, such as the location specific geology, and hence number of wells and depth required. This is then further augmented by the average electricity output, the technology deployed and whether the development is green or brownfield. The LCOE for geothermal has remained broadly between £4-£58/MWh ($5-$78MWh) over the past decade whilst comparable renewable energy sources have experienced considerable improvements due to advances in technology and manufacturing, driving down costs across the value chain. This LCOE is broadly in line with the Lazard LCOE calculations which have $64-$106/kWh as their levelized cost of energy.

Rystad Energy have noted that the overall LCOE at most geothermal developments increases incrementally as the capacity factor drops, with LCOE increase of approximately £38($50MW) per MWh decrease, highlighting the importance of consistent high availability in the returns for geothermal power.

Potential exists to reduce the LCOE of geothermal energy, mainly through reducing the upfront drilling and exploration costs and there have been a number of identified measures which will allow for this. One of the reasons for the significant decrease in shale oil and gas cost reductions over the past decade since the shale boom of the mid-2000s is that there has been a significant number of wells drilled and this has allowed for the spread of best practices across the industry and progression along the learning curve. The last two decades have seen 22,000 oil and gas wells drilled in North America and 150-200 geothermal wells drilled in the same period. Whilst there is a degree of read across, ultimately the number of geothermal wells drilled will need to increase significantly to begin to benefit from lower costs as companies become better at identifying and exploiting resources.

EGS and hydrothermal well costs are considerably higher than oil and gas well costs as a result of the lack of technical innovation and development, often 2-5 times more expensive than wells of comparable depth (most US oil and gas wells are drilled to an approximate depth of 2km).

Well drilling costs are typically split into 5 stages, pre-spud costs, casing and cementing, drilling- rotating costs, drilling- non-rotating costs and other costs. In EGS developments it is estimated that drilling costs can range from 42%-95% of the total cost of a development, again highly dependent on the overall resource available. This often must be committed before the characteristics of the resource are fully determined, creating the element of risk.

$$LCOE = \frac{Sum\ of\ costs\ over\ lifetime}{Sum\ of\ electrical\ energy\ produced\ over\ lifetime} = \frac{\sum_{t=1}^{n} \frac{It + Mt + Ft}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Et}{(1+r)^t}}$$

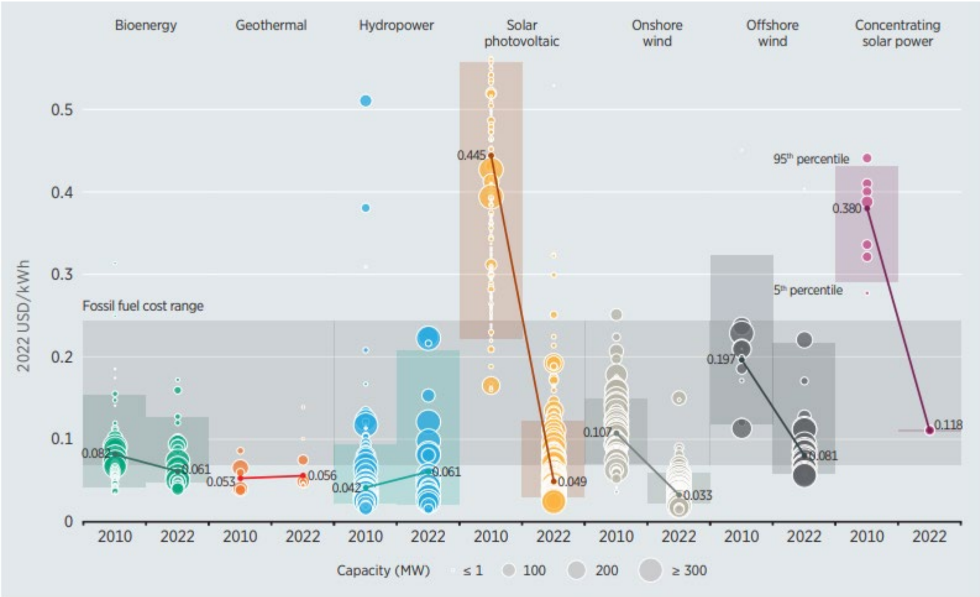
The make-up of costs for a conventional geothermal power plant includes installed costs (for the plant), upfront exploration and well drilling costs and continuing operations and maintenance. O&M costs on traditional geothermal projects can be typically low unless there is a significant issue, typically to do with scaling or atypical fluid chemistries causing issues.

Levelised Costs Compared

Levelised costs for geothermal (most costs are informed by power generation projects rather than heat, however, we think this is still valid for comparing against geothermal for heating uses particularly as the world moves away from fossil fuel-based heating options) compare very favourably with both existing fossil fuel generation but particularly well against offshore wind and slightly higher than solar PV and onshore wind. What is clear to see is the drop in costs that have been witnessed in the newer renewables technologies, with learning curves and competition driving prices downwards. There is another clear and directly analogous reference case for potential learning curve improvements for geothermal energy in the form of the US shale gas industry which experienced significant drilling cost improvements as more participants entered, more wells were drilled and iterative technology improvements all combined to drive costs lower and improve returns.

Whilst a decrease in costs is unlikely on the same scale for geothermal technology, we see scope for decreases in costs over the longer term, potentially putting geothermal energy on a more even footing with solar PV and onshore wind. Importantly in the levelized costs presented below, this does not include any storage included with wind/pv which would be relevant in including when comparing with geothermal energy given its dispatchable nature. Using the Lazard LCOE for onshore wind & storage of £34-£99/MWh or £45-£157/MWh ($45-$133/MWh or $60-$210/MWh) for solar & storage, geothermal energy looks particularly attractive from a LCOE perspective.

Weighted Average Levelised Costs Compared 2010-2022



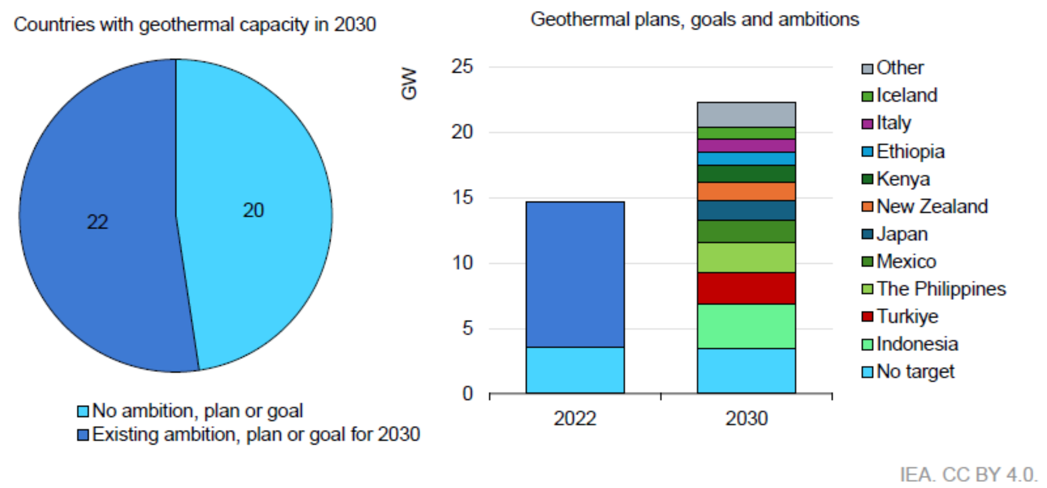
Source: IRENA, Power Generation Costs in 2022

We also note that there has been significant debate around the inclusion about imported LNG into the Carbon Border Adjustment Mechanism in the EU. Whilst UK policy could deviate from this, there is an expectation that LNG could be included in the mechanism. If so, this would significantly increase the price of imported LNG, which accounted for 45% of the UK's natural gas imports in 2022. If so, the relative cost of gas would make geothermal energy look increasingly attractive from an economic perspective, as well as an emissions perspective.

GEOTHERMAL POLICY IN KEY MARKETS

Below we explore the policy environment across key jurisdictions however the bulk of targets are directed towards power capacity rather than heating and cooling. We do note, however, that several countries that have recognised heating in its targets, particularly in the EU where this features in several National Energy and Climate Plans (NECPs).

Government plans, goals and ambitions for geothermal power capacity in 2030



Note: Left figure numbers include three regional aggregates, accounted as single countries. Actual number of countries may be larger than indicated.

Source: IEA, Future of Geothermal

<u>UK</u>

Regulatory Environment

Regulation of geothermal developments is determined by the devolved administrations in the UK and none of the individual governments have bespoke planning rules, licensing or environmental regulation specific to geothermal schemes. The most regulated area of the geothermal drilling process is the environmental regulations and specifically that around water sources and contamination. The Environment Agency currently regulates projects in England with SEPA in Scotland and NRW in Wales. As geothermal energy is not a recognised natural resource in the UK there is no other regime or regulatory mechanism like licensing required, however, a lack of clarity around this is widely seen as a barrier to investment and development of geothermal resources.

Existing Support Schemes

In terms of financial support and regulations, this does exist for geothermal energy in the UK, however only for the generation of electricity and not for the supply of heat, with geothermal having been included as a viable technology in Allocation Round (AR) 6 for contracts for differences (CfDs), at a strike price of £157/MWh in 2012 prices. In AR 5 Geothermal Engineering Limited were awarded the first 3 geothermal CfDs at its United Downs, Manhay and Penhallow projects at the maximum bid price of £119/MWh over a 15 year term life. It is unlikely that the CfD alone will cover the extensive capital cost of required for these projects and that economic returns will need to be derived over a longer period.

Two schemes are available in England and Wales to support the rollout of district heat networks. The Heat Network Delivery Unit (HNDU) and the Green Heat Network Fund (GHNF). The former saw £3.9m awarded to 30 local authorities in 2022/23 and as of December 2023 had awarded £33.8m in total across 13 allocation rounds. The GHNF opened in March 2022 with £288m of capital funding and this was topped up in 2024 with an additional £220m committed. To date they have distributed £117m of funds across 9 projects and there remains a significant pipeline of projects that have applied for funding. The GHNF will fund up to, but not including 50% of a project's total combined commercialisation and construction costs.

There is also the BHIVE Platform which acts as a platform, connecting providers of financing for heat networks with those seeking funding, ultimately aiming to develop an efficient market for financing.

In Scotland, three funding programmes are available for heat networks that could in turn support geothermal developments. The Scottish Heat Network Fund (SHNF), the Low Carbon Infrastructure Transition Programme (LCIPT) and the Community and Renewable Energy Scheme (CARES).

The British Geological Society released a white paper in 2023 requesting further financial incentives to support geothermal energy in the UK, however, there is currently no legislation being progressed in order to support geothermal technology further.

Areas Identified to Increase Deployments

There are several key areas which industry participants have identified as areas for improvement that could support further geothermal development in the UK (excluding issues with the wider planning and development process that plagues most UK infrastructure projects):

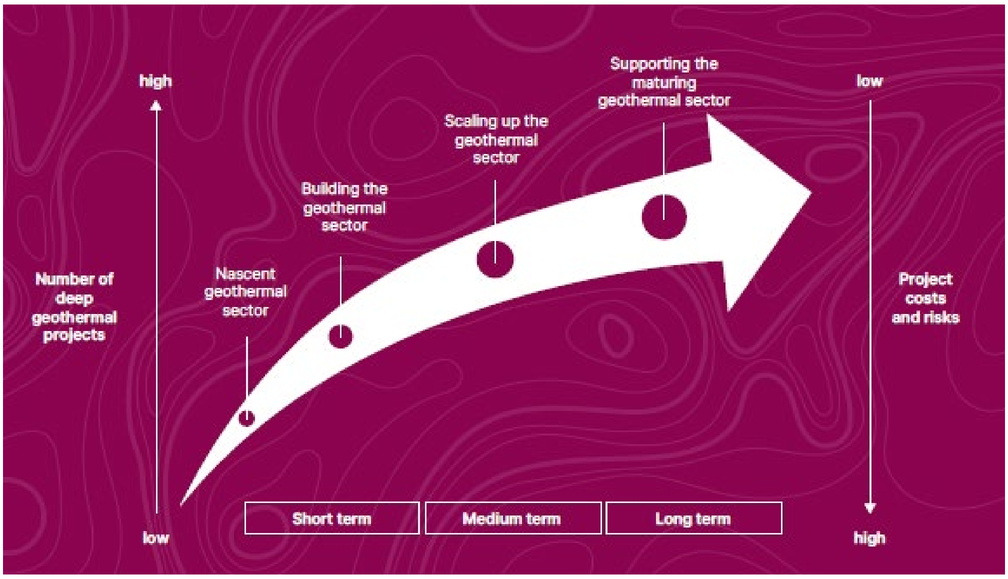
- Creating a fast-track approach for geothermal projects which brings the relevant agencies and authorities on board and allows for more rapid deployment
- Development of a heat production incentive and other geothermal specific revenue support mechanisms
- Introducing a rolling funding model in the medium term
- In the long-term developing a revenue sharing mechanism combined with risk sharing schemes

A faster geothermal approval process would significantly speed up the roll out and development of the technology. The government needs to take more of a technologically agnostic approach when it comes to decarbonising heat and buildings. Supporting a more rapid deployment of geothermal technology is critical in getting more projects off the ground. As we have seen with the grid congestion slowing new conventional renewables projects from coming online, a lack of joined up thinking can result in equivalent delays which can result in providers of capital looking to other jurisdictions or technologies.

For geothermal heating projects specifically, a heat production incentive dedicated to deep geothermal projects would be a long-term commitment to production which would de-risk early stage projects and support a nascent industry. Funding could come out of existing levies or be based on future CO_2 savings based on the existing carbon intensity of the UK grid and carbon pricing for example.

The North East Local Enterprise Partnership released a Deep Geothermal Whitepaper, funded by DESNZ, which noted the following policy improvements that could support a more robust geothermal sector in the UK. In the short term, adopting revenue measures such as Feed-in-Tariffs or CfDs with funding ringfenced for geothermal technologies. In the medium term using financing support like rolling funds that could allow for multiple project development as opposed to funding on a project-by-project basis, allowing for a faster development of projects. And in the long term, using a combination of revenue methods combined with risk sharing schemes, as have been successfully deployed in the Netherlands and Germany, both discussed further below.

Developing a UK Deep Geothermal Sector



Source: North East Local Enterprise Partnership

Lastly, whilst there have been no specific references to renewable heat, including geothermal energy in the mandate of GB Energy to date, it is hoped by some in the industry that this too could support a further rollout of geothermal energy in the UK.

European Union

Whilst the European Geothermal Energy Council has been pushing to increase the state support for geothermal projects in the EU, particularly in light of Russia's illegal invasion of Ukraine, policy support to date has been somewhat slow. There has been no update to the EU Deep Geothermal working group's implementation plan since its last revision in 2020. The bloc has spent around €700m on research subsidies for geothermal energy in the decade to 2020 compared to solar and wind technologies receiving an estimated €30 bn and €21bn respectively in 2020 alone.

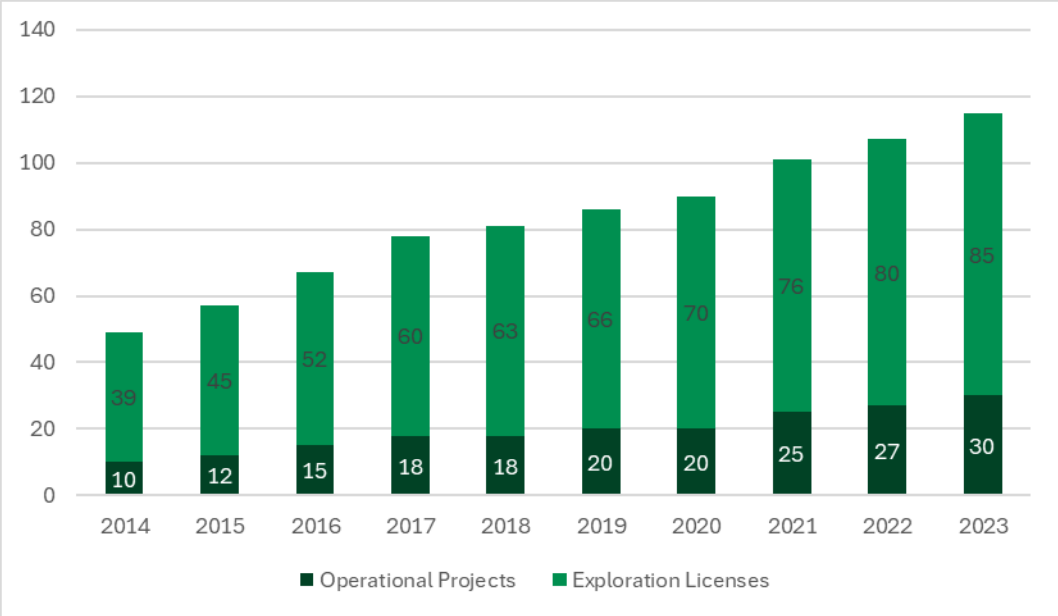
Regulation and incentivisation of geothermal energy is done on a national basis in Europe. As with the UK, geothermal regulation tends to fall under the jurisdiction of non-geothermal legislation, such as under mining laws or groundwater laws (depending on the depth of drilling and legislation etc). Germany, France and the Netherlands are all progressing policy frameworks around the technology focusing on both heat and electricity and this has been borne out by a number of developments in place in each jurisdiction. We expect to see this continue to develop across Europe as net zero targets continue to draw closer.

Netherlands

The developments in the Netherlands are perhaps most analogous with where the UK market could get to with sufficient support, as the bulk of projects in the country are 2-3km in depth targeting resources of 70-100°C and deployed in heat projects in order to replace existing gas consumption.

Since 2014 the Netherlands has seen a significant increase in the number of geothermal projects and licenses awarded, largely driven by a supportive policy backdrop. Operational projects have increased by 200% with exploration licenses having increased by 130% over the period.

Growth in the Dutch Geothermal Sector



Source: Longspur Research

The Master Plan for Geothermal Energy in the Netherlands describes the ambitions for the geothermal sector for 2030 and 2050 and the approach that is needed to achieve this. The plan sets out ambitious growth targets, namely increasing geothermal heat production from the current 3 petajoules (PJ) per year to 50 PJ by 2030, and further to over 200 PJ by 2050.

The Netherlands launched a mandatory participation scheme for all geothermal developers where Energie Beheer Nederland (EBN) had to become a partner in projects. This legislation ensures that EBN bears a degree of financial and risk-bearing participation in new geothermal projects. As an expert and financial stakeholder, EBN can participate in decisions that affect the sustainability and quality of projects on the basis of its public task. In addition, EBN can use knowledge from projects for other projects and aggregate experiences for policy development, innovation, public knowledge of the subsurface and tightening up incentive instruments.

Importantly Dutch geothermal companies are also able to benefit from state-level subsidies. The SDE++ supports the production of renewable energy and the reduction of CO_2 emissions. The subsidy is granted based on the amount of renewable energy produced or the CO_2 emissions reduced. It provides a guaranteed price for the energy produced, covering the difference between the cost price and the market price.

Under the SDE++ subsidies in the Netherlands, a grant of EUR 2 billion will be made available for at least 18 new geothermal projects in the coming years, as announced in April 2023. This is part of the country's sustainable energy transition subsidy scheme (SDE++) round of 2023, following a showing of interest in the 2022 round.

There are currently 22 geothermal projects under management or have SDE++ decisions that have not yet been realised. With the new announcement, the total number of geothermal projects in the Netherlands can reach more than 50. According to Geothermie Nederland, these projects will be able to provide sustainable heat production for 7% of the homes in the country, or up to 25% of the total Dutch heat demand in the future.

It is worth noting that safety is an absolute pre-condition for developments in the Netherlands, with permits only being issued where this can be guaranteed. The country has a history of seismic events related to the development of the Groningen gas field and this is a high salience issue for the public. The fact that the Netherlands has been able to develop a framework that is able to deploy geothermal energy with high levels of public approval highlight that this is possible.

Germany

In June 2024 it announced a draft law aiming to expedite the approval processes for geothermal plants and heat storage systems as the country looks to phase out fossil fuels from its heating system by 2045. The law is aiming to get 10TWh of heat generation in Germany by 2030. This effectively increases the current feed-in to the heating grid from geothermal by tenfold.

Germany already has a number (42 as of February 2022) of historic district heating networks powered by geothermal energy, notably in the Bavaria area, however further development has attracted sporadic local opposition and a heavy bureaucratic burden.

France

The National Geothermal Development Plan was set out in 2023 and aims to increase drilling capacity and refine the regulatory framework to increase the number of shallow and deep geothermal energy projects. It also aims to identify more deep aquifers suitable for constructing heat networks with the aim of increasing the number of projects to reach an output of 5.2TWh of production by 2028.

The plan also encourages new, innovative financial arrangements and provides support to project leaders to deploy geothermal solutions. It also involves mobilizing the Ecological Transition Agency (ADEME) and the Geological and Mining Research Bureau (BRGM) to contribute to these efforts. ADEME have a €800 fund for 2025 which they are able to deploy across projects for deep geothermal, which will provide guarantees for the drilling operations for deep geothermal projects of up to 30MW, helping to significantly de-risk the drilling stage for potential operators.

Croatia

Croatia has been implementing a wider policy to encourage renewable energy production in the country to both reduce carbon emissions and increase energy security, following the war in Ukraine. Croatia has significant geothermal potential, with a high thermal gradient and potential for heat generation and power generation in some areas. The Croatian Hydrocarbon Agency plays an active role in facilitating geothermal exploration and exploitation activities, providing potential developers with data and assistance in the development process and licensing specific blocks for exploitation, leading to production. A change in regulation in 2016 provided the possibility for thousands of disused oil and gas wells to be potentially reused for geothermal projects. Several projects are under development currently and the Hydrocarbon Agency is actively looking to pursue more of these.

Poland

Similarly, Poland is looking to increase its energy security and move away from a historic coal reliance and has accordingly developed a roadmap to support geothermal development, with a target of reaching 290MW of geothermal capacity by 2040. This is supported by the National Fund for Environment Protection and Water Management which has allocated c.£50m to support geothermal development in the country, and in particular to support geothermal heat networks.

USA

There is policy support in the USA for geothermal at the federal level in the form of the Inflation Reduction Act and the Bipartisan Infrastructure Act. The former extends tax credits to geothermal developments whilst the latter has an $84m allocation for EGS demonstration projects.

With the potential for 90GW of total geothermal capacity, there is a recognition that the country could significantly reduce emissions by investing in the technology. The bulk of this resource is largely difficult to extract however and thus the focus of US policy support to date has been to help develop EGS systems rather than conventional geothermal. This has also been reflected in much of the investment in the space from private parties also focusing on EGS technologies.

The US DOE has announced up to $74m for the development of seven pilot projects for EGS. The DOE is hoping that the projects will display the scope for using new and developmental techniques to enhance the geothermal potential in the USA. Ultimately the DOE hopes to reduce the total cost of geothermal energy in the USA by 90% by 2035 to $45/MWh.

The USA has a strong background in onshore oil and gas and $165m of funds are being used to transfer best practices from the oil and gas industry into geothermal. An additional $44m has been given to the Frontier Observatory for Geothermal Energy Research field laboratory to help spur innovations.

On the state level, several states are looking to try to streamline permitting procedures and create funding bodies for geothermal initiatives, notably in California, Nevada and Utah along the west coast, where the bulk of the identified geothermal resources in the USA exist.

Rest of the World

RoW conventional geothermal development is expected to remain focussed on countries with extensive geothermal resources that have already developed a significant amount of geothermal energy production, namely in Turkey, Japan, Indonesia and Iceland. Given the significant history in these areas and the continued drive towards net zero, new deployments and policy support will continue in established geothermal nations.

Iceland has a geothermal policy as a central element in its renewable energy goals, with geothermal energy currently representing 66% of the country's primary energy use. The National Energy Authority oversees geothermal resource assessment and monitoring and there is a master plan in place to categorise areas for exploitation, production or further research all with a view to ensuring there is a sustainable approach to the island's geothermal resources. Even with significant geothermal already deployed Iceland is looking to achieve carbon neutrality by 2040 and will be adding more geothermal capacity to achieve this.

Kenya continues to develop geothermal energy under the Ministry of Energy in the country. There is a strong institutional framework in place with the Geothermal Development Company in place to help facilitate the entry of independent power producers into the Kenyan geothermal sector by undertaking most of the higher-risk exploration and field development phases whilst the Kenya Electricity Generating Company is a state-owned entity developing and operating geothermal plants. Kenya is aiming to have over 51% of its total electricity requirements provided by geothermal power capacity by 2030 and there may be significantly more geothermal development here, particularly with Microsoft entering into the market in a $1bn dollar agreement to invest in a geothermal powered datacentre in the country.

The Philippines is one of the top producers of geothermal power in the world due to the country's location in a volcanic zone. Currently, approximately 14.6% of its energy production comes from geothermal energy, however, with a forecast shortage of energy commencing in 2040 significantly more geothermal energy is expected to be added to the grid before then. Historically geothermal energy was limited to state enterprises, however, in 2020 this was opened up with projects able to be 100% owned by foreign entities to enable further growth in the sector.

Indonesia is targeting 10GW of geothermal power capacity by 2030 as it looks to increase its renewable energy share on the road to net zero. Policy is overseen by the Ministry of Energy and Mineral Resources. The state company PT Geo Dipa Energi is able to develop geothermal projects, or private enterprises can also enter into agreements with the government to develop projects independently.

Japan is seeing geothermal as a resource to provide clean baseload power and help the country reach its net zero 2050 target as the country transitions away from imported fossil fuels. The government has targeted 1.5GW of capacity by 2030.

There is broad support for geothermal energy in China, with the 2017 release of the "13th Five-Year Plan for Geothermal Energy Development and Utilisation", which promoted the development of geothermal to reduce air pollution and supply continuous base-load electricity and heat for the first time. The 14th five-year plan for renewable energy calls for the development and use of geothermal energy, focusing on optimising geothermal heating and cooling deployment. Sinopec Green Energy (SGE) have used their oil and gas skills to develop a commanding presence in the Chinese geothermal district heating sector with over 35% market share, having drilled over 900 wells across 90 cities, providing a clear example of an oil and gas company using their skills in the energy transition.

Ultimately, across jurisdictions, there remains a need for more policy support. Explicit targets and goals are required for the development of geothermal energy beyond those currently stated.

With conventional geothermal energy, there remains significant upfront exploration risk and effective instruments will be needed to reduce this if the sector hopes to expand further and reach the forecast geothermal power generation figures as required to reach net zero by 2050.

Whilst specific policy targets and support are clearly important in the development of a more substantial geothermal industry, there is also a clear need to make geothermal energy competitive against fossil fuel alternatives. Overall, we see carbon pricing in the long term as a strong market incentive to increase the uptake of geothermal energy.

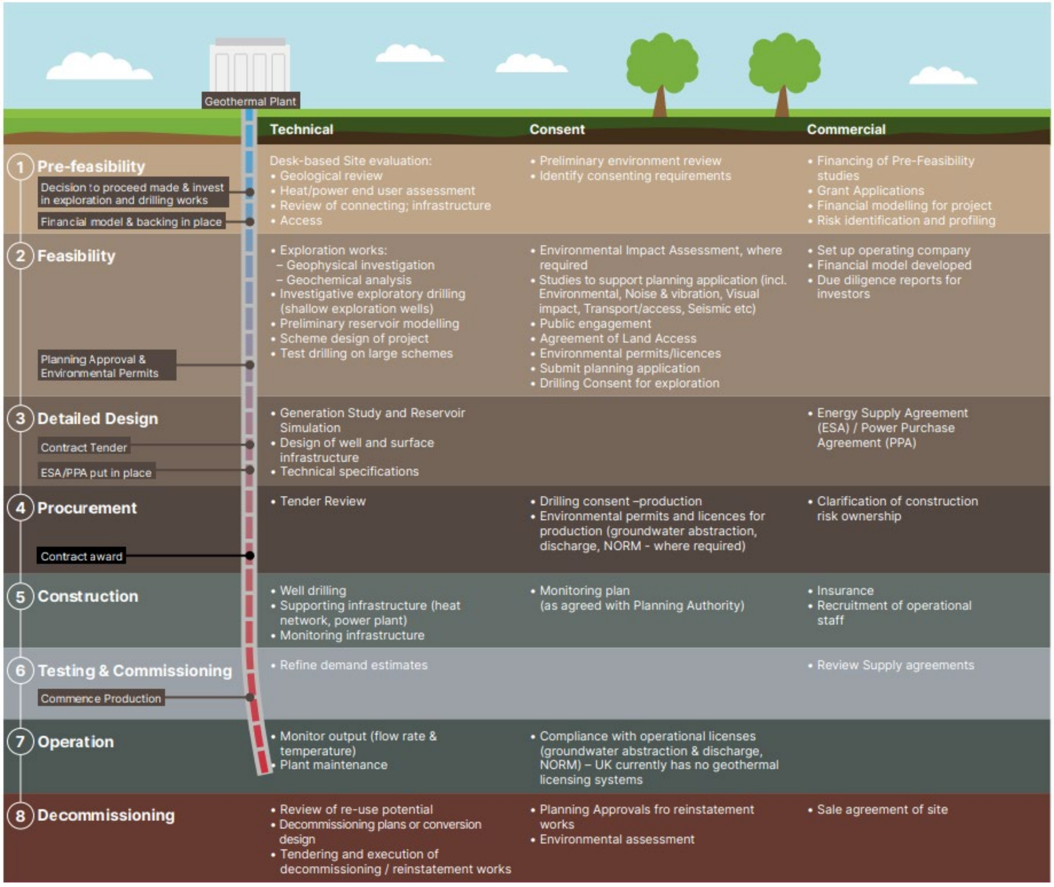
There is also a need for ongoing public policy work to educate the public about the relative merits and limited drawbacks of geothermal energy. Ultimately, as Sanjeev Kumar, Head of Policy at the European Geothermal Energy Council, has stated "Geothermal energy has never really been attractive because nobody really understands it"- policy and education will be required to help overcome this and unlock the benefits of this technology.

DEVELOPING A GEOTHERMAL PROJECT

A geothermal development is a multi-staged development, with the bulk of the work performed prior to commercial operations. The exploration and feasibility study stage can be time-consuming, but this is critical to ensure that the drilling process, which is the most expensive element of the endeavour is successful

The graphic below highlights the various stages in progressing a geothermal development and whilst this can vary globally, a number of the key elements remain the same on the consent and commercial elements and almost entirely so for the technical elements. This is a workflow that has been adapted from the oil and gas industry and shows that there is significant scope for oil and gas companies like Star Energy to transfer skills into the geothermal space. There are numerous stakeholders to engage with and workstreams to undertake prior to the construction phase and this is what drives much of the pre-commercial costs.

Roadmap to Develop a Deep Geothermal Plant



Source: Source: The case for deep geothermal energy- unlocking investment at scale in the UK: C Abesser; A Gonzalez Quiros; J Boddy

Exploration, Pre-Feasibility and Feasibility Stages

In simple terms, these steps in the process aim to identify geothermal reservoirs for possible exploitation, select the best sites for drilling production and then determine the commercial and technical feasibility of advancing to production.

Exploration typically begins with gathering data from existing nearby wells (where available) and other subsurface data, and goes on to surface and sub-surface surveying using geological, geochemical, and geophysical methods.

Naturally, a detailed knowledge of the project area geology is critical. Initial studies will focus on the broader area before these are more focused on finding the pathways that will allow for the most efficient extraction of thermal fluids to the surface for power production or heating.

Geochemistry and geophysics will also play a crucial piece in the testing phase, with an understanding of the exact chemical nature of the fluids being needed to understand how the fluid could flow and the impact on the surface level pump and heat equipment. Similarly, geophysics and an understanding of temperatures and flows are necessary to know that an identified resource will flow at the desired rates and temperatures to the surface, to ensure that there is sufficient heat to meet the offtake demand and to ensure there is sufficient demand generate a reasonable return on the development cost.

Once the necessary studies have been completed, this can then be input into a conceptual model to display the understanding of the geology, temperature and fluid pathways in the system, informing the future drilling to allow for a successful well and determining whether a development will be feasible from both a technical and commercial perspective.

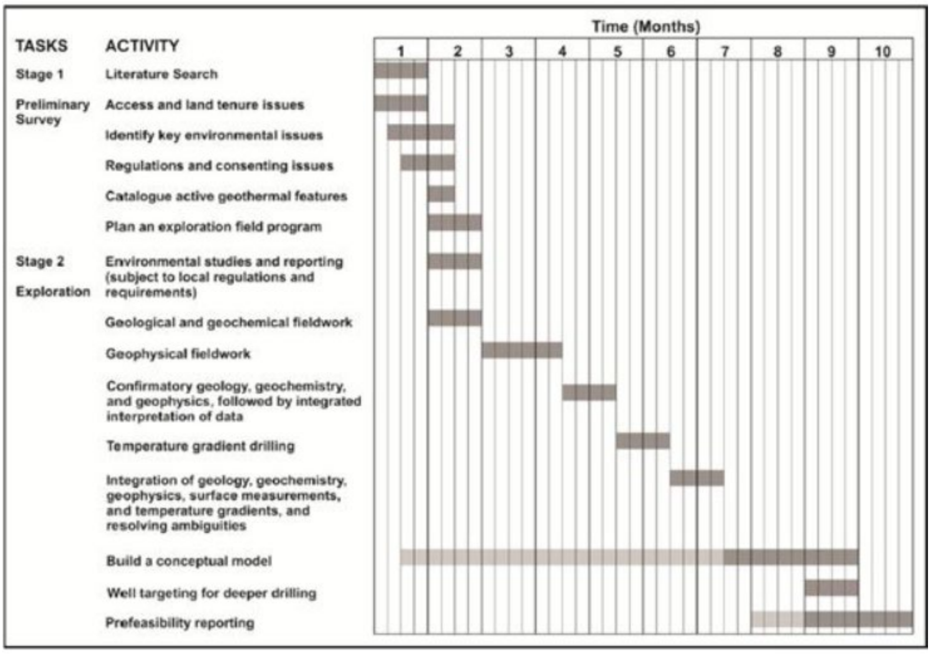
The exploration techniques will vary depending on the project and geological setting, however regardless of this all data requires experienced and grounded interpretation to reduce exploration risk.

There is a substantial amount of geological data that has been accrued through hydrocarbon exploration globally and this can be reinterpreted and evaluated for geothermal energy as part of the process of exploration, potentially negating the requirement to collate entirely new datasets and accelerating development opportunities. New technologies are being developed constantly to reinterpret and model existing data sets or to capture new datasets in order to better understand the subsurface resources and over time, increased knowledge in this area could help to substantially reduce risk when commencing drilling operations.

Not every identified project will make it through each of these stages prior to drilling commencing and while this can result in sunk costs requiring impairment, it is critical these steps are followed to develop a robust, commercially feasible project.

Timelines and the required exploration activities will inevitably vary according to location, existing data, project complexity, jurisdiction and developer priorities and skillsets however the below can be used as a very rough indication of progression through the early stages of a geothermal development.

Indicative Exploration Timeline



Source: Oil and Gas Portal

Drilling

Geothermal energy relies on the recognised skills and technology developed in the oil and gas industry to drill to significant depths, with large well diameters and often using lateral drilling techniques to exploit fluid reservoirs. Across Europe and the USA, there is a significant number of transferrable skills from the oil and gas industry, which can be applied to geothermal technologies, and we see this as being a key part of the energy transition.

Drilling an initial well is the final phase in any geothermal development and is, ultimately, the only means of confirming the characteristics of a geothermal reservoir and determining its energy potential.

The first well represents the period of highest risk and cost. Beyond this, the risk is reduced with regards to the viability of the resource as more wells can help prove this up. The number of wells required will be determined by the nature of the resource (high temperature, flow rates etc), the energy end-use type (heat, power or both), and the size of the demand.

Two or three wells can provide a suitable balance between resource appraisal and cost for convection-dominated geothermal plays. In many instances the first well drilled can be done to production standards and design, meaning that the first well drilled (technically called an exploration or even a wild-cat well) can be re-used for production should it prove successful.

The production well itself is determined by the depth of the resource and the well design, whether this is a coaxial system involving one well with both injection and production inside it, or as is more commonly seen, as a doublet with a separate injection and production wells, or a design with multiple production and injection wells.

Success in Drilling

Unhelpfully, there is no universal basis for defining the success of a geothermal well. In the longer term, this is clearly derived from the return on investment, however, in the shorter term, test results in line with or exceeding those modelled are generally seen as a good outcome. This can result in a blurry line between good and bad which can be re-evaluated as you go.

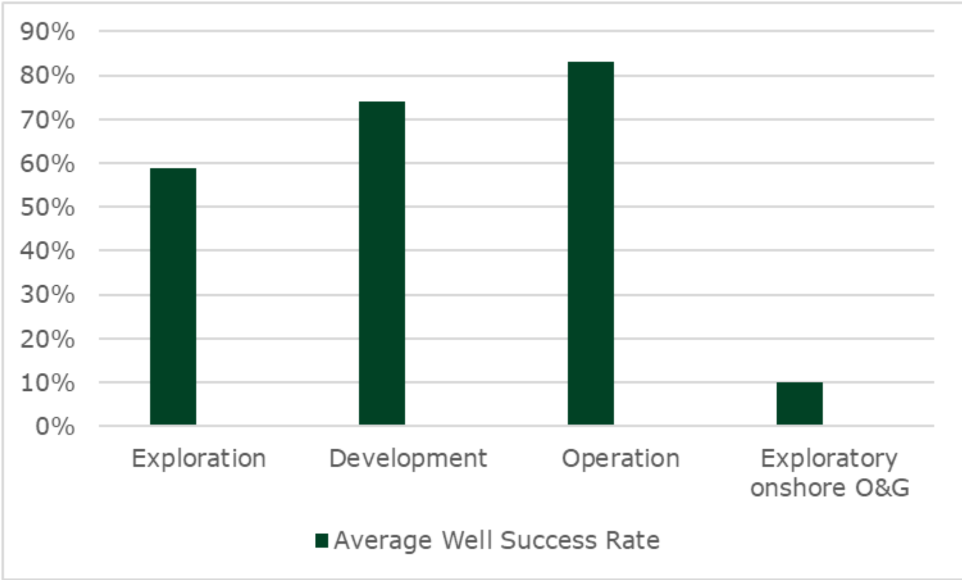
There is an element of risk in the drilling process and issues experienced can range from more minor logistical issues such as drill pad location and availability of rigs and services which can cause project delays and impact on returns to more technical and geology based risks, i.e. issues such as stability of the rock that must be drilled through, pressure conditions or the geology not aligning with that modelled, which can sometimes only be identified once drilling has commenced. Again, these can be mitigated against, particularly when leveraging skills from the oil and gas industry where drilling issues such as this are seen more frequently. As any issues will likely see a departure from the geological and economic model, the cost impact can vary and should be viewed in the context of the wider economic model.

Success in geothermal drilling does differ from that in oil and gas. In geothermal the concept of a “dry hole”, i.e. a failure due to the discovery of water rather than hydrocarbons, does not exist. Most geothermal wells flow to some extent and it is a given that as one drills deeper the temperature rises. The points of failure can vary from unexpected mechanical problems to inadequate temperatures, inadequate pressures, unacceptable chemical problems or reservoirs that are too tight. The biggest challenge is ensuring that flow rates are high enough to support the commercial case. And (as noted below) that there is sufficient heat replenishment to support the long-term economic viability of the plan.

There are solutions to save a “failed” well i.e. one that has come in below modelled estimates in terms of temperature or pressure, however, the availability of said solutions depends on the targeted use case of the geothermal energy (heat projects generally run at a lower risk in that they typically require lower temperatures and flow rates for success) and the resource itself. These factors combined with the learnings of the resource from the drilling will inform the available options. These will naturally come with a cost and it may be that the solutions to remedy low temperatures or flow rates will make the development uneconomic.

In 2013 the IFC found that in a study of 2,600 geothermal wells around the world the “success” rate for the first well drilled to test a new reservoir was about 50%. The average success rate rose to 59% over the first five wells, to 74% during field development, and averaged 83% for wells drilled in operating fields. It is also possible to re-drill an initial well which is less expensive than drilling a new well. Rystad Energy Onshore estimates that oil and gas success rates in 2020 reached an all-time low of 10.6%, having previously been between 40-60%, naturally, this varies significantly by area and on the resource, however, it presents a frame of reference.

Historic Well Success Rates



Source: IFC, World Bank 2013, Longspur Research

Ongoing Operations

Once operational, there are limited ongoing risks that can impact the project. These are mainly to do with the water resource, the well or the plant operation. Most of these risks can and should be identified and mitigated through the design process prior to reaching operations.

From a resource perspective, there can be a faster-than-anticipated decline in pressure or production rates, premature cooling of the aquifer from either groundwater or the injection water breaking through into the reservoir. Sustainable management of geothermal resources requires a utilisation rate that can be supported by the system for a long time. This is fundamental to avoid overexploitation. Extraction rates higher than the natural replenishment of the system can result in a decline in either temperature or fluid volumes (however in almost all modern geothermal developments what is extracted is re-injected elsewhere in the reservoir making permeability the main limiting factor in a geothermal reservoir). These can all impact on the heat or electricity generation from a given well. This can be reduced in likelihood as more geothermal developments are progressed and a wider body of knowledge exists on how to deal with these issues. From a practical perspective, this should also be monitored and mitigated through an ongoing resource monitoring program and a comprehensive reservoir model.

In terms of the well structure itself, similar issues exist as those in the oil and gas industry, albeit the majority of these can be mitigated against. Failures can include casing collapsing within the drilled well or other downhole issues, which can be remedied using a traditional workover and monitored on an ongoing basis.

With regards to the above-ground installation, any issues directly related to the geothermal well are likely to be related to adverse chemical effects from the geothermal fluids which can cause scaling or a build-up in solids from cooling gas, which can impact heat exchangers or plant machinery in a power plant, causing scaling or impacting on fluid dynamics. Once again, these can be monitored and mitigated with an active maintenance regime, helping to ensure minimal plant downtime.

Once operational we see a significantly de-risked project and an attractive entry point for potential investors, discussed further in our assessment of funding options for geothermal developments below.

PERCEIVED DIFFICULTIES IN GEOTHERMAL DEVELOPMENTS

Whilst geothermal energy has wide public acceptance and support, there are perceived difficulties in development, all of which can be appropriately planned around but which require good communication and work with the community during the planning process to resolve.

These difficulties are, in practice, no different to the local opposition that is presented to other large capital projects. In the UK this is undoubtedly more emblematic of the wider issues that surround getting planning consents to build any kind of project, renewable energy or otherwise.

Public Sentiment

Much of the sentiment around geothermal developments are issues that are conflated with fracking for shale gas, even though non-EGS developments have no relevance to this. Whilst there are concerns, a large amount of the information that is disseminated around developments can be easily addressed with appropriate communication around the project and workarounds and solutions can be developed to make developments more socially acceptable. Conventional geothermal energy has a long and safe history and there needs to be a degree of dissociation with more exotic EGS systems and shale gas fracking. This can be difficult in a public discussion where nuance can be challenging. Whilst there is always going to be a degree of opposition to any development, this is a safe and dependable technology with a non-invasive footprint and should be supported as another tool in the toolbox in the race to net zero.

Impact on Water Sources

One of the concerns around geothermal resources, particularly those located near urban populations, is that they can have a negative impact on the water table. Whilst the environmental regulations differ from jurisdiction to jurisdiction, in the UK and EU there is significant regulation to prevent the contamination of groundwater sources. In the UK, most groundwater aquifers are between 100 and 200m underground. A geothermal project will drill significantly through this and there are safeguards to prevent any contamination during the drilling process, including the use of potable drinking water during the drilling process for lubrication and using biodegradable drilling mud. Wells are then typically lined with steel and cement to prevent any well fluids interacting with the water table.

Noise

Once in operation, the geothermal plant does not emit a great deal of sound, however, the drilling process can be loud when getting to depths of several thousand feet. Whilst this only covers a short period in the overall project lifetime, there are means by which to mitigate this. Star Energy whilst drilling wells in Surrey and Nottinghamshire deployed noise abatement solutions to drilling rigs and associated equipment which at the nearest dwellings reduced the noise to below background. Geothermal Engineering Limited are deploying an acoustic cocoon at their Penhallow development in the UK which will reduce drilling noise by over 10db, bringing the noise at the nearest home to approximately 33.9dB, the equivalent of a light rainfall.

Induced Seismicity

There is a perception that geothermal projects have an impact on seismicity. This is more typically associated with hydraulic fracturing, more commonly known as fracking, where this has been a commonly deployed argument. With EGS, this does remain a risk, however the experience of the US shale gas experience has shown more limited induced seismicity. This will be more acceptable to certain local populations than others, as has been seen with shale gas in the USA compared to significant opposition in the UK and Europe.

AGS systems are thought to negate this risk as their deep closed-loop systems do not require the fracturing of any rock. Hydrothermal systems also do not involve the fracturing of rock, so the risk of induced seismicity is reduced.

In general, induced seismicity is caused when faults slip, whilst geologists do comprehensive modelling around the geology the impact of the fracturing can be impacted by the ambient stresses in the reservoir rock and the local geologic structure. The size of a given seismic event will then depend on the amount of stress causing the slip and the size of the slip area.

Whilst this is a developing industry there are several case studies in the space to date and not all of these have been positive, as the industry continues to mature. The Basel EGS project involved the circulation of fluid in a conventional EGS system described above. Micro-seismicity is generally accepted with EGS however there have been cases where this has been above acceptable levels, notably at the Basel Deep Heat Mining Project. Hydraulic simulation at the project saw event magnitudes of up to Richter local magnitude (ML) 2.6, increasing to ML 3.4 after the well had been shut in, ultimately leading to the closure of the project. A root cause analysis has established that this was broadly caused by multiple fractures shifting for reasons that remain unclear.

There are alternate means of measuring and treating induced seismicity, at the Eden Project in Cornwall, under Cornwall Council's planning guidelines for blasting, quarrying and mining, rather than using a local magnitude scale for seismic activity, ground motion (peak ground velocity, PGV) measurements are used as an indicator for risk of structural damage to buildings from injection induced seismic events. In Cornwall, a PGV of 8.5mm/s is used as the maximum permitted level from blasting operations during working hours. The Eden Project, a conventional geothermal project uses 0.5mm/s for prudence. This was breached in March 2022 and the well testing programme was reviewed to minimise the likelihood of another event.

Two of the assumptions on induced seismicity are that minor seismic events deep underground could have the same structural impact at ground level as larger seismic events like earthquakes. The second is that smaller seismic events, again deep underground, could be a precursor to more substantial seismic events due to the fractures underground or a shifting geological base. Before addressing the former it is necessary to note that the Richter scale is a logarithmic scale meaning that each level at which it increases represents a seismic event that is a magnitude of ten times larger than the last.

There is little if any scope for induced seismicity for geothermal applications where no fluid is injected or withdrawn from the native formations, or if the fluids that are injected or withdrawn are done so at a shallow level. In simple terms, this means that heat pumps or shallow wells have no scope for induced seismicity.

Visual Impact

There is a misconception that geothermal energy has a large footprint that can disturb the aesthetic of an area. Whilst during the drilling period there is a large rig, this is a short-term period of visual impairment, after which buildings are typically below 10m in height and can be surrounded with foliage if in a rural environment. The scale of impact will depend on whether for heat or for power. The latter will (normally) require banks of fan-cooled evaporators, which require a considerable amount of space (albeit relatively low down). A heat application will have a small building to house the well heads and heat exchangers.

APPENDIX A

EMERGING GEOTHERMAL TECHNOLOGIES AND ALTERNATIVE GEOTHERMAL APPLICATIONS

Enhanced Geothermal Systems (EGS)

There are a number of emerging geothermal technologies aiming to unlock the vast geothermal resource potential however these remain largely untested and controversial in some areas, with a number still in the development phase. Whilst there are no guarantees over their success, this could be important for the wider geothermal sector in that it can bypass some of the limitations of low flow zones and allow for the exploitation of a wider area of resources.

Whilst there is no set definition for enhanced geothermal systems, MIT have stated it is defined as 'engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or permeability resources'. This can broadly be achieved through the use of chemical, thermal, mechanical or hydraulic stimulation.

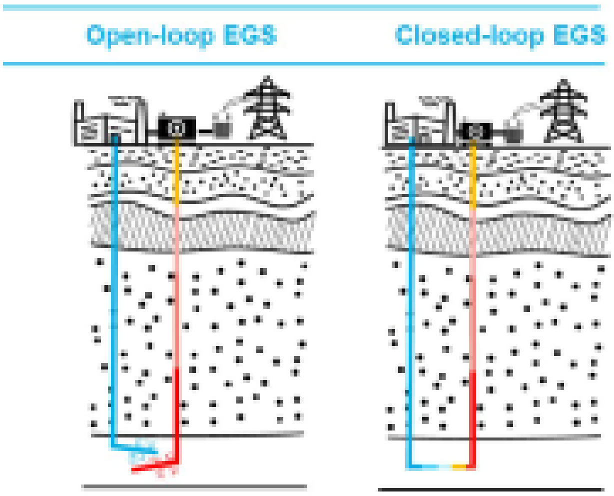
At its most basic level, one could consider the development of EGS as an attempt to create a manmade geothermal reservoir by pumping water into a well that can stimulate the formation of a reservoir. In doing so this addresses two of the hurdles for areas where there are no geothermal prospects currently. It generates both water and permeability in the rocks through fractures allowing for the heat which is omnipresent to rise to the surface and provides options in locations where there is no suitable water-bearing geology between the surface and basement. Water is first injected with a small amount of chemicals at high pressure to create or reopen fractures in the deep rock. Proppants are then added to ensure that these fractures do not close again once the pressure from the injection has decreased.

Notable startups in the EGS space are Fervo Energy and Greenfire Energy. The former of these is using a method similar to hydraulic fracturing whilst Greenfire is looking to retrofit non-producing geothermal and oil and gas wells to turn these into producing geothermal resources. EGS is primarily used in conjunction with a binary plant. Given there is no natural flow of water all the brine has to be re-injected into the reservoir to keep the pressure and production stable. As this is not a true hydrothermal resource the temperature will typically be lower, hence the requirement for a binary plant.

According to BNEF, a next-generation geothermal power project (like EGS or Advanced Geothermal Systems- discussed further below, featuring early-stage technologies) in 2022 requires more than $8.7m/MW in capex compared with $1.8m/MW for onshore wind or $1.1m/MW for solar. The deeper the project and the higher the temperature, the higher the price. Whilst geothermal energy has the ability to provide constant baseload power from a cost perspective these will need to fall to be competitive with solar and wind plus storage in the longer term and will likely need to be deployed in areas where the economics for alternatives (from a power perspective) are unsuitable.

The newer technologies in the geothermal sector hope to bring down costs from economies of scale, cheaper drilling from more effective techniques and improved exploration. If we look to the US shale explosion there were a number of reasons for the improvements in drilling but from a technical perspective, a lot of this was achieved through a very iterative process involving the drilling of thousands of wells.

EGS technology summary



Source: BNEF

Open Loop EGS

Open Loop EGS is the more conventional next-generation geothermal system. This involves an engineered resource being combined with two deep wells being combined with an existing power plant technology to generate electricity, typically a binary plant. Fervo Energy is one company operating in this space in the USA, with their commercial scale, first-of-a-kind plant in Houston becoming the most productive EGS product in the world based on initial testing in 2023.

Whilst open-loop EGS projects do not negate geographical limitations, they can significantly lower the threshold at which a resource is able to generate power economically.

EGS Case Studies

Whilst this is a developing industry there are several case studies in the space to date and not all of these have been positive. Micro-seismicity is generally accepted with EGS however there have been cases where this has been above acceptable levels, notably at the Basel Deep Heat Mining Project. The Basel EGS project involved the circulation of fluid in a conventional EGS system described above. Hydraulic simulation at the project saw event magnitudes of up to Richter local magnitude (ML) 2.6, increasing to ML 3.4 after the well had been shut in, ultimately leading to the closure of the project.

The most high-profile incident in the development of EGS was the Pohang project in South Korea, where a MW scale geothermal power plant with a 4km deep well was developed. The region was hit by a 5.4 magnitude earthquake, the second largest in South Korean history that was directly attributed to the site. It is thought the high-pressure water likely lubricated an unknown fault in the rock and caused it to slip, triggering the earthquake. EGS remains highly controversial, however South Korea continue to develop conventional geothermal projects, with Seoul looking to grow its geothermal heating and cooling capacity despite the experience with Pohang.

Hydraulic Stimulation

Hydraulic stimulation is the injection of fluids at a high flow rate into a reservoir to develop new fractures or to enhance or reopen the permeability of existing fractures.

The oil and gas industry has pioneered horizontal, multi-stage hydraulic fracturing as part of the shale revolution in the USA. This is where multiple fractures are undertaken across a long lateral well and are seen as being key to the success of future EGS developments. The benefits of a long lateral well are that it allows for much more access to a formation or reservoir, with a long lateral increasing the surface area, so to speak, in contact with the formation and therefore maximising the amount of heat generation (this is the case for all geothermal wells). The ability to create lateral wells not only enhances the amount of geothermal energy potentially available at a project but also allows for certain projects that would have otherwise been unfeasible to generate economical amounts of heat and electricity.

Thermal Stimulation

Thermal stimulation is when cold water is injected below the fracturing pressure over a few days to weeks. Due to the low temperature of the water compared to the temperature of the rock, the stress in the rock changes, leading to stimulation of natural fracture networks or initiation of new fractures. This is typically used in areas with high temperatures and low permeability geology.

Chemical Stimulation

Chemical stimulation involves the injection of fluids with chemicals into the subsurface which helps overcome formation damage in the rock formation or when the formation will benefit from acidification for example. The chemicals can allow for the dissolving of certain minerals and therefore increase the pathways and permeability of fluids in the rock.

There are generally three types of chemical stimulation acid washing, matrix acidizing and fracture acidizing and these are generally differentiated by pumping pressure and penetration depth. Due to the degradation of acids injected at pressure and heat, chemical stimulation is generally only effective in the immediate vicinity of the well, making it unsuitable for increasing the permeability of a large formation.

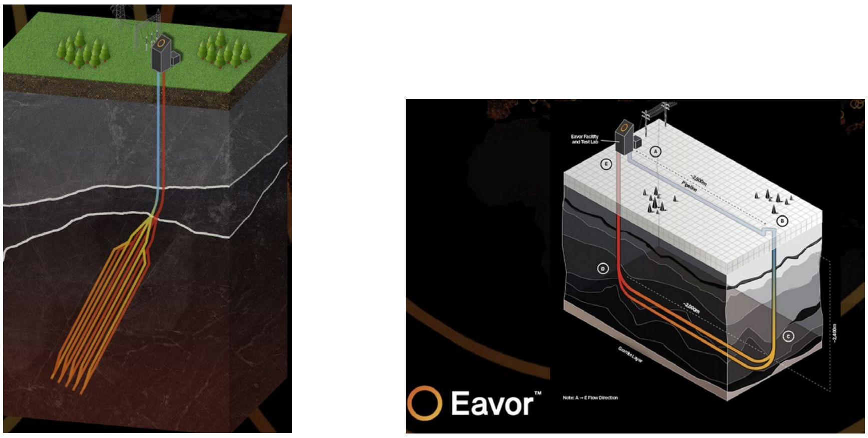
Advanced Geothermal Systems (AGS)

AGS systems create an underground heat exchanger by only using drilling techniques – without stimulation. Shallow closed loop geothermal has been in existence for a number of years, in the form of a ground source heat array (used to supply a heat pump). Normally applied at the individual or district heating level, these can be done in a horizontal or vertical configuration. In the former, there are a number of plastic pipes 6-10 ft deep typically coiled and spread over several hundred meters. Water and heat transfer fluids are then circulated continuously around the closed loop by a heat pump and the ground is used either as a heat source or a heat sink. The same premise applies to vertical loops, however, in this instance, two or more boreholes 200-500 feet deep are drilled- with performance.

The development of deep closed-loop systems exists on the same premise as that of vertical ground source heat pumps. Eavor is currently leading the development of the system. Eavor's designs allow for the exploitation of geothermal resources in areas that would not have been typically suitable for exploitation due to a lack of suitable aquifer or geology that has low permeability. Initially, the company developed the Eavor Lite system and this is to be followed by the Eavor Europe project being deployed in Germany and expected to commence operations in 2024. The Lite system is not commercial and was developed as a reference point for the next generation of systems.

The Company's first project in Germany is expected to require 360km of total drilling with 4 loops drilled to a total depth of circa 4500m underground and estimated to be able to generate 8.2MW of electric energy and 64MW of thermal energy. There are several important elements of the Eavor design that ought to enable to efficient generation of energy. The first of these is that due to the differing pressures and temperatures experienced underground by the fluids due to the loop design, there is no requirement for a pump to circulate fluids in theory. The thermosiphon effect sees fluids moving naturally on their own due to the natural motion of fluids associated with convection and conduction, taking the heated fluid to the surface and then the cooled fluid back underground. Other key elements in the design include specially insulated drill pipes allowing for greater temperature control when drilling. This in turn allows for drilling to depths previously thought impossible and faster drilling, both of which are thought to have cost benefits. If pioneering developments like this are successful, there could be a wider boost to the industry as technology transfers and learnings are adopted, potentially boosting returns in the space over time.

Eavor Lite and Europe Designs



Source:Eavor

Closed-loop geothermal is not without its detractors, however. Closed loop geothermal works on the premise of conductivity of heat, namely that the rock surrounding the drilled wells is conductive enough to heat the fluid within the wells to a sufficient degree that the energy extracted will ever cover the capital cost required to drill the substantial distances required.

Whilst the technology can theoretically be deployed across different geologies, this obviously comes with the very obvious drawback in that the amount of drilling required is substantial and therefore expensive and there are societal objections that can exist to such substantial drilling operations, as discussed previously.

Super Hot Rock (SHR)

SHR is in its infancy, and likely decades away from commercial and technical success, but is becoming an increasing focus area for governments and private investors who are looking to tackle the technical and economic challenges involved in it. Iceland is at the forefront of this development, understandably given the history of geothermal energy on the island, with its Iceland Deep Drilling Project. A number of technical challenges are involved in SHR developments and these require new well drilling techniques, cementing and completion and reservoir creation and operation. Advances in these areas could have a trickle-down impact across the wider geothermal sector.

The logic behind the high capital cost from these innovative technologies required to develop SHR geothermal projects is expected to be offset by the high yield that can be derived from a SHR geothermal resource, which will enable a very low levelized cost of energy (LCOE).

ALTERNATIVE GEOTHERMAL APPLICATIONS

GEOTHERMAL AND LITHIUM

There has been a renewed interest in geothermal energy as a result of the spike in lithium prices in 2021 and 2022, with lithium having been a long-recognised presence in deep mines or geothermal springs. First discovered in hot springs in deep Cornish mines in 1864, there has long been a recognition that there are lithium-enriched geothermal waters globally. Historically, there was little demand for this lithium, however, the explosion in demand for lithium-ion batteries has driven this as a secondary consideration at a number of geothermal projects.

Lithium, currently, is mainly sourced from hard rock mines or in underground brine reservoirs. Hard rock lithium extraction is an energy-intensive process that requires crushing, grinding and roasting (amongst numerous other steps) to get to battery grade lithium carbonate or lithium hydroxide. Underground brines have a heavy water requirement to extract the lithium rich water and then significant amounts of land to then dry out the brine.

Vulcan Energy for example are trying to extract 40,000 tons of geothermal lithium hydroxide from the Rhine Valley in Germany by 2025, powering the equivalent of about one million cars a year, whilst Geothermal Engineering Ltd has several projects in Cornwall where they are exploring using lithium from their geothermal extraction efforts, including the United Downs Project where they have received funding for a pilot lithium extraction plant to be built.

The bulk of geothermal activities, particularly for district heat networks or power generation, do not have significant quantities of lithium and whilst lithium discoveries can be additive to the economics of a single project, we do not see this as a significant part of the majority of geothermal projects moving forwards. There remains limited economic and technical data on lithium extraction from geothermal brines and it remains subject to significant uncertainty.

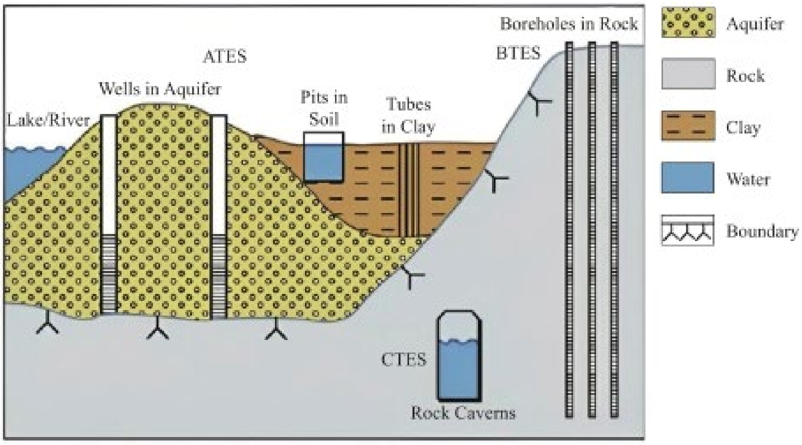
UNDERGROUND THERMAL ENERGY STORAGE (UTES)

UTES is the concept of seasonally storing heat and cold into the ground through boreholes, caverns, aquifers (aquifer thermal energy storage -ATES) or pits using water as a storage medium. These are typically for low-temperature building systems, for example ATES has recently been deployed at the National Maritime Museum in Greenwich, the UK's first project using this technology.

In general terms, the majority of UTES applications remain in their infancy, certainly in the UK but less so in Europe, but increased knowledge and understanding of the geological conditions required for successful ATES, could see a significant level of transferable skills and technologies from conventional geothermal developments or oil and gas. Development has been limited in the UK, however shallow ATES has reached relative maturity in other markets such as the Netherlands. As with geothermal developments, ATES systems have a high upfront cost from drilling and the techniques and costs required for a commercial development at mid-to-deep levels remain unclear.

This could potentially present an alternative use for unsuccessful geothermal developments, in that aquifers where there is not sufficient permeability of fluids, could potentially still be used to store heat. Indeed, studies at Groningen in the Netherlands have suggested a LCOE potentially lower than natural gas which would therefore demonstrate significant economic benefits from the use of the technologies.

Underground Thermal Energy Storage Techniques



Source: Ying-nan Zhang, Yan-guang Liu, Kai Bian, Guo-qiang Zhou, Xin Wang, Mei-hua Wei

GEOTHERMAL AND CCUS

There have been numerous studies considering whether it is possible to capture CO2 during geothermal energy production. The primary aim in most studies is to develop a geothermal resource, with carbon capture either boosting the geothermal energy produced or acting as an added bonus. Projects have looked at injecting supercritical cooled CO2 into reservoirs to stimulate the reservoir and encourage heat production or using CO2 in EGS wells or depleted reservoirs. Ultimately all technologies involve CO2 being injected underground. The bulk of these technologies remain very immature, at the early stages of technological readiness. Further work will likely need to be done before commercial business models can be developed in this space.

GEOTHERMAL AND POWER TO X (PTX)

There have been some initial studies exploring the potential for the use of geothermal energy in PtX applications. Deep geothermal used for power generation could in theory provide steady baseload power for the production of hydrogen. High availability (c.95%) would enable steady hydrogen production in conjunction with an alkaline or solid oxide electrolyser (the latter potentially being able to benefit from using process heat to reduce electricity requirements). This could in turn be used to produce a number of derivatives such as ammonia or fertiliser or if combined with methanation, methanol could be produced. Given the relatively low LCOE and abundance of geothermal energy in certain regions this could be a particularly attractive solution for some developers. Some geothermal developments have higher concentrations of non-steam gases in their mix and in cases where there is hydrogen or methane present, this could support the economics of a PtX project, although as with most projects, this would again be highly dependent on the project resources, location and individual project economics. The drawback in this solution is that most geothermal developments tend to be smaller, on the individual megawatt scale compared to the 100+MW scale size PtX project currently being undertaken across the globe.

APPENDIX B

Selected Private Geothermal Companies

Company	Location	Last Round	Notable Investors	Description
XGS Energy	USA	$20m	Constellation Technology Ventures, with BlueScopeX and Thin Line Capital, Valo Ventures, VoLo Earth Ventures, MIH Capital, B Current Impact Investment	Closed-loop system
Geothermal Technologies	USA	n/a	n/a	Conventional geothermal
Greenfire Energy	USA	$20m	Baker Hughes, Helmerich & Payne, Vallourec	Closed loop AGS
GeoX Energy	USA	$11m	Nabors	Supercritical heat
Zanskar	USA	$30m	Munich Re Ventures, Union Square Ventures, Lower Carbon Capital, Safar Partners, First Star Ventures, Clearvision Ventures Obvious ventures	AI Software for geothermal exploration
GA Drilling	USA	$15m	Nabors, alfa8, Underground Ventures, Neulogy Ventures	Ultradeep Drilling
Altarock	USA	$37m	Google, Vulcan Capital, Kleiner Perkins, and Khosla Ventures	EGS
Quaise				
Fervo Energy	USA	$244m	Devon Energy, Galvanize Climate Solution, John Arnold, Liberty Mutual Investments, Marunouchi Innovation Partners, Mercuria, Mitsubishi Heavy Industries, Capricorn's Technology Impact Fund and Congruent Ventures	Conventional geothermal
Eavor	USA	$182m	Canada Growth Fund, Japan Energy Fund, Monaco Asset Management, and Microsoft's Climate Innovation Fund	Close loop system
CeraPhi	UK	n/a	n/a	End-of-life oil and gas asset geothermal
Geothermal Engineering Limited	UK	£15m	Kerogen Capital, Thrive Renewables	Conventional geothermal
TownRock Energy	UK	n/a	n/a	Conventional geothermal

Source: Longspur Research, BNEF

GLOSSARY

Term	Definition
Aquifer	A permeable layer of rock, sand, or gravel that holds groundwater, used as a heat source or sink.
Binary Cycle Power Plant	A geothermal plant that uses a secondary fluid with a low boiling point, vaporized by geothermal fluid.
Brine	Salty water found in geothermal reservoirs, often containing dissolved minerals.
Closed-Loop System	A system where a heat transfer fluid circulates in a closed circuit, extracting heat without mixing.
Direct Use	The use of geothermal heat directly for applications like heating without generating electricity.
Enhanced Geothermal Systems	Engineered reservoirs created by fracturing rock to improve permeability for heat extraction.
Flash Steam Power Plant	A plant using high-pressure hot water that flashes into steam to drive a turbine.
Geothermal Gradient	The rate of temperature increase with depth, measured in degrees Celsius (°C) per kilometre.
Geothermal Heat Pump (GHP)	A device that uses stable underground temperatures to heat or cool buildings.
Hydrothermal System	A natural geothermal system with hot water and/or steam in porous rock formations.
Injection Well	A well used to re-inject cooled fluids back into the geothermal reservoir.
Magma	Molten rock beneath the Earth's surface, the ultimate source of geothermal energy.
Permeability	The ability of rock to allow fluids to pass through, crucial for extracting geothermal energy.
Production Well	A well drilled into a geothermal reservoir to extract hot water or steam.
Reservoir	A subsurface pool of hot water or steam accessed for geothermal energy.
Thermal Conductivity	A measure of a material’s ability to conduct heat, important for geothermal resource quality.
Volcanic Geothermal System	A system associated with volcanic activity, sourcing heat from shallow magma bodies.
Wet Steam	Steam containing water droplets, typically found in geothermal reservoirs.
Dry Steam Power Plant	A plant using steam directly from the ground to drive a turbine.
Heat Exchanger	A device that transfers heat between fluids without mixing them.
Seismic Imaging	A technique to map geothermal structures by measuring seismic wave reflections.
Hot Dry Rock (HDR)	Geothermal systems in impermeable rocks requiring artificial fluid injection.

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