Technology Fact Sheet

Energy Transitions Commission

Beneath the surface

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

Ground-source heat pumps

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.

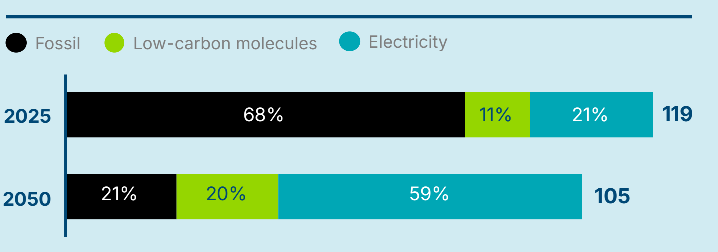
Learn more at www.energy-transitions.org/beneaththesurface

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.

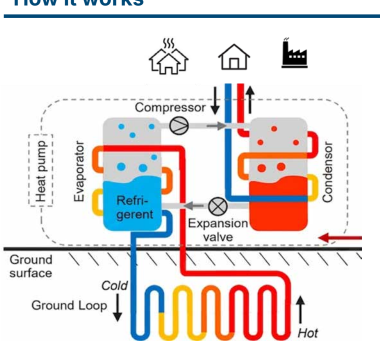
1. Shallow geothermal		2. Conventional hydrothermal	3. Next-generation geothermal
Ground-source heat pumps	Underground thermal energy storage		EGS, CLGS and Superhot rock

Technology overview and status: Shallow geothermal (1/2): Ground-source heat pumps (GSHPs)

Geothermal Technology	Typical depth (km)	Resource temperature (°C)	Application	Surface technology	Geographic technical potential	TRL Technology readiness level	Current global capacity
Ground-source heat pumps (GSHP)	< 0.5 km	4 - 25 °C	Heating and cooling	Heat pump (output)	Anywhere (Higher value in cold climates)	9	78 GW-th

Techno-economics: Ground-source heat pumps work like air-source heat pumps (ASHP) but draw on stable subsurface heat which makes them 20-40% more efficient.

How it works

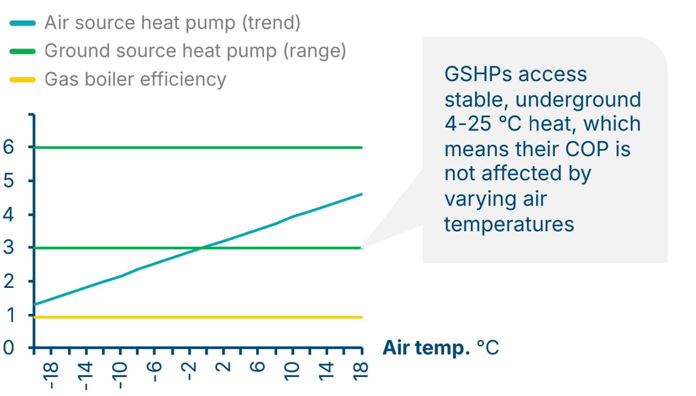


1. Underground pipes circulate a working fluid that absorbs geothermal heat. Typical depths range from ~2 m for horizontal slinkies to 50-200 m for open loop systems and boreholes.

2. The heat is transferred to a refrigerant circuit above ground that upgrades the temperature using electricity.

3. A separate piping system distributes the heat to a building, industrial process or district heating system.

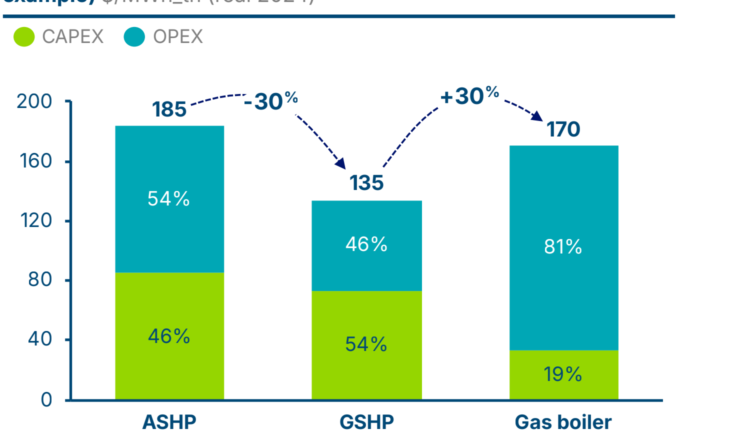
Indicative coefficient of performance (COP) for GSHP vs ASHP, for different *air* temperatures, compared to gas boiler efficiency



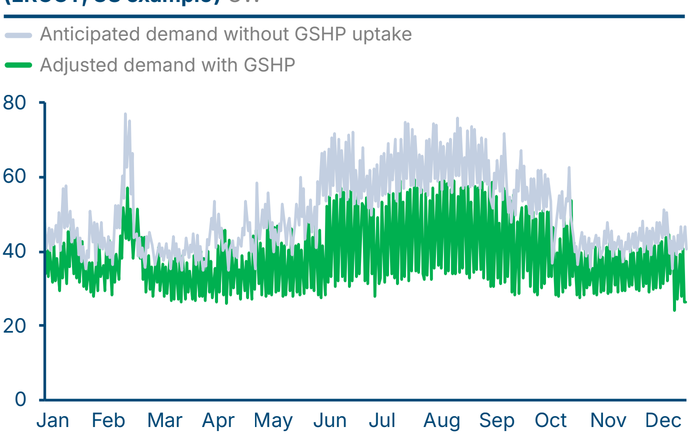
- **GSHPs are applicable in residential, commercial and industrial settings** either through individual heat pumps or network systems with shared ground loops or district heating systems (which may be connected to other heat sources too).
- **GSHPs are more efficient than ASHPs.** GSHPs have more consistent and higher average COPs of 4-5 vs. 3-4 for ASHPs, making them 20% more efficient in summer, 40% in winter in cold-climate buildings.

System benefits: The higher performance coefficient means GSHP can have lower lifetime costs than ASHP, and result in higher power system benefits by decreasing peak power demand in winter through heating and summer through cooling.

LCOH breakdown for ASHP, GSHP and gas boiler (UK retrofit example) $/MWh_th (real 2024)



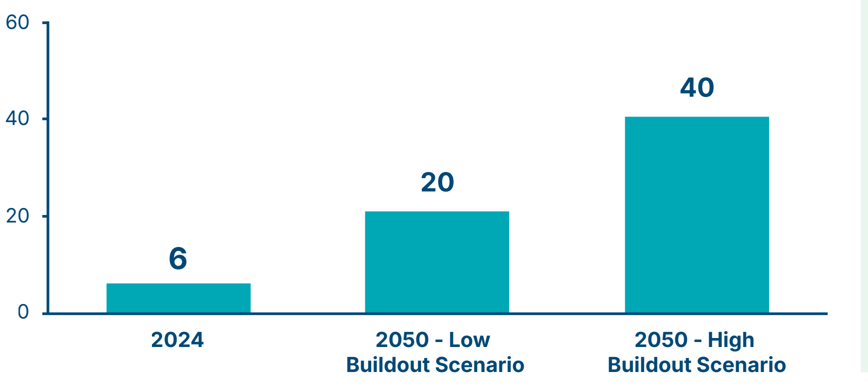
Illustrative impact of mass GSHP uptake on electricity demand (ERCOT, US example) GW



- **Higher upfront CAPEX and relative contribution to LCOH, but lower overall lifetime costs than ASHPs and gas boilers:** GSHPs typically have higher absolute CAPEX than ASHPs but lower LCOH, driven by higher COP (decreasing electricity input costs) and longer lifetimes.
- **High COP drives system-level savings:** Higher and consistent GSHP COPs mean lower winter peak demand at a system-level when rolled out at scale (e.g., ~10% of building stock). Seasonal swings narrow, avoiding peak capacity and transmission buildout at national level.

Deployment prospects: GSHP are a small share of the global heat pump market today but deployment is set to grow by 2050.

Global GSHP stock by geography (ETC estimates based on IEA SP & BNEF NZS) Million units



Global installed base today:

~6.5 million GSHPs with ~78 GW-th capacity

versus ~65 million ASHPs with ~920 GW-th capacity.

Energy share:

GSHP meets ~0.3% of global final heat consumption today.

Geography:

Concentrated in cold-climate countries, including the US, China and parts of northern Europe.

2050 potential:

Could rise to ~20-40 million GSHPs based on current trends (compared to ~600-700 million ASHPs).

Barriers to deployment: High upfront CAPEX, siting, policy and consumer trust – not the technology itself.

High CAPEX	Siting & permitting constraints	Misaligned policy incentives	Supply chain constraints
Higher upfront cost than alternatives (ASHPs and gas boilers) and owners need to understand borehole maintenance requirements. Lifetime costs are competitive, but capital and financing availability is constrained.	Some GSHP types have land access constraints and long planning and permitting processes – especially for larger systems.	Government funding is generally limited, and system benefits are not monetised in tariffs, meaning that consumers often don't see the benefits of GSHP system value through lower energy bills.	Drilling workforce is limited in locations with no existing/ transferable workforce.

GSHPs have limited environmental risks – these are not a deployment barrier.

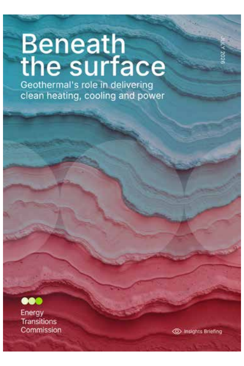
- **Emissions:** Lower operational emissions than fossil heating and decrease further as grids decarbonise.
- **Land and subsurface**: Localised drilling disturbance during installation and, for open-loop systems, low risk of groundwater contamination.
- **Refrigerants:** GSHP uses refrigerants in the heat pump unit, with leakage and global warming potential (e.g., R410A, GWP 2,088), however, this can be managed through a shift to low-GWP natural refrigerants such as propane (R290, GWP <1).

Policy actions: Policymakers should act to unlock scale and power system benefits.

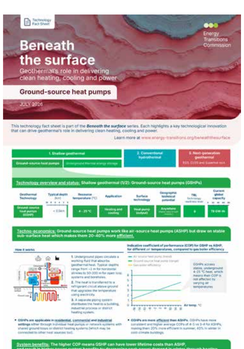
Shallow geothermal enabling actions and lead actors

	Action	Lead actors
1	**Address up-front CAPEX through financial instruments** Anchor load connections to heat networks, mortgage integration, on-bill recovery, concessional loans and stamp-duty differentials.	Mortgage lenders, treasuries, green banks, utilities, third-party providers, energy service companies.
2	**Standardise design & permitting** Use repeatable system designs by building archetype to ease installation and align subsurface/building-code rules to cut soft costs and speed approvals.	Standards bodies, manufacturers, sub-national regulators, building-code authorities.
3	**Fix tariff structures** Reward peak demand reduction through demand charges, time-of-use pricing and capacity payments so consumers capture GSHP's system value.	Electricity regulators, system operators, distribution network operators, utilities.
4	**Rebuild workforce capacity** Set-up drilling and heating, ventilation, and air conditioning (HVAC) apprenticeships to expand the skilled labour base in underserved locations.	Governments, training providers, trade associations, contractors.
5	**Build system scale and trust** Focus on developer-led networked deployment and utility-coordinated installers in dense urban areas, share independent performance data on reference sites.	Developers, municipalities, utilities, installer trade associations, manufacturers, energy service companies.

Further reading In the Beneath the Surface series



Beneath the Surface Insights Briefing
Main Report



Ground-source heat pumps
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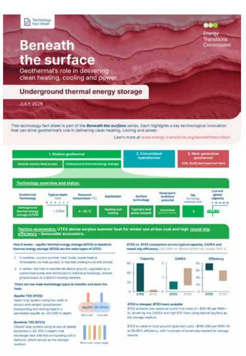
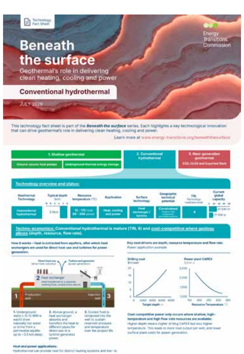


Underground thermal energy storage
Technology Fact Sheet



Conventional hydrothermal
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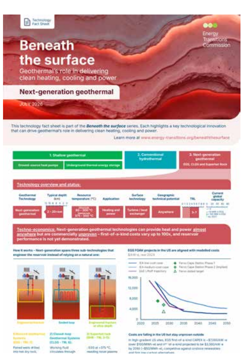

Next-generation geothermal
Technology Fact Sheet

Sources and notes

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;* Systemiq analysis for the ETC (2026); Element Energy for The Kensa Group (2023), *Low Carbon Heat Study – Phase 1*; Department for Energy Security and Net Zero (2025), *Quarterly Energy Prices*.
System benefits: Systemiq analysis for the ETC (2026); Element Energy for The Kensa Group (2023), *Low Carbon Heat Study – Phase 1*; Ofgem (2026), *Ofgem, Energy Price Cap, Q2 2026 (1 April–30 June 2026)*; Department for Energy Security and Net Zero (2025), *Quarterly Energy Prices; Pathways to Commercial Liftoff: Geothermal Heating and Cooling;* Oak Ridge National Laboratory (2023), *Grid Cost and Total Emissions Reductions Through Mass Deployment of Geothermal Heat Pumps for Building Heating and Cooling Electrification in the United States.*
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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