Accelerating adoption: A network+ road map for geothermal heat

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Network+ for Decarbonisation of Heating and Cooling

net-zero research network

A Network+ for the Decarbonisation of Heating and Cooling

Durham University

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Geothermal heat

Executive summary

Former U.S. Vice President Al Gore wrote "*Our Choice – A plan to solve the climate crisis*" in which he described geothermal energy as the "*potentially largest – and presently the most misunderstood – source of energy in the U.S. and the world today.*"

Today, geothermal energy is well established in nearly 100 countries and is not confined to volcanic regions such as Iceland, Turkey, and Indonesia. China, the United States, and Sweden lead globally in installed geothermal heat capacity, while the United States remains the world's largest producer of geothermal electricity.

Historically, the UK's engagement with geothermal energy has been limited. The Southampton-based geothermal district heating scheme, commissioned in 1986, has remained the country's only operational geothermal installation for several decades. However, this is now changing rapidly. The UK currently has two operational geothermal heat plants in Gateshead, alongside additional schemes in Gloucestershire and Cornwall. Further projects are under development or planned in Belfast, County Durham, Leeds, Scunthorpe, South Tyneside, Sunderland, South Wales, and other locations.

In parallel, the UK is moving into geothermal power generation. The geothermal power plant at United Downs in Cornwall is expected to deliver its first power to the electric grid in 2025, marking a significant milestone for the sector.

Supporting this momentum, the National Geothermal Centre was launched in 2024 with a strategic ambition to position the UK as a "Geothermal Nation" by 2050, embedding geothermal heat and power as a core component of the country's net zero energy system.

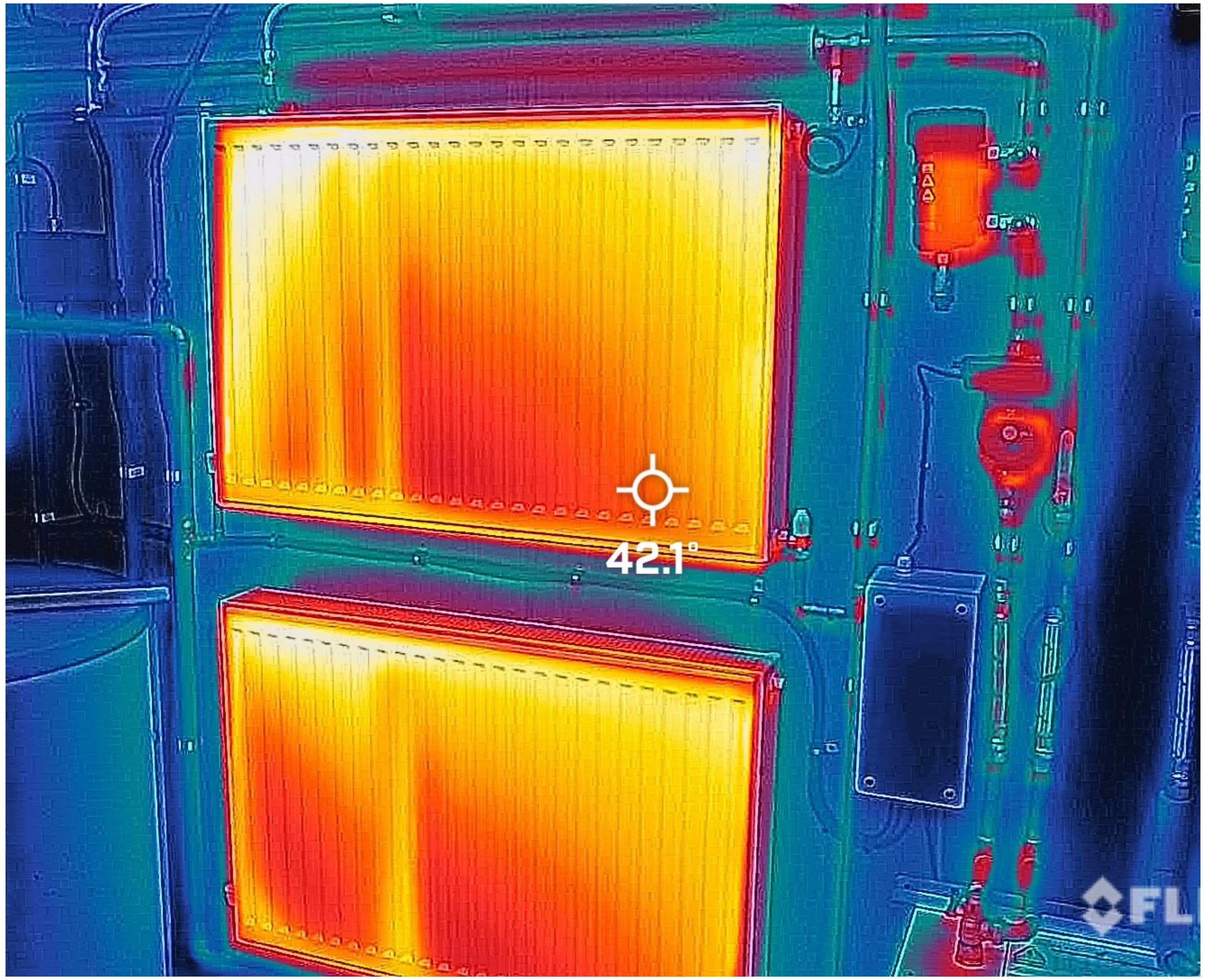
Key messages

1. Geothermal energy is local, secure energy for local communities, providing long-term heat, cooling, and power.
2. Geothermal energy is available everywhere, with modern technologies enabling deployment across all regions of the UK.
3. Geothermal energy is ultra-low carbon and sustainable, operating on geologicaltimescales with minimal environmental impact.
4. Geothermal energy is always on, delivering reliable, 24/7 energy independent of weather and seasons.
5. Geothermal energy maximises efficiency through cascade use, supporting industry, buildings, and agriculture from a single resource.

Geothermal heat or geothermal power?

Geothermal energy is fundamentally accessed as heat. This heat may be used directly or, where temperatures are sufficiently high, converted into electricity. The efficiency of geothermal electricity generation is strongly dependent on the temperature differential between the produced geothermal fluid and the ambient environment, with higher temperature resources enabling more efficient power conversion.

Importantly, even where geothermal fluids are used for electricity generation, substantial residual heat remains available downstream of the power cycle. This low- to medium-grade heat can be utilised directly for a wide range of applications, including industrial processes, crop drying, space and district heating, aquaculture, fish farming, and other heat-intensive uses. Such cascading or "cascade use" of geothermal heat significantly improves overall system efficiency and maximises the value extracted from the resource.



Introduction to the Network+

The EPSRC Network+ for Decarbonisation of Heating and Cooling is a four-year funded programme which aims to provide leadership, coordination and facilitation for EPSRC research funded in this challenging area.

The Network+ is led by researchers from Durham, Heriot-Watt, Oxford, Leeds, Brunel and Northumbria Universities who aim to bring together disciplines across 5 cross-cutting themes within the decarbonisation of heating and cooling to create a "world leading" network of expertise and support for developing research and researchers through connecting all national and international stakeholders relevant to a net zero carbon heating and cooling future for residential, business and industry sectors.

Outputs from the Network+ include; funding for early career researchers in areas of developing interest, policy and technology roadmaps, an established community of researchers, knowledge sharing events, secondments and travel bursaries and public engagement activities as well as development of academic expertise and capacity building.

Further information about the Network+ can be found here: **Our Network | Net Zero Research Network (net-zero-research.co.uk)**

Introduction to the road map

This road map provides an accessible, up-to-date assessment of geothermal heat as a critical technology in the UK's path towards decarbonised residential space and water heating, place of work heating and low-enthalpy heat requirements in industry. It was developed by the EPSRC Network+ for Decarbonisation of Heating and Cooling building on the diverse insights generated across projects associated with the Network+. It takes a whole system perspective reporting on insights generated across technology, infrastructure, policy, markets, business models, cultures, norms, and use, whilst drawing out where additional research would add value.

The road map is split into three main sections.

- Technology research and development,
- Infrastructure,
- Policy support and leadership.

Introduction to geothermal energy

- Geothermal energy is heat contained in the Earth and it is sustainable (inexhaustible).
- Geothermal energy is available 24/7 and 365. It is good baseload.
- Geothermal energy is available everywhere on Earth, albeit some areas have heat closer to surface than others (the UK has average to above average heat flow).
- Geothermal energy is ultra-low to zero carbon and its supply near zero carbon.
- Geothermal energy infrastructure is largely subsurface with negligible surface requirements or impact.
- Operating expenditure (OPEX) is low but capital expenditure (CAPEX) during build can be high.
- Deployment of geothermal energy does not require exotic materials or metals supply for which can be problematic.
- Geothermal infrastructure is long life (measured in decades) and needs minimal maintenance at or beyond the customer interface.
- Geothermal heat is inherently safe and environmentally benign (it is natural).
- Geothermal heat systems are highly efficient.

UK deployment status

The UK has fewer geothermal developments than many countries with a similar resource base.

In 2021, the UK had only two operational geothermal heating developments: the Southampton District Energy Scheme and the Lanchester Wines installation in Gateshead, together delivering just over 1 TWh of heat per year. This contrasts sharply with Sweden and Finland, which generate more than 17 TWh/year and approximately 6.5 TWh/year of geothermal heat respectively. These countries have broadly similar geothermal heat flows and comparably cool climates; however, their lower overall heat demand—driven by smaller populations and higher standards of building insulation—has enabled more rapid and effective deployment of geothermal heat.

Since 2021, the UK geothermal sector has begun to accelerate. Three additional developments have entered operation: SLB Stonehouse in Gloucestershire, a second geothermal heat scheme operated by Gateshead Council, and the Eden Project installation in Cornwall. In parallel, the United Downs geothermal project in Cornwall is expected to deliver electricity to the national grid in 2025, marking the UK's first commercial-scale geothermal power generation.

Road map

	Short term (before 2030)	Medium term (2030–2040)	Long term (2040+)	National Geothermal Centre Role
Technology research and development	• Adopt deep /fast drilling technology from the US • Open national data portal • Develop digital twin of UK to test geothermal role in UK energy mix	• Development of high-temperature wellbore tools • Development of passive continuous monitoring systems		• Facilitation and networking to improve and optimise R&D
Training	• Reskilling of petroleum workforce: conversion programmes, apprenticeships, university hubs • Develop priority clusters: Cornwall, N England, Midlands, Scotland, N. Ireland • 5+ living lab projects for hands on learning • 7000 trained	• Recognition of geothermal energy in national schools' curriculums in in home nations. • 15,000 trained	• 50,000 trained	• NGC hosts or manages training for school leavers, university subject, life long learning and executive education.
Infrastructure	• Heat networks – all new at <70°C to be geothermal/heat pump ready • Thermal storage in aquifers, mines to have 5 full scale exemplars • Drilling capability restoration in UK	• Develop manufacturing capability for drilling, completions, monitoring in geothermal energy		• NGC provides linkage between technology developers and technology users
Policy support & leadership	• UK government to recognise heat as a commodity • Develop regulation scheme for geothermal heat • Develop licensing system for onshore geothermal heat. • Dedicated risk insurance. • Included underground/aquifer thermal energy storage in UK energy storage plan • City targets for optimising heat use and minimising heat wastage (crosslinked to built environment)	• Legislate to ensure geothermal options are included in all district heating schemes • Early 2030s integrate heat into Contracts For Difference • Defragment permitting landscape		• NGC provides support and expert advice to national and local government
Business and market innovation	• Provide support to business via relaunch of renewable heat incentive. • Provide market access for communities and local authorities • Align with district heating expansion	• Geothermal energy as a key renewable energy commodity recognised throughout industry and local government		• NGC acts as an advocate for geothermal energy supporting business and national interests.

	Short term (before 2030)	Medium term (2030–2040)	Long term (2040+)	National Geothermal Centre Role
Cultural adoption	• Develop and roll-out briefing documents, webinars and social media campaign explaining geothermal energy • Formulate heat offtake models for national adoption		• Geothermal taken for granted by bulk of UK population and seen as desirable by much of population in areas where not developed	• NGC leads outreach campaigns
Consumer experience	• Gather and promote experiences from early adopters in the UK and more widely from larger groups of users in Europe.	• Scale up experience to build comprehensive knowledge base that can be used to enhance cultural adoption.	• Geothermal heating becomes the UK norm	• NGC gathers data from consumer and interpretation of the data for government
Sustainability/ environmental impact	• Carbon savings updated annually	• Reduced combustion products in air (particulate matter and gases)	• 10 Mt CO_2e reduction	
Energy security impact	• Demonstration projects unaffected by power and gas price hikes.		• UK energy secure for heat (for ever!)	
Equity/ affordability impact	• Demonstration projects improve affordability for adoptees.	• Parity or cheaper than gas	• Measurable reduction in energy poverty associated with geothermal adoption	

Technology R&D:

Geothermal energy technology is considered mature, having developed in parallel and sharing some crossover with petroleum technology of the past century and more.

However, technology development within petroleum drilling and completion systems has advanced dramatically over the past two decades. The commercial exploitation of lower unit-revenue resources—such as tight gas and shale gas (including liquids)—has driven major improvements in drilling efficiency, well delivery, and cost reduction. As a result, the cost base associated with drilling, typically the single most expensive element of subsurface energy projects, has fallen substantially.

These advances are now beginning to be applied to geothermal developments. Improved drilling techniques, completion methods, and subsurface characterisation are enabling more reliable well delivery at significantly lower cost, improving the economic viability of geothermal projects.

Historically, the comparatively lower revenues associated with steam and hot water production—relative to oil and gas—have been cited as a key reason for the slow uptake of geothermal energy. This position is now changing. Growing environmental concerns around petroleum production and use, alongside the increasing costs of remediation, regulation, and mitigation, are eroding the economic advantage traditionally enjoyed by hydrocarbons. In contrast, geothermal energy offers a markedly lower environmental impact and a near-zero operational carbon footprint.

UK companies, together with UK subsidiaries of overseas operators, are now beginning to deploy these improved drilling and completion technologies within domestic geothermal projects, accelerating the development of a more competitive and scalable geothermal sector.

Key technologies

- **Drilling:**
  Recent advances in drilling technology have enabled significantly faster well delivery and improved penetration of hard crystalline rocks such as granite. Historically, well construction has been expensive and heavily front-end loaded in project costs. Many of these advances originated in the US shale gas industry, where economic pressures drove rapid innovation. These technologies are now being applied to geothermal projects, combining deep vertical drilling with shallow, high-angle and slant wells, as demonstrated at the Stonehouse project in Gloucestershire. Both shallow and deep geothermal drilling technologies are now considered mature, at approximately TRL 8.

- **Completions:**
  A range of geothermal well completion options is now available. The simplest approach—a coaxial pipe configuration—ensures that any correctly drilled geothermal well will deliver heat. Unlike oil and gas exploration, where unsuccessful wells are common, geothermal wells are inherently productive, although thermal output will vary between wells. Completion technologies are currently assessed at TRL 5, with ongoing optimisation for efficiency and longevity.

- **Water Reinjection:**
  Water reinjection is critical for sustainable geothermal heat production, allowing extracted heat to be replenished through natural conductive heat flow. Long-term operational experience at The Geysers in California demonstrates that wells can operate for decades, particularly when periodically rested to allow thermal recovery. While reinjection systems are operational, further modelling and validation of long-term performance is underway, calibrated against early adopters. Current system-level readiness is estimated at TRL 5.

- **Solute Management:**
  Mineral precipitation ("furring") within pipework can occur in both low- and high-temperature geothermal systems. However, the UK petroleum industry has decades of experience managing similar challenges in oil and gas production. Chemical treatments are routinely used to keep minerals in solution, including those that could otherwise precipitate as Naturally Occurring Radioactive Materials (NORM). As geothermal developments typically operate as closed-loop systems, solutes remain contained within the subsurface and associated surface pipework. This technology is well established offshore and is estimated at TRL 7 for onshore geothermal applications.

- **Heat Networks:**
  Heat networks are a cornerstone of the UK's strategy to decarbonise heat. These systems distribute centrally generated heat to homes, commercial premises, and public buildings, removing the need for individual boilers and improving system efficiency. The UK government is actively expanding heat networks through initiatives such as the Heat Network Transformation Programme. Conventional heat networks are fully mature (TRL 9), while geothermal-supplied heat networks are assessed at TRL 8.

- **Power Generation (Organic Rankine Cycle):**
  Geothermal power generation has traditionally required large temperature differentials due to the inherent inefficiency of low-temperature heat-to-power conversion. Organic Rankine Cycle (ORC) systems address this by using organic working fluids that vaporise at lower temperatures to drive turbines. Recent innovations by a UK technology developer have demonstrated the potential to approximately double conventional efficiency benchmarks. These systems are currently assessed at TRL 7–8.

- **CO_2 Plume Geothermal (CPG):**
  Geothermal power generation can be further enhanced by using CO_2 as the working fluid, either in closed-loop or carefully managed open-loop systems. Known as CO_2 Plume Geothermal (CPG), this approach exploits the favourable thermophysical properties of CO_2 to improve heat extraction and power conversion. System concepts have been defined by US and Swiss researchers, and a UK research programme is currently underway involving Manchester and Durham universities. Overall system readiness is estimated at TRL 4, with individual components spanning TRL 2 to TRL 9.

Infrastructure issues

To work, geothermal energy must be extracted from the ground and the heat transferred from the produced fluid, via a heat exchanger to fresh water that can be circulated to the end users.

The heat con be used directly for space heating, if hot enough (typically around 70 ºC required for conventional radiators and around 20 ºC for underfloor heating). For ultra-low enthalpy geothermal (tepid) energy, a heat boost may be needed to produce hot water using a heat pump. Power (electricity) is required for the pumps.

In almost all geothermal systems the fluid used to transfer heat from the subsurface to the surface is water (or brine). An alternative is to use waste CO2 instead of emitting it to the atmosphere (see text box). The subsurface contains was quantities of water some of which is easy to extract (in flooded mines or in many saline aquifers), however, it may be necessary in some dry rock formations to inject water and then once the injected water and the rock have come into thermal equilibrium, extract the heated water. Some systems will replenish naturally, and others will not.

Housing

The UK housing stock is poorly insulated. Homes built to be heated by coal or other open fires need to be draughty to remove poisonous combustion products. Homes heated by radiators are also woefully inefficient with systems running at around 70 ºC have substantial heat losses. Adoption of underfloor heating, triple glazing and use of building materials which meet the highest standards of insulation needs to become the norm. Passive housing should also be built when and where possible. These measures will ensure minimum addition energy is required to heat or cool our homes. Improving the energy efficiency of the UK housing stock will aid heat geothermal energy and pump adoption. Both capital and running costs of using geothermal energy will be lower in energy efficient homes, though the cost of energy efficiency measures may be greater initially than savings made.

Future research avenues:

- **Transmissivity:** The UK has a relatively good understanding of its geothermal gradient; however, far less is known about the absolute permeability—and therefore the transmissivity—of deep onshore rock formations. Since the first onshore well was drilled at Hardstoft in 1919, approximately 2,000 deep wells have been drilled onshore in the UK, predominantly in the search for petroleum. For many of these wells, permeability measurements are available.

  The majority of onshore wells are concentrated within the East Midlands, Wessex, and Hampshire basins, with far fewer drilled elsewhere. As a result, subsurface knowledge remains spatially uneven. In contrast, offshore regions are much better characterised: more than 10,000 wells have been drilled, and tens of billions of cubic metres of water and petroleum have been produced from over 400 fields—many of which are now mature and produce significantly more water than oil.

  Improving understanding of deep-rock transmissivity is critical to reducing geological risk in geothermal developments and to enabling appropriately designed, reliable, and cost-effective geothermal schemes.

- **CO_2 Plume Geothermal Energy (CPG):** CO_2 Plume Geothermal (CPG) systems use carbon dioxide as the heat-transfer fluid to transport thermal energy from the subsurface to the surface in a closed system. This approach exploits the strong temperature-dependent density variation of supercritical CO_2, making it particularly well suited to thermosiphon operation with little or no parasitic pumping power.

  CPG has the potential to deliver higher power output than conventional water-based geothermal systems, while also offering the prospect of long-term CO_2 storage. However, despite strong theoretical and component-level development, CPG has not yet been demonstrated at commercial scale. A dedicated demonstration plant is required to validate system performance, efficiency, and operational reliability.

To be effective, geothermal energy must be extracted from the ground and the heat transferred from the produced subsurface fluid to a clean secondary water circuit via a heat exchanger. This secondary circuit then distributes heat safely to end users.

Geothermal heat can be used directly for space heating where temperatures are sufficiently high. Conventional radiator-based heating systems typically require supply temperatures of around 70 °C, whereas underfloor heating systems can operate effectively at much lower temperatures, typically around 20–40 °C. For ultra-low enthalpy (tepid) geothermal resources, a heat pump is often required to raise temperatures to a level suitable for domestic hot water and space heating. Electrical power is required to operate circulation pumps and, where used, heat pumps.

In almost all geothermal systems, water or saline brine is used as the heat-transfer fluid to convey heat from the subsurface to the surface. An alternative approach is to use captured CO_2 as the working fluid instead of releasing it to the atmosphere (see text box). The subsurface contains vast quantities of water, some of which is readily accessible—such as in flooded mines or saline aquifers. In other geological settings, particularly dry or low-permeability rock formations, water may need to be injected to create a heat-exchange pathway. Once thermal equilibrium between the injected fluid and surrounding rock is achieved, the heated fluid can be extracted. Some geothermal reservoirs naturally replenish heat and fluids, while others require active management through reinjection to sustain long-term operation.

Housing and Heat Demand

The UK housing stock is, on average, poorly insulated. Many older homes were originally designed for coal fires or other open combustion systems and therefore rely on high levels of ventilation to remove combustion gases. Even homes heated by conventional radiators often exhibit high heat losses and inefficient thermal performance.

Low-temperature geothermal systems operating at around 70 °C or below are particularly sensitive to heat losses within buildings and distribution networks. To maximise the effectiveness of geothermal heat, high standards of building fabric efficiency are essential. The widespread adoption of underfloor heating, triple glazing, and high-performance insulation materials should become the norm. Where feasible, passive house standards should be pursued.

These measures minimise the additional energy required to heat or cool buildings and significantly improve the performance and economics of geothermal systems and heat pumps. While the upfront cost of energy-efficiency upgrades may exceed short-term savings, both capital and operating costs of geothermal heating systems are substantially lower in energy-efficient homes, improving whole-life value and system resilience.

CO_2 Plume Geothermal Energy (CPG)

CO_2 Plume Geothermal Energy (CPG) is an emerging technology that combines carbon capture and storage (CCS) with geothermal energy extraction. In this approach, captured CO_2 is injected into deep, naturally permeable geological formations, where it absorbs heat from the surrounding hot rock. The heated CO_2 is then produced through wells and used to generate electricity or provide heat at the surface.

CPG exploits the favourable thermophysical properties of CO_2—particularly its low viscosity and strong density variation near supercritical conditions—enabling efficient heat extraction and the potential for thermosiphon circulation with minimal parasitic pumping power. While highly promising, CPG has not yet been demonstrated at commercial scale, and a full-scale demonstration project is required to validate long-term performance, economics, and CO_2 containment.

Geothermal heat

Policy support and leadership

The UK government needs to recognise heat as a commodity. This then will allow development of a regulatory system for geothermal, captured solar them and waste heat.

This in turn provides a framework for licensing of areas for geothermal exploration and development. Such licensing options already exist for petroleum and carbon storage and such systems would form the basis for geothermal regulation and licensing. In order to facilitate the uptake of the heat beneath our feet, the government also needs to recognise that development of a heat and in particular geothermal heat industry will require both investment and other forms of support – such as renewable heat incentives and dedicated risk insurance. The initial drilling and infrastructure CAPEX for geothermal is high and OPEX low. Government needs to recognise this and provide a way in which investment in the supply chain will enable CAPEX reduction and so boos industrial confidence.

Supporting material

List of references and supporting material to get started

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- A. Kirkup *et al., A Mine Energy White Paper*, updated ed., Newcastle upon Tyne, UK, 2024. [Online]. Available: https://evidencehub.northeast-ca.gov.uk/report/a-mine-energy-white-paper

List of any major UKRI and other projects which are on-going or have recently completed.

- Geothermal Energy from Mines and Solar Geothermal Heat – GEMS – https://gems.ac.uk/
- Immersive Cooling and Heat Storage – ICHS – https://ichs.webspace.durham.ac.uk/
- UK Digital Geothermal Catalogue version 1 https://www2.bgs.ac.uk/nationalgeosciencedatacentre/citedData/catalogue/05569ed5-db0e-4587-807c-58e39ee240fa.html? ga=2.44522208.591671838.1721049542-417849119.1721049542
- Galleries to Calories (G2C) https://bonnyrigganddistrict.community-council.org.uk/news/galleries-to-calories-g2c-minewater-energy-in-scotland-30-jan-2025
- Geothermal Power Generated from UK Granites https://bonnyrigganddistrict.community-council.org.uk/news/galleries-to-calories-g2c-minewater-energy-in-scotland-30-jan-2025
- Net Zero Geothermal Research for District Infrastructure Engineering (NetZero GeoRDIE) https://gtr.ukri.org/projects?ref=EP%2FT022825%2F1

net-zero research network

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Engineering and Physical Sciences Research Council