Technology Fact Sheet

Energy Transitions Commission

Beneath the surface

Geothermal's role in delivering clean heating, cooling and power

Conventional hydrothermal

JULY 2026

This technology fact sheet is part of the ***Beneath the surface*** series. Each highlights a key technological innovation that can drive geothermal's role in delivering clean heating, cooling and power.

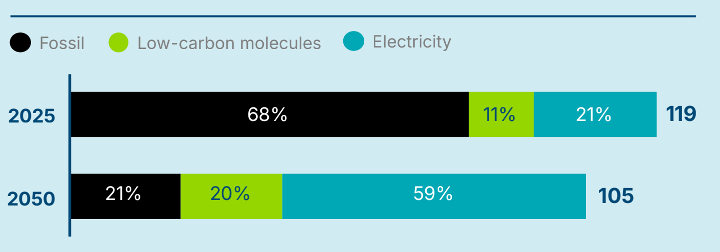
Learn more at www.energy-transitions.org/beneaththesurface

The ETC's energy transition vision

A net-zero global energy system is possible by 2050, driven by clean electrification:

- Electricity increases from 20% to 60%+ of final energy demand, which decreases overall due to energy productivity gains.
- Solar and wind can provide 75%+ of power system generation in most systems, supported by batteries, flexibility and other firm power sources.
- Some flexible dispatchable power capacity will be needed to complement variable renewables.

Global 2025 and 2050 final energy demand breakdown by source (ETC Accelerated but Clearly Feasible scenario) '000 TWh



Geothermal can provide firm low-carbon power, heat, cooling and seasonal energy storage. It spans three broad technology categories across a wide range of depths and temperatures.

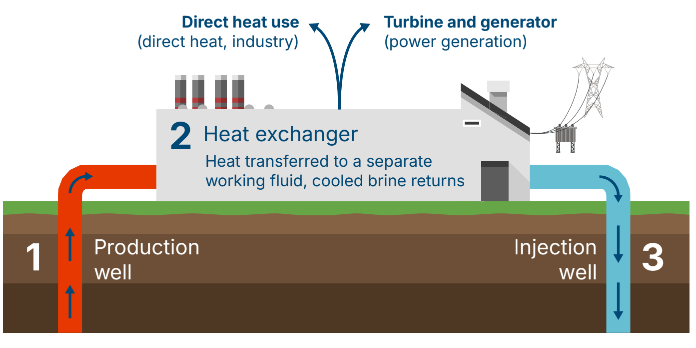
1. Shallow geothermal		2. Conventional hydrothermal	3. Next-generation geothermal
Ground-source heat pumps	Underground thermal energy storage		EGS, CLGS and Superhot Rock

Technology overview and status:

Geothermal Technology	Typical depth (km)	Resource temperature (°C)	Application	Surface technology	Geographic technical potential	TRL Technology readiness level	Current global capacity
Conventional hydrothermal	3.5 km	10 - 170 heat 80 - 300 power	Heat, cooling and power	Heat exchanger / turbine	Constrained (shallow, high temperature permeable aquifers)	9	31 GW-th 17 GW-e

Techno-economics: Conventional hydrothermal is mature (TRL 9) and cost-competitive where geology allows (depth, resource, flow rate).

How it works – Heat is extracted from aquifers, after which heat exchangers are used for direct heat use and turbines for power generation.



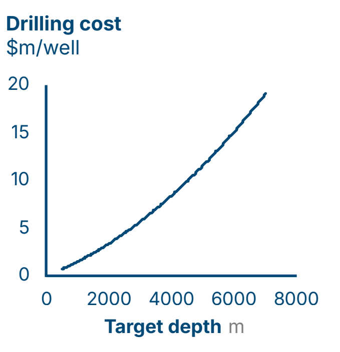
1. Underground wells (~5–10 MW-e each) draw naturally hot water or brine from a permeable aquifer up to ~3.5 km deep.

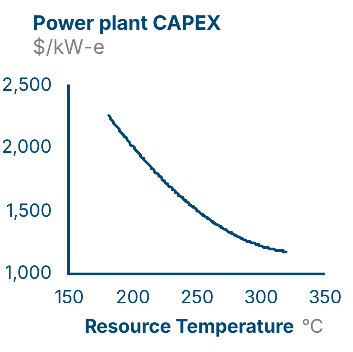
2. Above ground, a heat exchanger absorbs and transfers the heat to different pipes for direct use or a turbine generates power.

3. Cooled fluid is reinjected into the well to sustain reservoir pressure and temperature over the project life.

Heat and power applications:
Hydrothermal can provide heat for district heating systems and low- to medium-grade (50–300 °C) industrial processes that are hard to electrify and generate firm dispatchable power via binary (low-temperature) or steam turbines when the well temperature is sufficiently high (>80 °C for binary and >180 °C for steam).

Key cost drivers are depth, resource temperature and flow rate.
Power application example

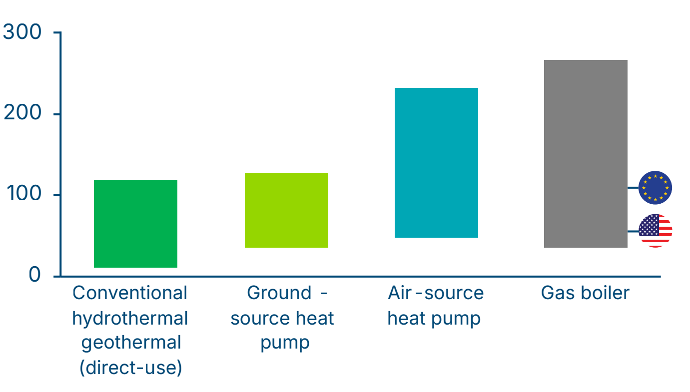




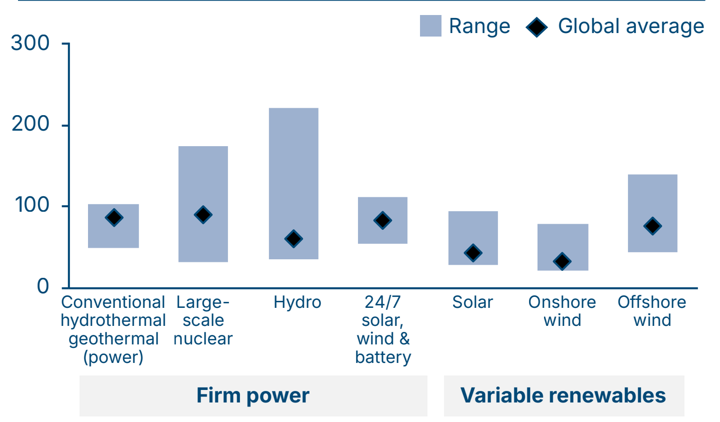
Cost-competitive power only occurs where shallow, high-temperature and high flow-rate resources are available:
Higher depth means higher drilling CAPEX but also higher temperature. This leads to more heat output per well, and lower surface plant costs for power generation.

Cost competitiveness: Firm, dispatchable low-carbon heat and power where the resource exists – a resource-bound baseload role, most valuable in high-renewables systems short of land or firm options.

Heat – European levelised cost range by technology, representative of early-2020s costs $/MWh-th (real 2024)



Power – 2035 global levelised cost of energy ranges for key clean energy technologies $/MWh-e (real 2024)



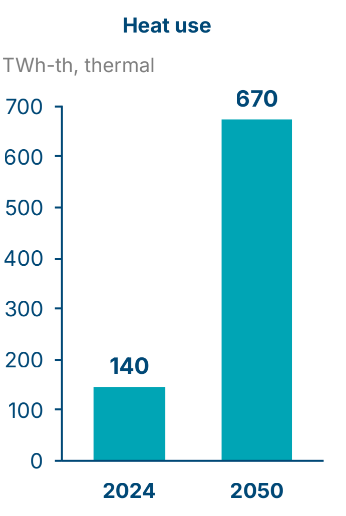
Heat at a competitive cost:
~$10–140 per MWh-th (typically ~$20–110) – equal to European gas but not US gas.

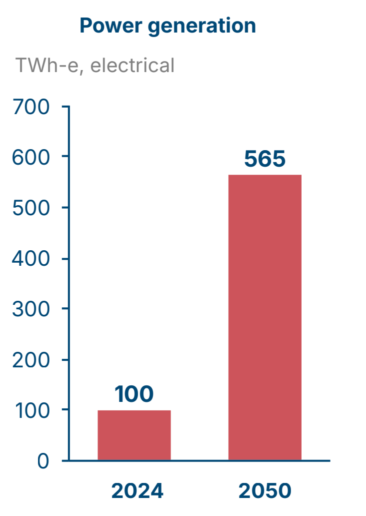
Key drivers behind geothermal district heating variation:
Reservoir depths, distance from end users, well flow rates, utilisation rates, drilling costs, learning-by-doing effects and economies of scale.

Competitive firm power where resource quality is high:
~70%+ capacity factor gives dispatchable generation, higher than wind and solar, but competitive for firm capacity - with nuclear, hydro and hybrid 24/7 renewables ($80–130 per MWh) and new fossil fuel generation.
Flexibility is technically possible but operationally unproven and economically challenging due to high upfront costs.

Deployment prospects: Mature and cost-competitive where geology allows, but highly geographically concentrated with a slow build-rate.

Global annual heat use and power generation estimates by year
2025-2050 (IEA APS, BNEF NZS)





Installed base today:
~140 TWh-th per year (~31 GW-th) of heat (0.2% of global) and ~100 TWh-e per year (~17 GW-e) for power (0.3%)

Heat use dominated by district heating:
District heating ~70%, residential and commercial direct ~19%, agriculture and fishing ~9%, industry ~2%.

Strong geographic concentration:

Heat: 50% in district heating networks in the US, Turkey, Iceland and Japan.

Power: ~60% in the US, Indonesia, the Philippines and Türkiye, ~30% across 6 other countries.

2050 potential at 3–5x from today:
Heat could triple in capacity but stays <1% total heat use, power could increase by 1.5–4x but stays at <1% of generation, untapped mainly in Kenya and Indonesia.

Barriers to deployment: Resource availability, front-loaded exploration risks, high upfront drilling CAPEX, long development timelines and environmental and social risks cap its further growth.

Resource & exploration risk
Needs high temperature gradient, natural permeability and proximity to demand – only confirmable by drilling, making exploration inherently risky.

Front-loaded risk & high WACC
Permitting, exploration and test drilling are only ~10–15% of cost but carry the highest cancellation risk; investors want 15–20% returns, so more projects are cancelled than commissioned.

Up-front drilling CAPEX
~80% of LCOE is upfront, dominated by reservoir-depth-driven drilling – cost roughly doubles from 2 to 4 km and again from 4 to 6 km.

Long timelines & permitting
7–10 years greenfield-to-operation. Permitting and land access often takes longer than drilling, driven by seismicity, water-use and land-rights concerns and drilling supply chain capacity constraints.

Conventional hydrothermal has manageable environmental risks – lower than oil & gas.

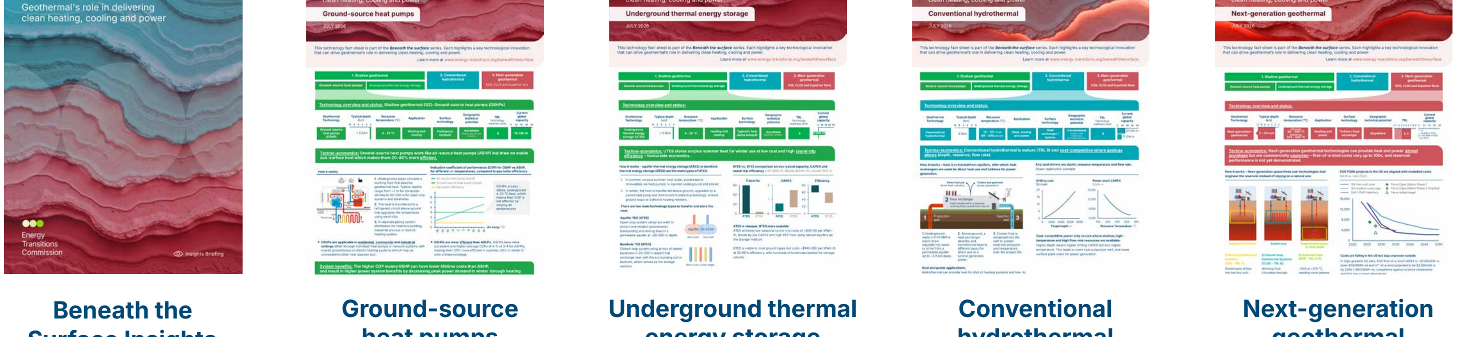
- Induced seismicity is relevant for deeper resources but lower than for EGS – natural reservoirs need no hydraulic stimulation; managed via monitoring protocols.
- Groundwater and emissions: sealed casing and cementing protect aquifers; small-scale H_2S and CO_2 can be released when native fluids are vented, mitigated by reinjection and abatement.
- Water use and, for power, (indigenous) land rights are the main social license concerns.

Policy actions: Lower the cost of capital and de-risk exploration to unlock deployment where geology allows.

Conventional hydrothermal enabling actions and lead actors

	Action	Lead actors
1	**De-risk exploration & drilling** Provide state-backed drilling-risk insurance and/or convertible exploration loans that convert to grants if drilling is successful to absorb downside exploration risks.	National governments or geothermal funds, agencies (for e.g. ADEME, BRGM), treasuries, development finance institutions, green investment banks.
2	**Lower the cost of capital** Provide concessional finance, public co-investment, and revenue mechanisms (e.g., contracts-for-difference) to lower the WACC.	(Green) infrastructure investment banks, development finance institutions, treasuries.
3	**Secure heat offtake via district-heating frameworks for direct-use** Support with zoning, connection mandates and tariff transparency (Denmark, Germany, Iceland and Sweden lead).	Municipalities, district-energy operators, regulators.
4	**Enable predictable regulation** Introduce or ensure clear ownership, licensing and pricing rules (Türkiye 2007 law, Kenya 1982 Act).	National and sub-national regulators, geological surveys.
5	**Support drilling-crew capacity** Support oil & gas skill transfer programs.	Drilling contractors, trade associations.

Further reading In the Beneath the Surface series



Beneath the Surface Insights Briefing Main Report

Ground-source heat pumps Technology Fact Sheet

Underground thermal energy storage Technology Fact Sheet

Conventional hydrothermal Technology Fact Sheet

Next-generation geothermal Technology Fact Sheet

Sources

The ETC's energy transition vision: ETC (2025), *Carbon in an electrified future: Technologies, trade-offs and pathways*.
Techno-economics: Kearney Energy Transition Institute (2025), *Geothermal Energy, Turning Up the Heat;* NREL (2025), *2025 Geothermal Drilling Cost Curves Update;* Koenraad F. Beckers (2019), *GEOPHIRES v2.0: updated geothermal techno-economic simulation tool.*
Cost competitiveness: KEARNEY Energy Transition Institute (2025), *Geothermal energy, turning up the heat*; IEA (2024), *The Future of Geothermal Energy.*
Deployment prospects: Systemiq analysis for the ETC (2026); IEA (2024), *The Future of Geothermal Energy;* BNEF (2026), *New Energy Outlook*.
Barriers to deployment: Systemiq analysis for the ETC (2026).
Policy actions: Systemiq analysis for the ETC (2026).

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SYSTEMIQ