Energy
Transitions
Commission

ETC key messages: The role of firm low-carbon power – nuclear and geothermal

ETC Representatives Meeting

14 May 2026

Why are we focusing on nuclear and geothermal now?

Clean power technologies	Previous ETC coverage	Other coverage	Expected clean system role
Wind and solar	✔ Clean electrification series	IEA, IRENA (International Renewable Energy Agency), BloombergNEF	Significant – set to dominate electricity generation
Hydro (reservoir / run-of-river)	– Not a key focus (mature, geography-limited)	IEA, IRENA (International Renewable Energy Agency)	Large existing but limited expansion
Gas with CCS, hydrogen	✔ Clean electrification series	IEA, IRENA (International Renewable Energy Agency), BloombergNEF	Residual / niche
Bioenergy	✔ Bioresources	IEA, IRENA (International Renewable Energy Agency), BloombergNEF	Constrained
Nuclear	✖ Minimal focus until now	IEA, sightline climate, Department of Energy United States of America	▪ Uncertain, potentially material in some regions ▪ Increasing attention: "nuclear renaissance" and "surging next-generation geothermal investments"
Geothermal			

This workstream is the first time the ETC has addressed the future role of nuclear and geothermal in detail

Source: ASME (2026), *Nuclear Energy Outlook for 2026*; IEA (2026), *Investment in next-generation geothermal is surging. Policies are key to further growth*

Agenda

- **Key messages – nuclear**
- Key messages – geothermal
- Next steps

Key messages – nuclear

1. **Maintaining a ~9% nuclear share in global power generation is a major build challenge as power systems triple in size by 2050.** Life extensions for nuclear should be carried out where they can be done safely; extending to 80-year lifetimes retains ~240 GW of additional capacity, reducing new build requirements by 25% from ~950 to ~700 GW of new build needed by 2050.

2. **Deployment of new nuclear should be based on a rigorous country-specific assessment of system benefits and deliverability, not ideology. New nuclear can play a relatively more prominent role in specific contexts** (e.g. in China, South Korea).

3. **New nuclear is likely to remain higher cost than clean alternatives across most geographies on a levelised cost of energy basis.**

4. **New nuclear costs strongly vary regionally – up to 8x,** driven by differences in financing costs, replicable project pipelines, and regulation.

5. **Total system costs of nuclear (including generation, balancing, and grids) are comparable to wind- and solar, if deployed at limited shares (e.g. 10–20% generation)** – it reduces the need for renewables overbuild, backup capacity and grid buildout.

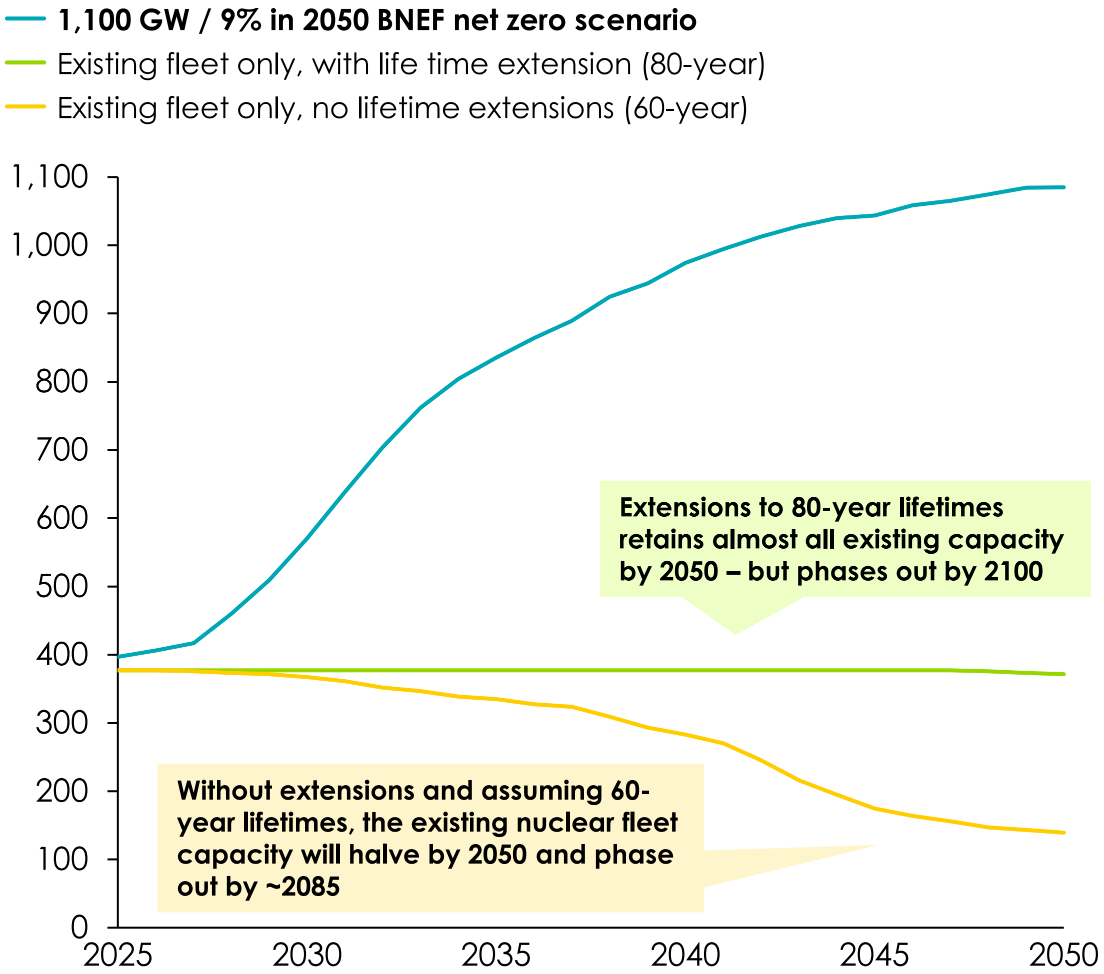
6. **Small modular and next-generation reactors are unlikely to materially reduce costs or speed up scale-up in the near term, but may enable location-specific niche applications** (e.g., new build heat and power offtake systems).

7. **Nuclear fuel supply chain concentration is a key risk.** Other risks related to supply chains, safety, waste are real but are mainly manageable with appropriate regulation, institutional capacity, and project design.

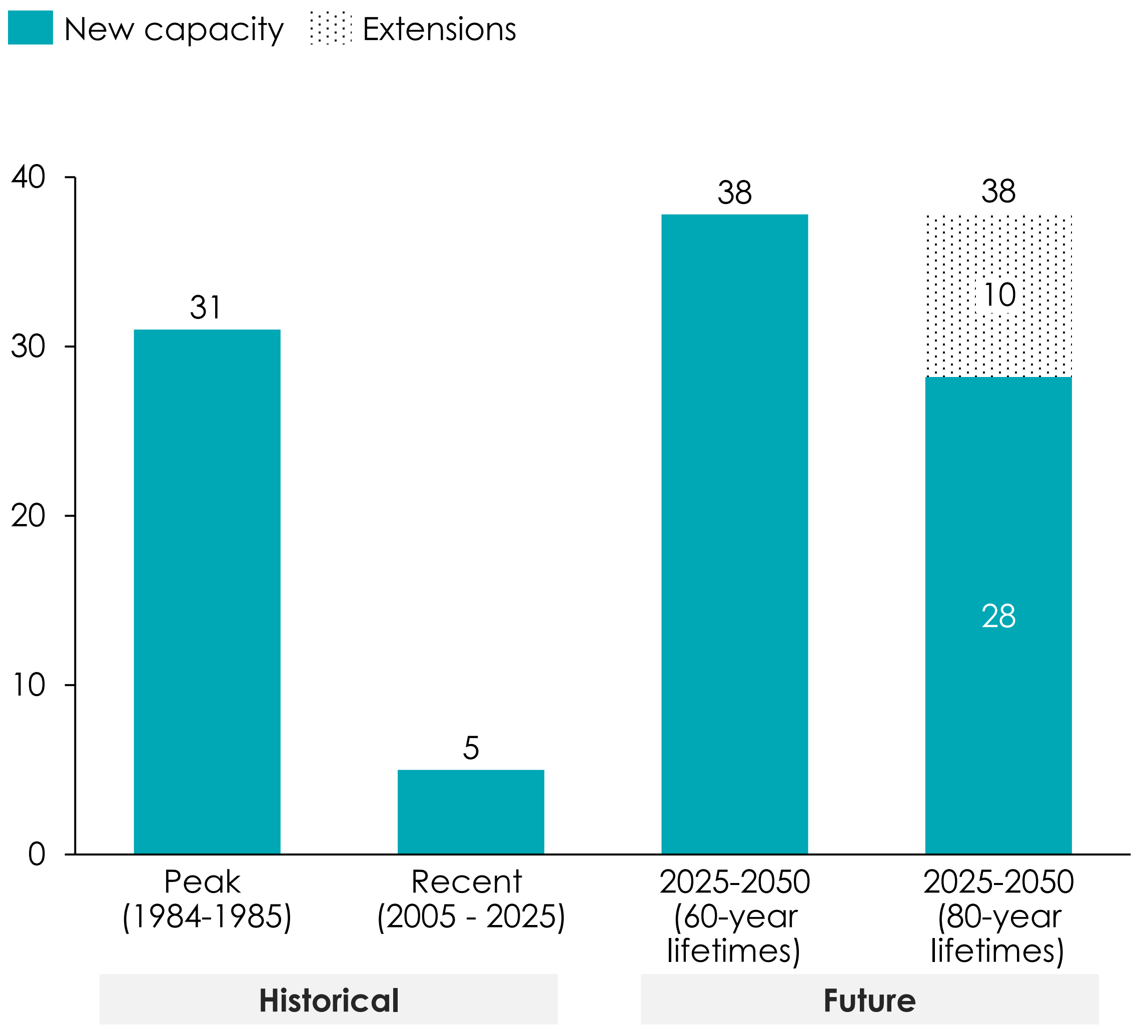
8. **Nuclear does not consistently deliver greater economic or societal benefits than other clean technologies**; perceived "higher gross value-add" reflects higher capital intensity rather than superior productivity, and job creation varies significantly by country and supply-chain depth.

1. Maintaining a 9% nuclear global share is a major build challenge; average startups need to increase from 5 to ~30-40 GW per year

Capacity needed to meet 9% of 2050 generation in a net-zero pathway (assuming 60-year lifetimes), GW



Average annual reactor startups, historic vs future need
GW/year



Source: IAEA (2026), *Power Reactor Information System*, BNEF (2025), *New Energy Outlook*; Mycle Schneider (2025), *World Nuclear Industry Status Report 2025*

2. Deployment of new nuclear should be based on a rigorous assessment of system benefits and deliverability, not ideology

Six criteria determine the role of nuclear by country

A. System benefits – when is nuclear most valuable?

1) Power system benefits	→	High value where wind/solar potential and alternative secure firm capacity are limited, increasing the need for reliable firm supply
2) Energy system benefits	→	Attractive where heating demand is large and alternative solutions are constrained or costly

B. Deliverability – what enables rapid, low-cost deployment?

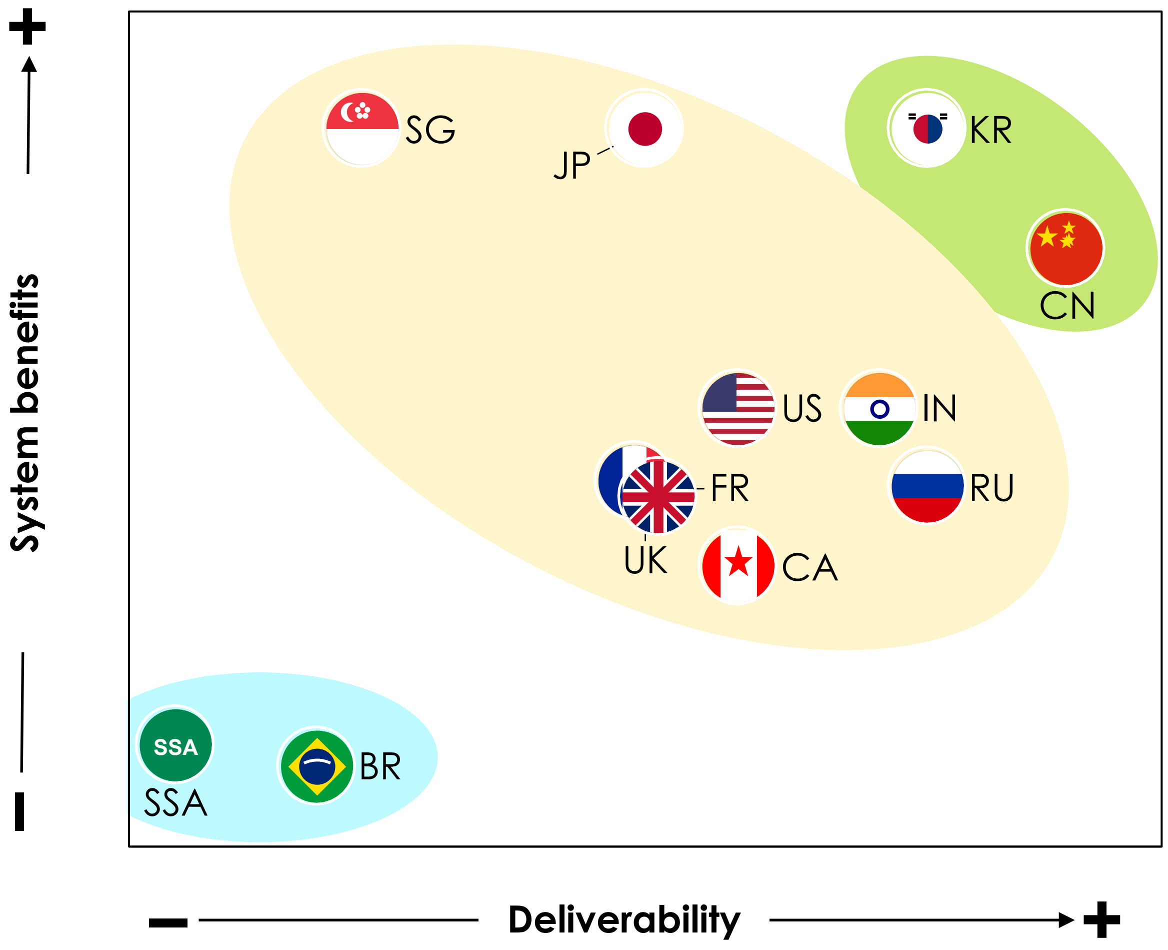
3) Supply chain capacity	→	Experienced suppliers and workforce capable of standardised repeat build to deliver projects on time and on budget
4) Resource availability	→	Secure nuclear fuel supply
5) Regulatory capacity	→	Credible, proportionate and predictable regulatory and siting frameworks across the project lifecycle
6) Financing availability	→	Access to low-cost capital and credible risk allocation and revenue frameworks

Scoring high means a high potential for:

- ✓ **Good system outcomes:** Total system cost and resilience
- ✓ **Managing financial risk:** Reducing time and cost overrun
- ✓ **Political durability:** Institutional stability and public support

2. System benefits and deliverability criteria map countries into three archetypes: “clear role”, “valuable but limited”, and “limited role”

Indicative assessment of relative suitability of selected countries based on system benefits and deliverability



Clear role for nuclear

Where: China, South Korea

Why: High system benefits; Recent low-cost delivery; Trained workforce; Institutional capacity

Nuclear share: Higher system shares feasible e.g. 20%

Nuclear is valuable but limited

Where: Japan, Singapore, India, US, UK, Canada, Russia

Why: Either limited system benefits or deliverability; alternatives likely to scale faster

Nuclear share : Nuclear limited to low shares e.g. <10-20%

Minimal near-term role for nuclear

Where: Countries with high VRE and/or hydro resources

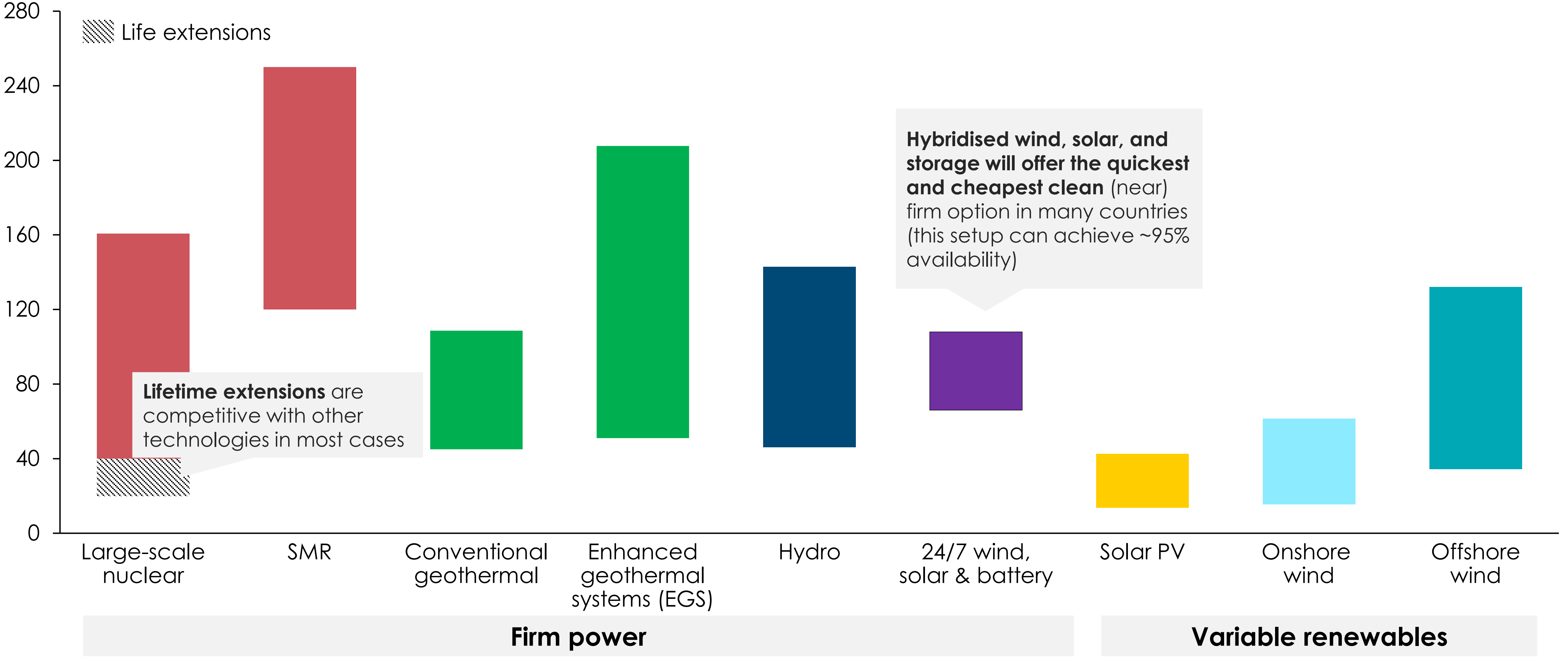
Why: Low system benefits and deliverability; alternatives will scale faster

Nuclear share: Negligible in short- to medium term

Notes: BR = Brazil, CA = Canada, CN = China, FR = France, IN = India, JP = Japan, KR = South Korea, RU = Russia, SG = Singapore, SSA = Sub-Saharan Africa (regional), UK = United Kingdom, US = United States

3. New nuclear capacity is likely to remain higher-cost than clean alternatives on a LCOE-basis in most geographies

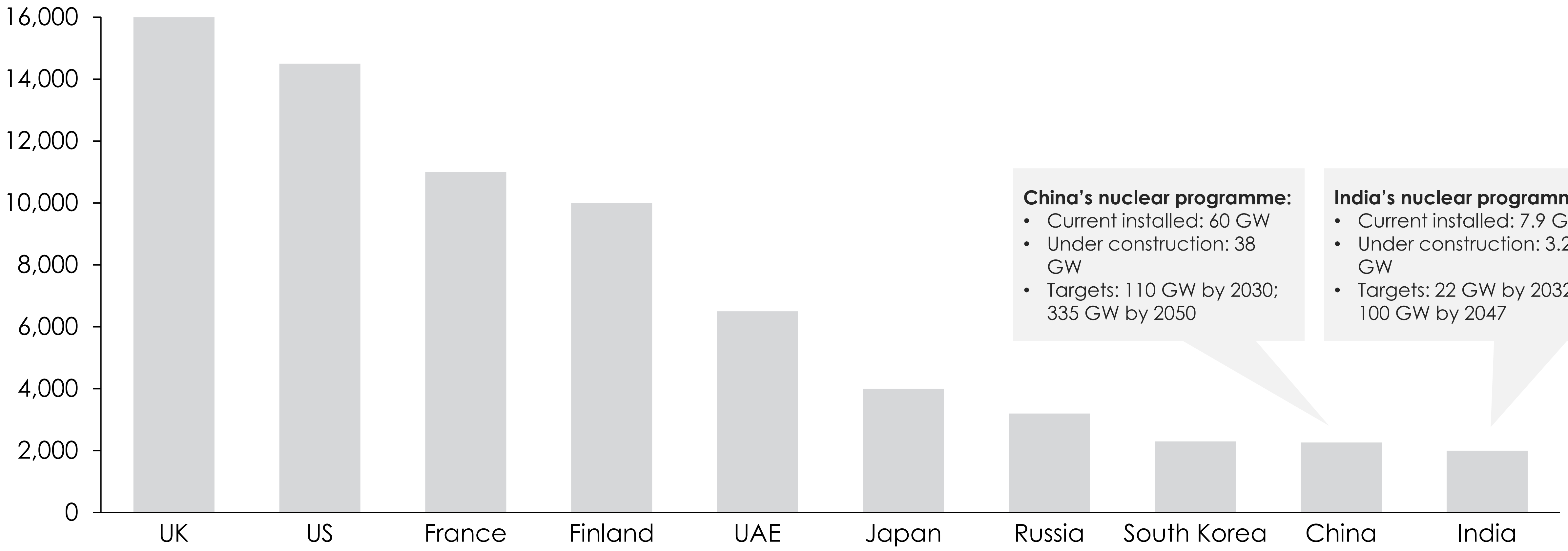
2035 global levelised cost of energy ranges for key clean energy technologies, ranges reflect different geographies and technologies
$/MWh (real 2024)



Notes: Next-gen. geo. includes enhanced geothermal systems and closed loop geothermal systems, SMR = small modular reactor. Life extensions only included for nuclear due to the large opportunity based on the ageing plants. Hybrid 24/7 wind & solar based on IEA 2035 STEPS estimates from China (lower bound) to the EU (upper bound), with hybridized systems achieving ~95% availability. Source: BNEF (2025), LCOE Data Viewer; BNEF (2025), *US Next-Generation Geothermal Makes Unsung Progress*; IEA (2025), *World Energy Outlook 2025*

4. Nuclear CAPEX varies significantly by country, driven by standardisation, programmatic buildout, construction duration, regulatory complexity

Recent Generation III overnight CAPEX estimates by country
$/kW, real 2024



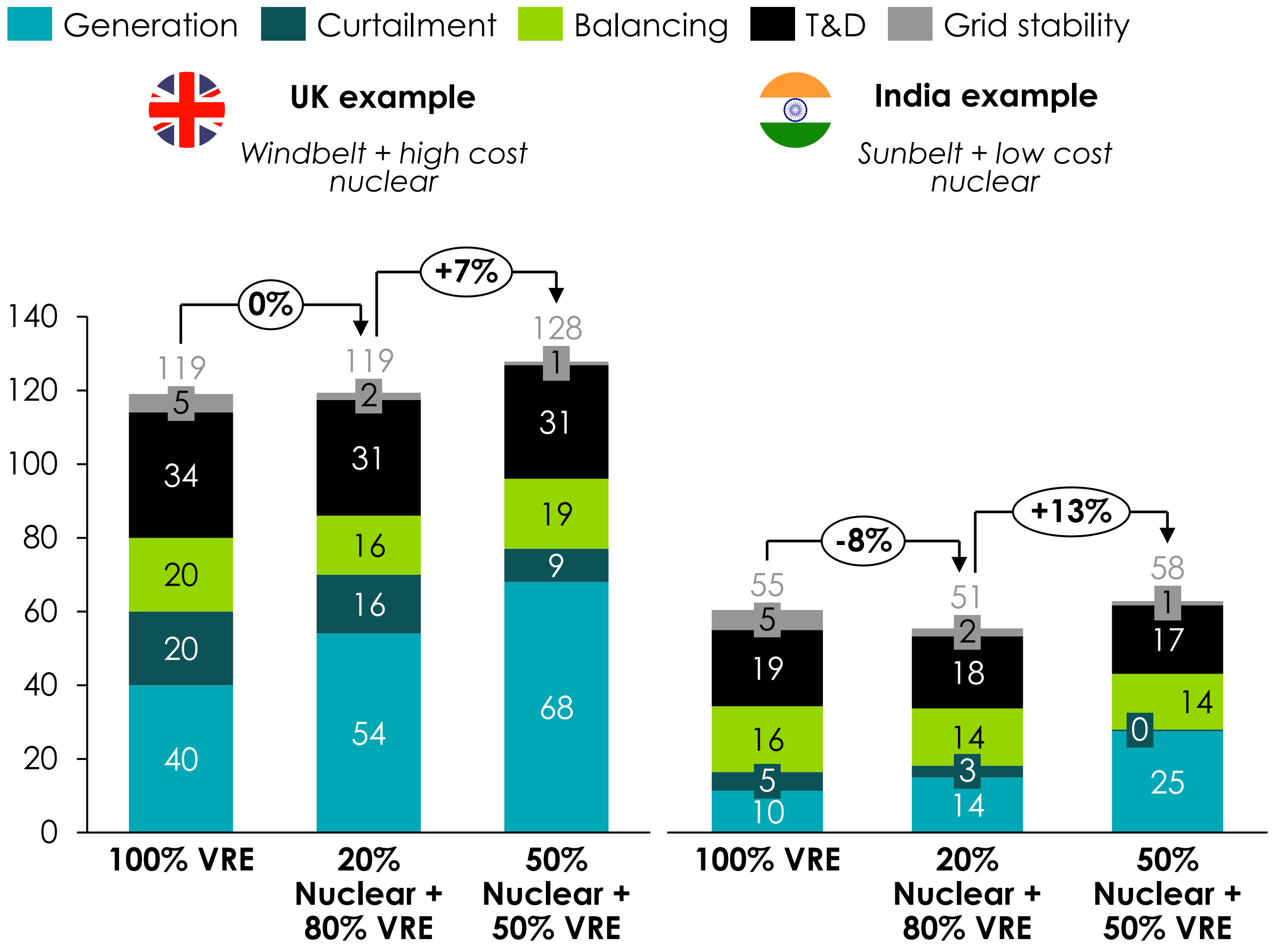
China's nuclear programme:
- Current installed: 60 GW
- Under construction: 38 GW
- Targets: 110 GW by 2030; 335 GW by 2050

India's nuclear programme:
- Current installed: 7.9 GW
- Under construction: 3.2 GW
- Targets: 22 GW by 2032; 100 GW by 2047

Notes: FOAK = 1st of a kind; NOAK = nth of a kind. Source: BNEF (2025), *LCOE Data Viewer*; Energy Technologies Institute (2020), *The ETI Nuclear Cost Drivers Project*; INL (2024), *Nuclear Energy Cost Estimates for Net Zero World Initiative – 2024 Update*; Financial Times (2025), *Cost of Sizewell C nuclear project expected to reach close to £40bn*; Green Prizm (2024), *2023 Report on Chinese Nuclear Power Generation and Costs Analysis; WNA (2026),* China - World Nuclear Outlook Report; *WNA (2026),* India - World Nuclear Outlook Report

5. Nuclear can reduce clean power system costs - but only at limited penetration

Illustrative view of components of total system cost and variation by system, UK and India case studies in 2050, $/MWh (real 2024$)



A system with some nuclear can reduce total power system costs

1. ***Drivers:* Systems with more nuclear relative to VRE…**

   \+ *Increase* generation costs due to higher LCOE

   – *Can lower* curtailment, balancing costs, grid stability and T&D costs, at low nuclear penetrations

2. **The net impact is region specific** e.g., in India system costs *reduce* with nuclear, in the UK there's limited impact. Note: India is one of a small subset of countries in the sunbelt with existing nuclear capacity.

3. **Nuclear's optimum penetration is capped:** at e.g. ~20% the net effect of respective power system drivers (generation, curtailment,…) switches and increases system costs, nuclear capacity should not exceed baseload power demand.

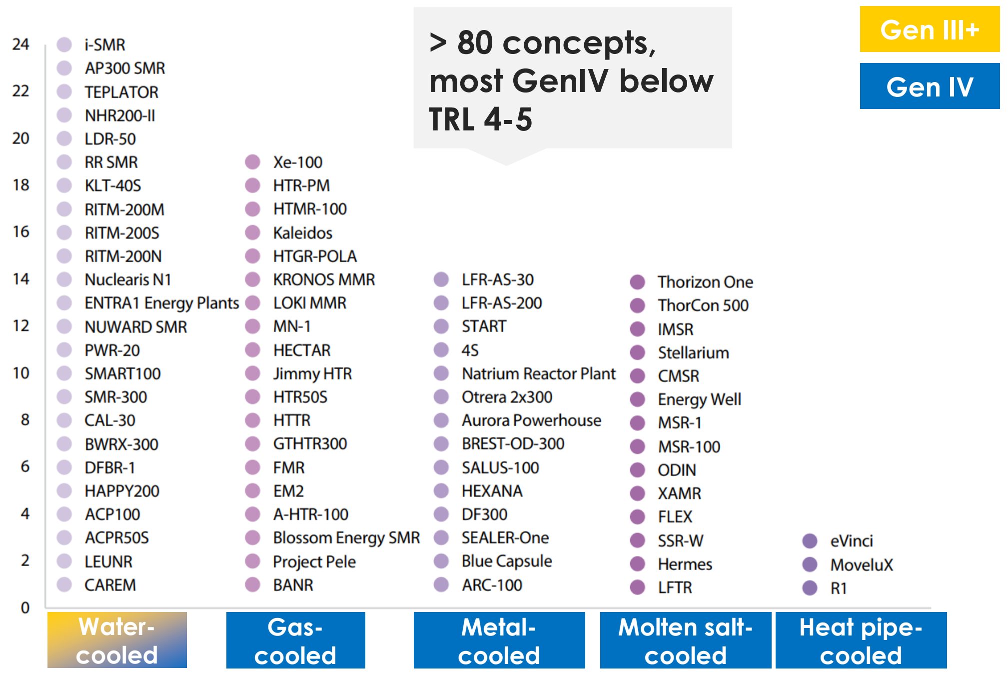
Notes: "20% nuclear" refers to the share of generation. VRE = variable renewable energy; T&D = Transmission & distribution. Sensitivities: Generation - BNEF's low, medium, and high 2050 CAPEX and OPEX estimates and assumptions for capacity factors, WACC, and lifetimes based on ETC modelling; Curtailment – surplus electricity at the weighted average wind & solar LCOE (assuming no nuclear is curtailed); Balancing – central CAPEX +/- 20% for high/low alongside high/low electricity input costs based on generation; Transmission & distribution - central CAPEX +/- $5/MWh for high/low. Source: Systemiq analysis for the ETC (2025); BNEF (2025), *LCOE Data Viewer*

6. SMRs will only deliver low costs if design consolidation and standardisation occurs; this has not been achieved in early SMR deployment

Scaling up SMR could reduce costs by 20% - but this requires consolidation to achieve standardisation & economies of scale

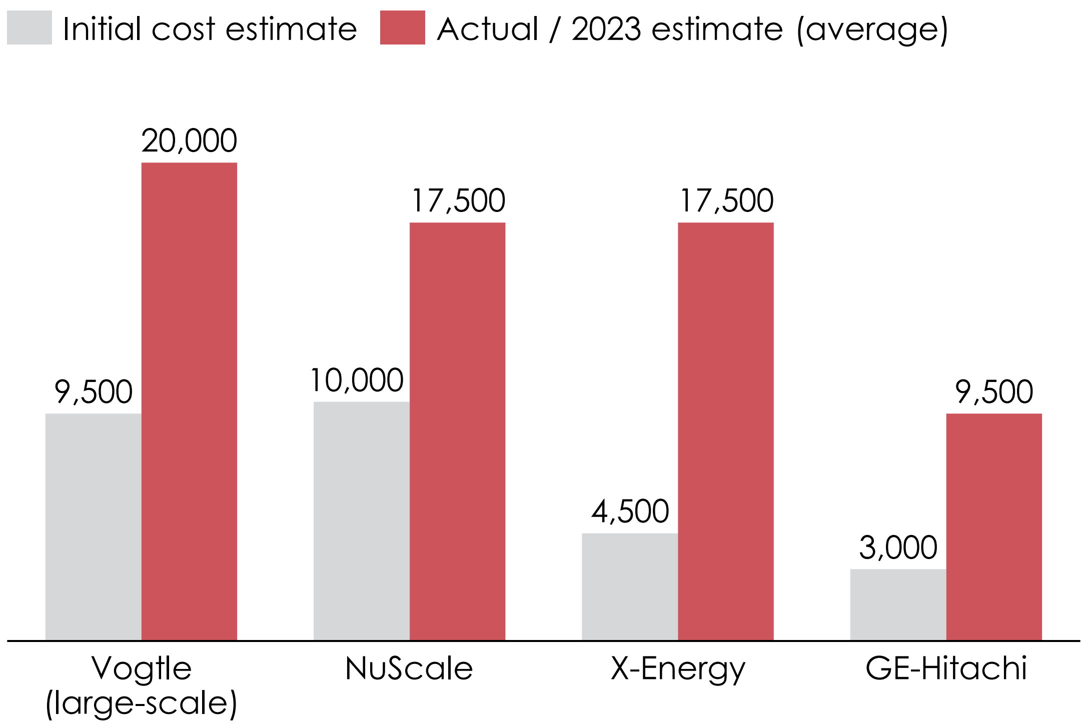
However, citations from SMR vendors show a rising cost trend, driven by inflation, labour costs and supply chain constraints

SMR concepts in development by reactor type



Projected cost increases for proposed North American SMRs

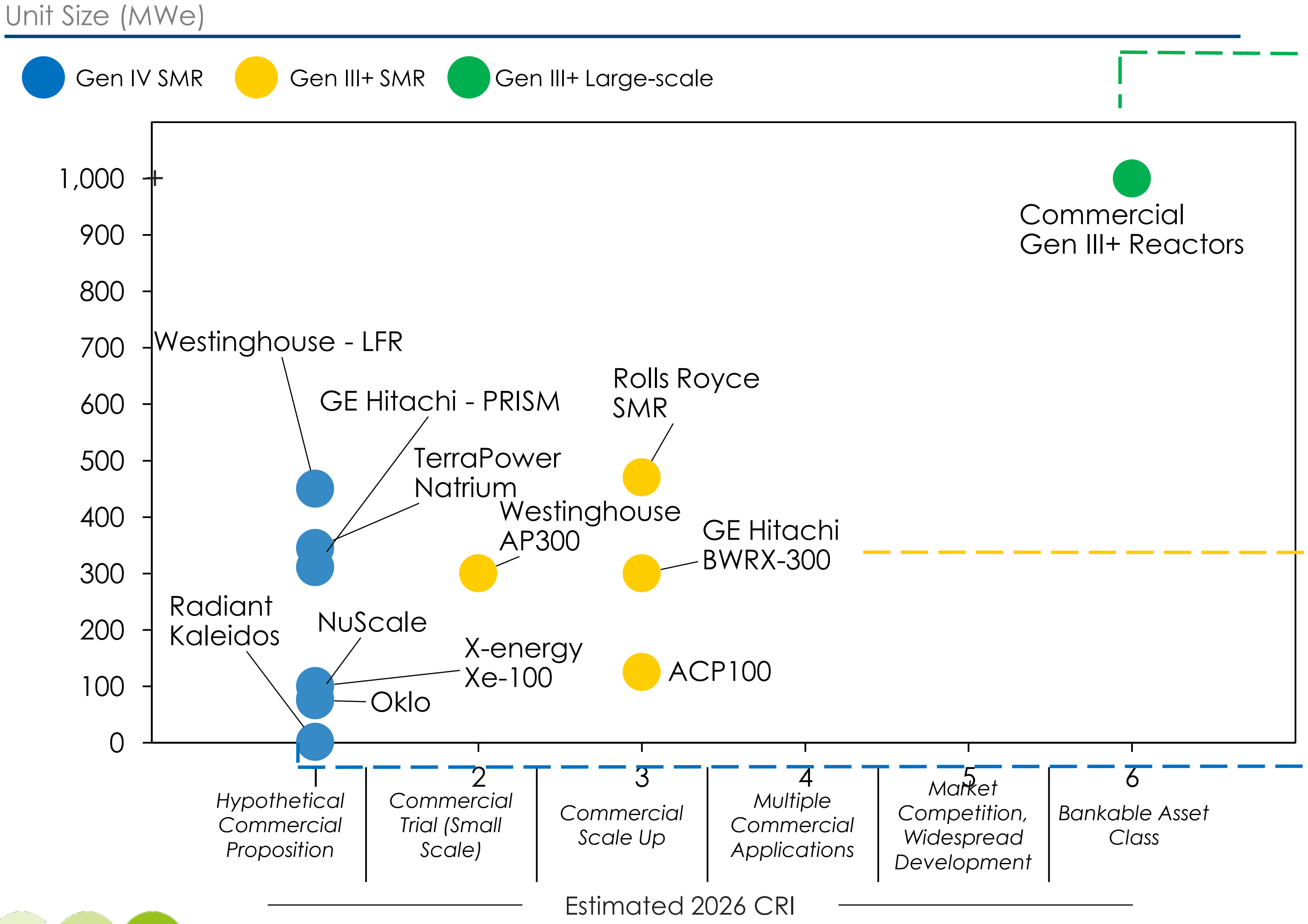
$/kW, real 2023



Source: IEEFA (2023) Small Modular Reactors; Still Too Expensive, Too Slow and Too Risky; Source: NEA (2025), *The NEA Small Modular Reactor Dashboard: Third Edition*.

6. Small modular and next-generation reactors are unlikely to materially reduce costs or speed up scale-up in the near-term

Illustrative diagram of the unit size and Commercial Readiness Index (CRI) of selected designs



High near-term deployment potential:

1. **Conventional technology (Gen III+)**
2. **Large unit sizes** (e.g., 300+ MW)
3. **Standardisation and modularisation** (high project replicability)

Medium near-term deployment potential:

1. **Conventional technology (Gen III+)**
2. **Larger SMR unit sizes** (100+ MW)
3. **Standardisation and modularisation**

Low near-term deployment potential:

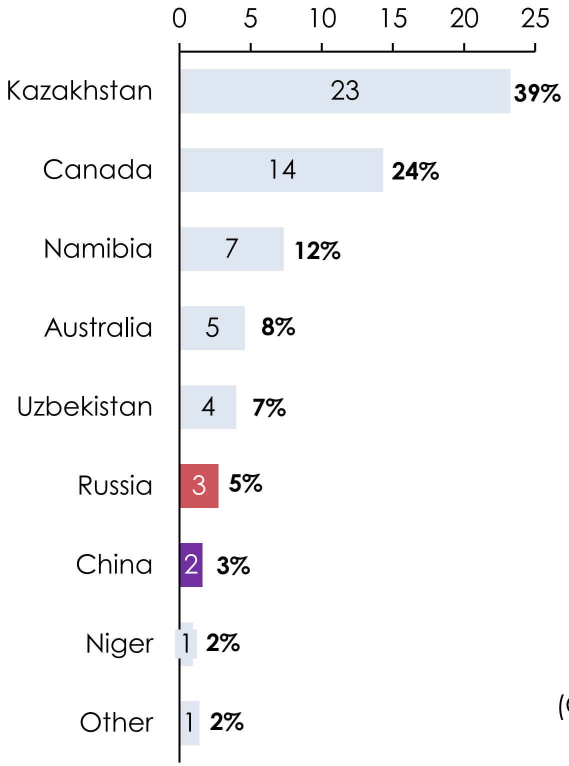
1. **Advanced technology (Gen IV)**
2. **Small unit sizes**
3. **Low standardisation**

Notes: Circle diameter represents CAPEX scale. CRI 1 = TRL 2-8; CRI 2 = TRL 9. Commercial Gen III+ Reactors include reactors such as AP1000, EPR, APR-1400, HPR-1000. FOAK = first of a kind, NOAK = nth of a kind. Source: Systemiq analysis for the ETC (2025); ARENA (2014), *Commercial Readiness Index for Renewable Energy Sectors*

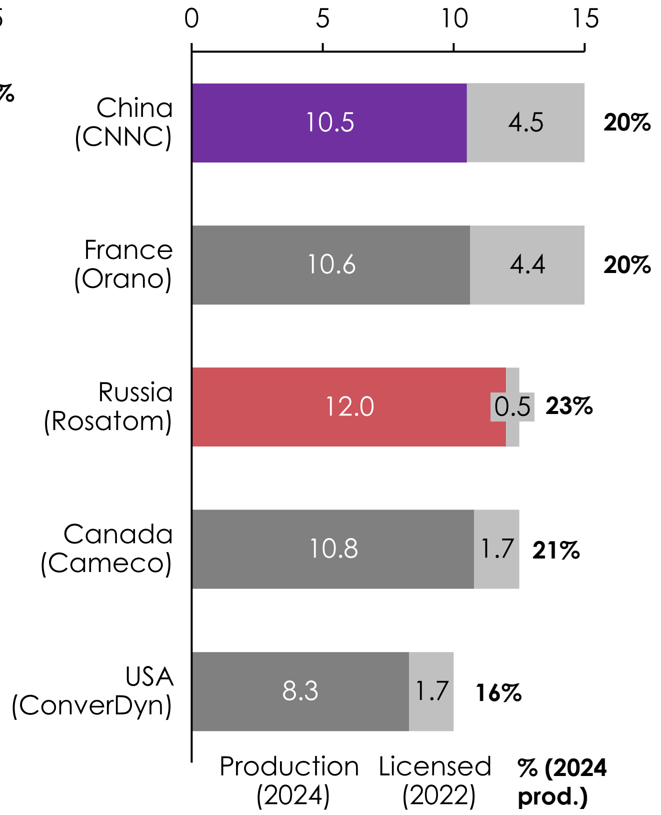
7. Conventional fuel conversion and enrichment capacity is concentrated in Russia and, increasingly, China

Country / operator share of global capacity or production across the four low-enriched uranium (LEU) fuel-cycle stages

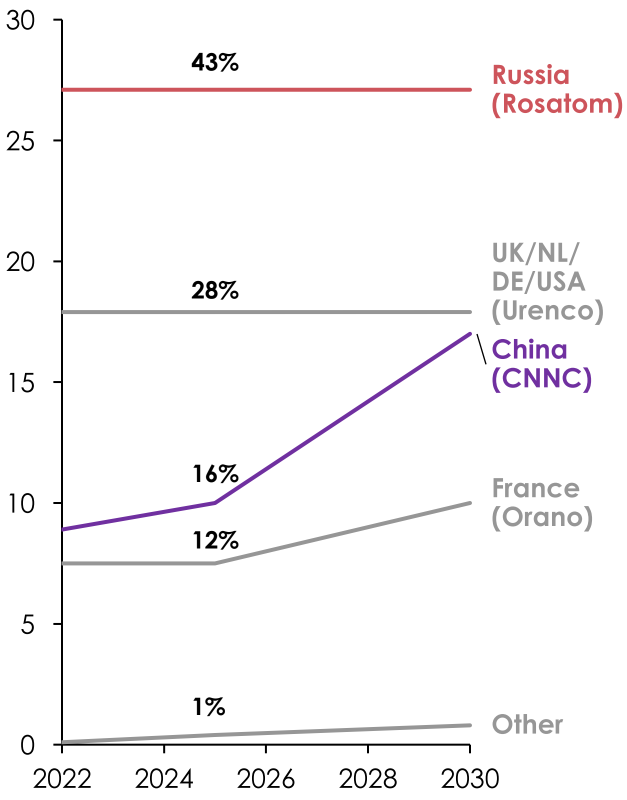
1. Mining – 2024 uranium mine production share, 000 tU/yr [1]



2. Conversion – licensed capacity vs actual UF_6 production, 000 tUF_6/yr [2]



3. Enrichment – capacity, 000 SWU/yr [3]



4. Fabrication – supplier and reactor Type [4]

Supplier	Reactor types
TVEL / Rosatom (RU)	VVER (dominant), PWR
CNNC (CN)	Domestic LWR fleet
Westinghouse (US/SE/UK)	PWR, BWR, VVER
Framatome (FR/DE/US)	PWR, VVER (in dev.)
GNF (US/JP)	BWR
KEPCO NF (KR)	Domestic OPR/APR

Notes: Capacities correspond to conventional LEU (≤5% U-235) for LWRs and PHWRs; HALEU, MOX and military fuel cycles excluded. Conversion data shows licensed capacity bars (2022) alongside production bars (2024) due to data availability. ConverDyn 2024 figure of 8,300 t is "planned 2024 output" not actual. BWR = Boiling Water Reactor; PWR = Pressurised Water Reactor; LWR = Light Water Reactor (PWR + BWR); PHWR = Pressurised Heavy Water Reactor; VVER = Vodo-Vodyanoi Energetichesky Reaktor (Russian-design PWR); OPR = Optimised Power Reactor (Korean); APR = Advanced Power Reactor (Korean); HALEU = High-Assay Low-Enriched Uranium; MOX = Mixed Oxide fuel; SWU/yr = Separative Work Units per year, the standard annual enrichment capacity unit. Source: [1] World Nuclear Association (2025), World Uranium Mining Production, updated 23 Sept 2025 (2024 data). [2] World Nuclear Association (2025), Nuclear Fuel Report: Global Scenarios for Demand and Supply Availability 2025–2040; Cameco (2024) Annual Report; Orano disclosures. [3] World Nuclear Association (2025), Uranium Enrichment, updated 6 June 2025; Orano press releases (2024). [4] World Nuclear Association (2025), Nuclear Fuel and its Fabrication.

Agenda

- Key messages – nuclear
- **Key messages – geothermal**
- Next steps

Key messages - geothermal

1. **The largest value of geothermal lies in shallow applications: heating, cooling and storage.** These are **mature, least geographically constrained**, and can have **significant system impacts**, subject to policy and financing.

2. **Existing scenarios suggest that (conventional) geothermal power could maintain a ~0.3-0.4%** share of global generation in 2050, meaning a tripling of generation/capacity from 15 to 45 GW as the global power system expands by ~3x

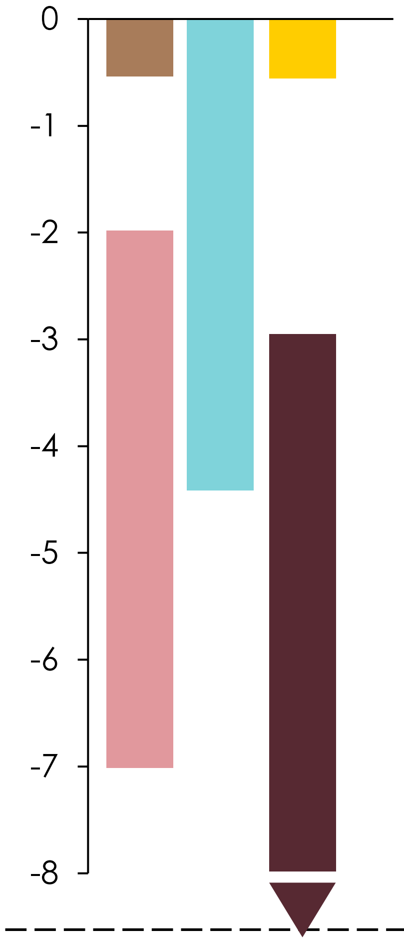
3. **Conventional hydrothermal power is scalable where geology allows** (e.g., in the East African Rift and Pacific Ring of Fire), but cannot exceed the limits set by natural reservoir characteristics.

4. **Next-generation geothermal power could break the resource constraint** via engineered resources, but commercial competitiveness outside high-gradient hotspots **requires strong cost reductions and demonstrated reservoir longevity** – limiting realistic deployment to 30-800 GW by 2050 (~0.2-4.5% of generation) of the 600 TW technical potential.

5. **Next-generation geothermal could become competitive in industrial heat applications in the 2030s** – particularly in regions with high-cost and volatile alternatives (e.g. gas in Europe).

6. **Risks related to safety, pollution, emissions, seismicity, and resource intensity are real** but, based on international experience, **are small in magnitude and manageable** with appropriate regulation, institutional capacity, and project design.

Geothermal energy encompasses different resources and uses; power generation with conventional hydrothermal is currently geographically limited



Geothermal Technology	Temp (°C)	Use Case	Geographic potential	Sector	TRL
Ground source heat pumps	4 - 25 °C	Heating, Cooling	Global	Resi., Industry	9
Geothermal energy storage	< 100 °C	Storage	Global	Resi., Industry	9
Conventional hydrothermal	10 - 120 °C (heat) 80 - 300 °C (power)	Heating, Power	Shallow resources	Grid, Industry	9
Next-gen. technologies					
Enhanced geothermal systems (EGS)	80 - 300 °C	Heating, Power	Global	Grid, Industry	7
Closed loop geothermal systems (CLGS)	80 - 300 °C	Heating, Power	Global	Grid, Industry	6
Superhot rock	375 - 500 °C	Heating, Power	Global	Grid, Industry	3 - 5

Heating Cooling Storage Power

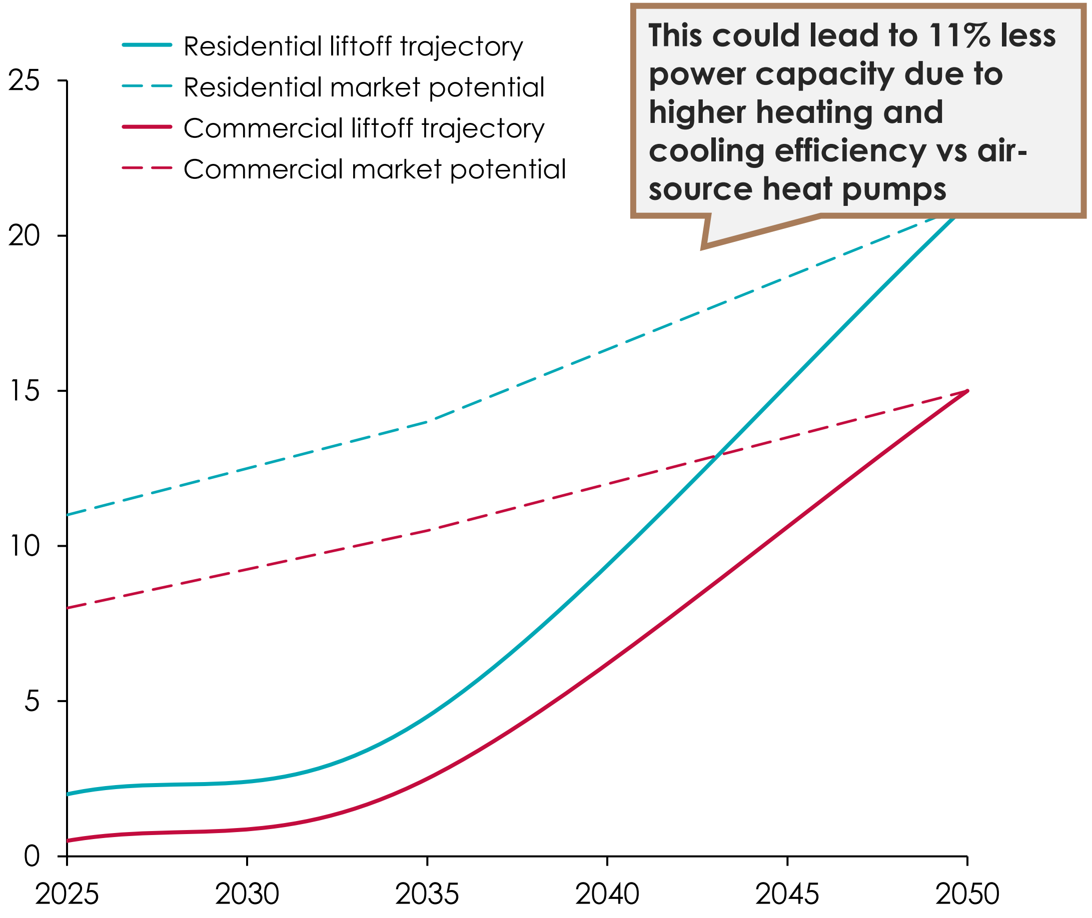
Resi. Industry Grid

Notes: Underground energy storage parameters refer to underground thermal energy storage (excluding more nascent options such as geothermal mechanical storage).
Assumed TRL scale: TRL 1-3 = Research to Proof of Concept; TRL 4-6 = Lab to Pilot Demonstration; TRL 7-9 = Prototype Demonstration to FOAK / Full Commercial Deployment

1. Globally, the highest near-term potential and system value of geothermal lies in shallow applications: heating, cooling and thermal energy storage (TES)

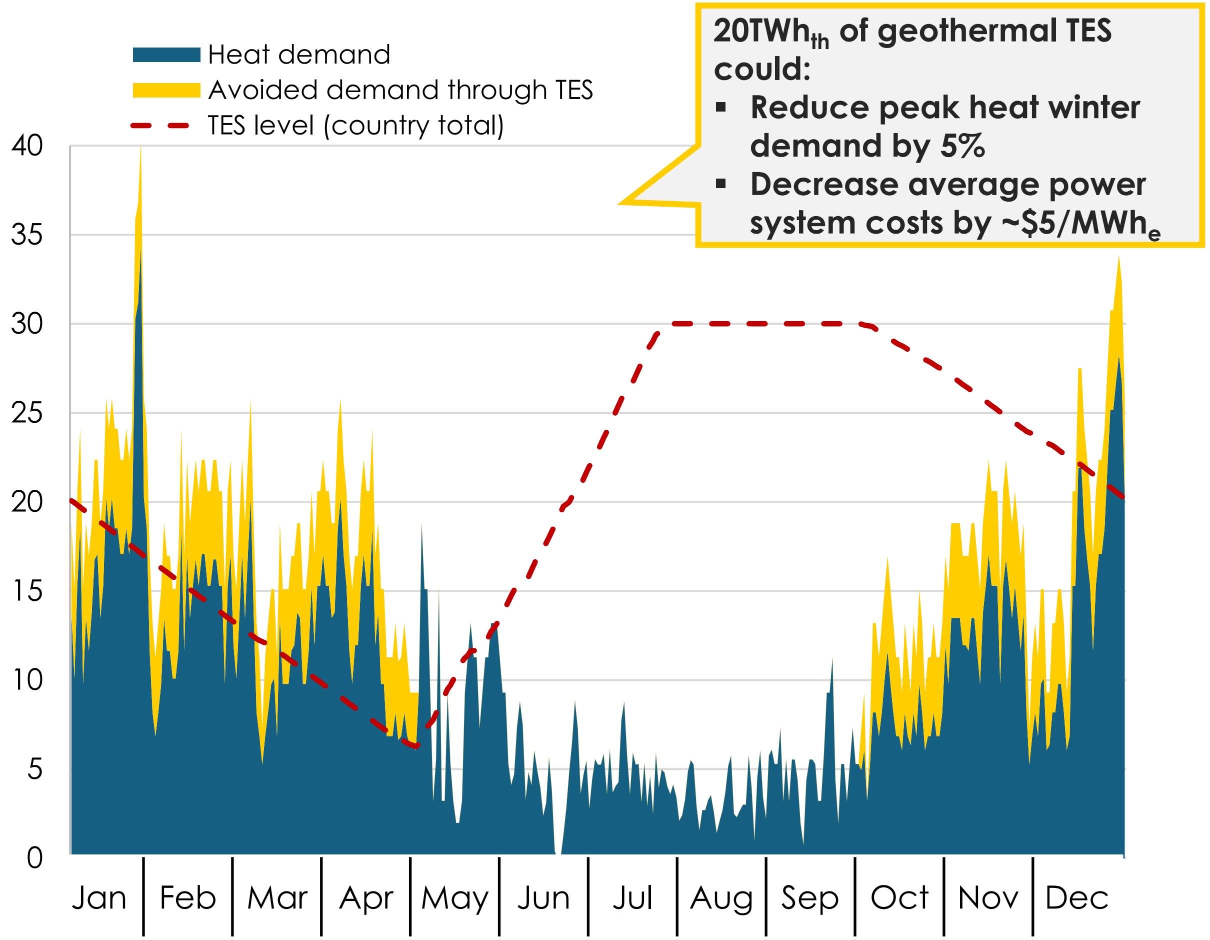
US DoE Liftoff trajectory for ground-source heat pump installations

Million homes equivalent (by building type)



Hypothetical TES impact on UK 2050 clean electrified heating demand

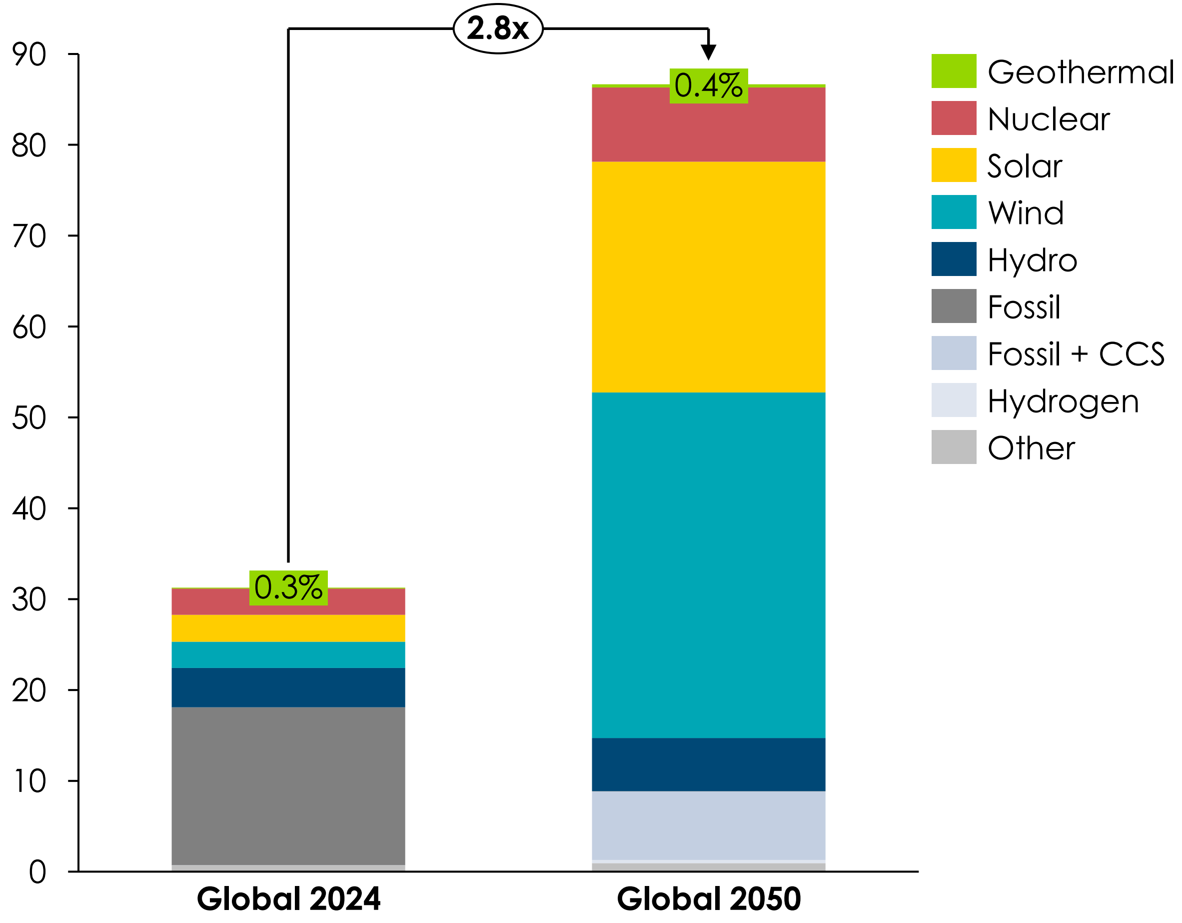
Daily average heat demand – GW_e; TES level – TWh_{th}



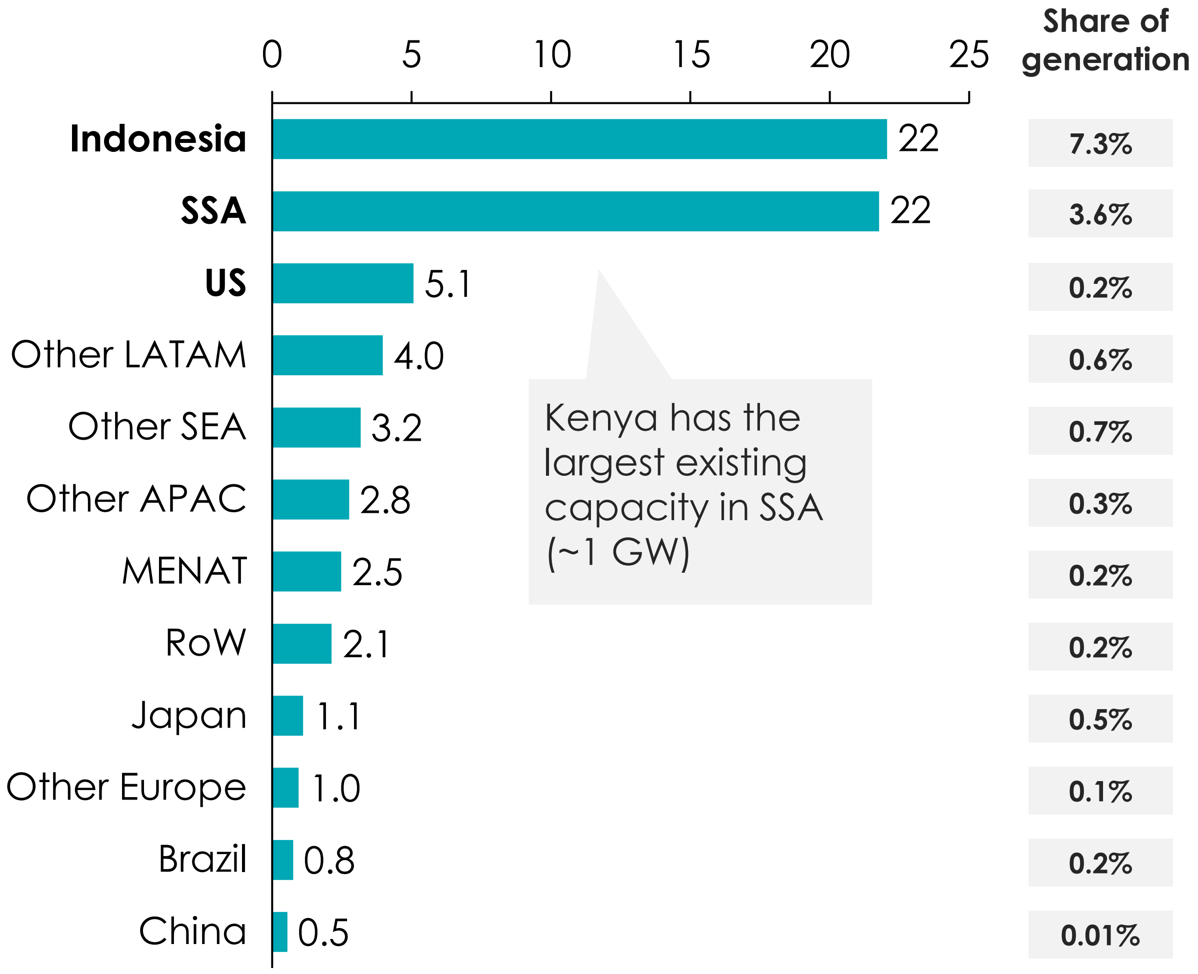
Sources: Oak Ridge National Laboratory (2023), *Grid Cost and Total Emissions Reductions Through Mass Deployment of Geothermal Heat Pumps for Building Heating and Cooling Electrification in the United States*, Systemiq analysis for the ETC (2025); ETC(2025), *Power Systems Transformation: Delivering Competitive, Resilient Electricity in High-Renewable Systems*; NESO (2022), *Future Energy Scenarios 2022 (FES 2022)*; C.S. Brown (2024), *Assessing the technical potential for underground thermal energy storage in the UK*

2. Existing scenarios suggest that conventional hydrothermal could maintain a <0.5% share of global electricity generation in 2050

Share of conventional hydrothermal vs other technologies in BNEF's 2050 Net Zero Scenario, 000 TWh/y



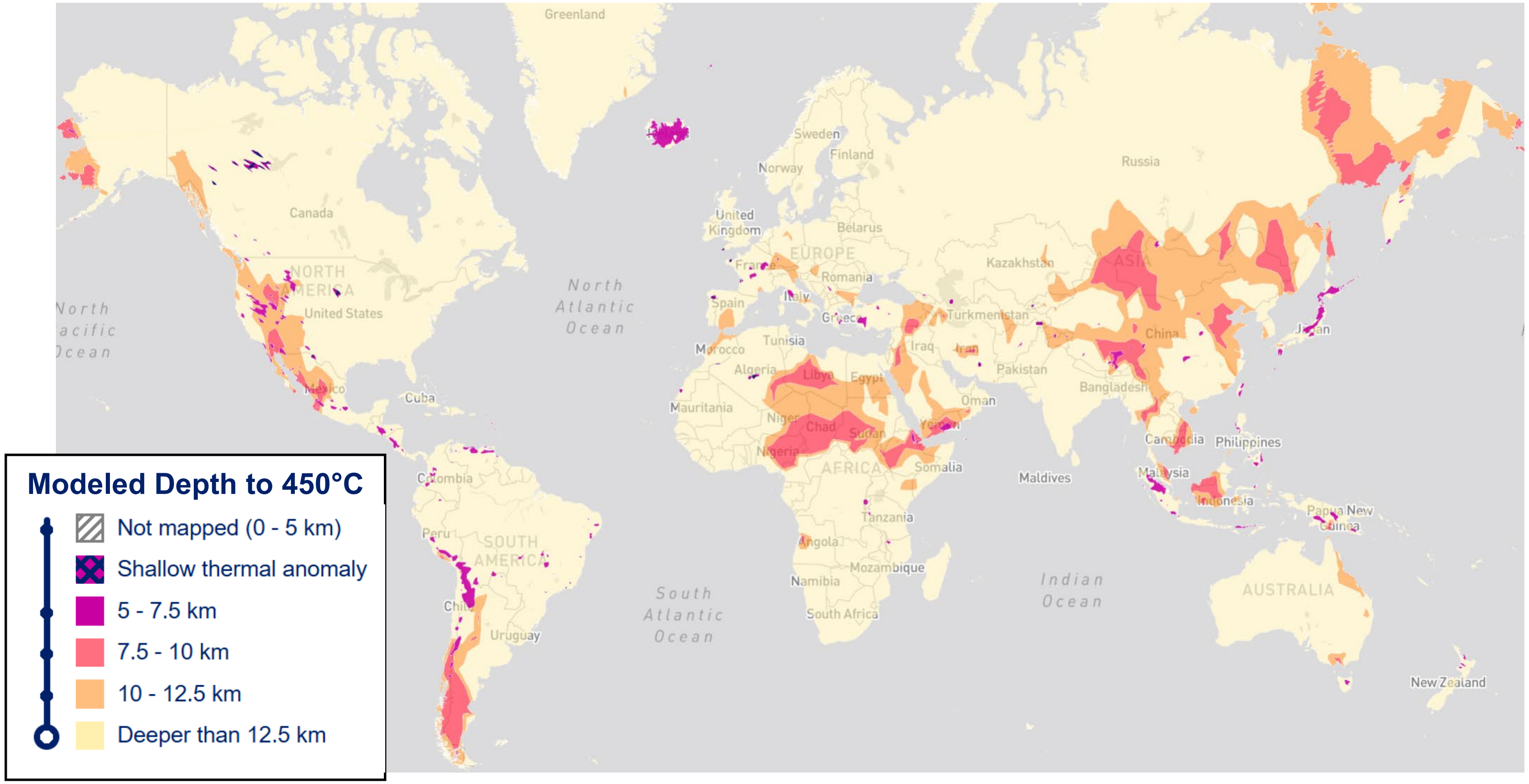
2050 conventional hydrothermal capacity by region (BNEF NZS)
GW



Notes: RoW = rest of world, SEA = Southeast Asia, APAC = Asia-Pacific, MENAT = Middle East and Northern Africa, SSA = Sub-Saharan Africa, LATAM = Latin America
Source: BNEF (2025), *New Energy Outlook*

3. Conventional hydrothermal can scale competitively in regions where shallow heat is available, but its ceiling is set by natural reservoir limits

Shallow high-temperature anomalies indicate where hydrothermal can scale



...but economic development and output is fixed by 3 key reservoir characteristics

1 Temperature

Determined by the natural reservoir – sets thermal-to-electric conversion efficiency

2 Depth & permeability

Determines drilling cost and whether fluid can move through the rock at viable rates

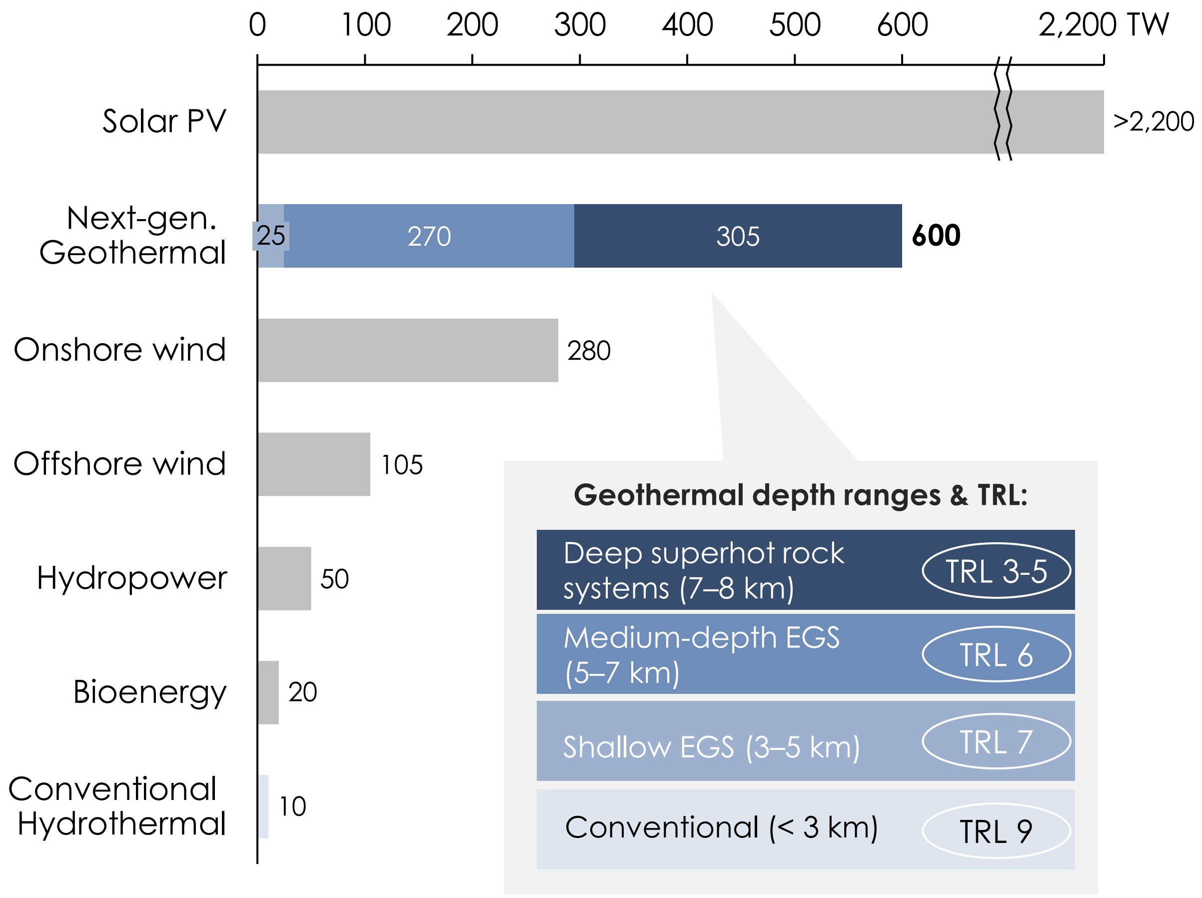
3 Flow rate

- Driven by reservoir size, ΔT and reinjection – limits MW per well
- The binding constraint on project economics

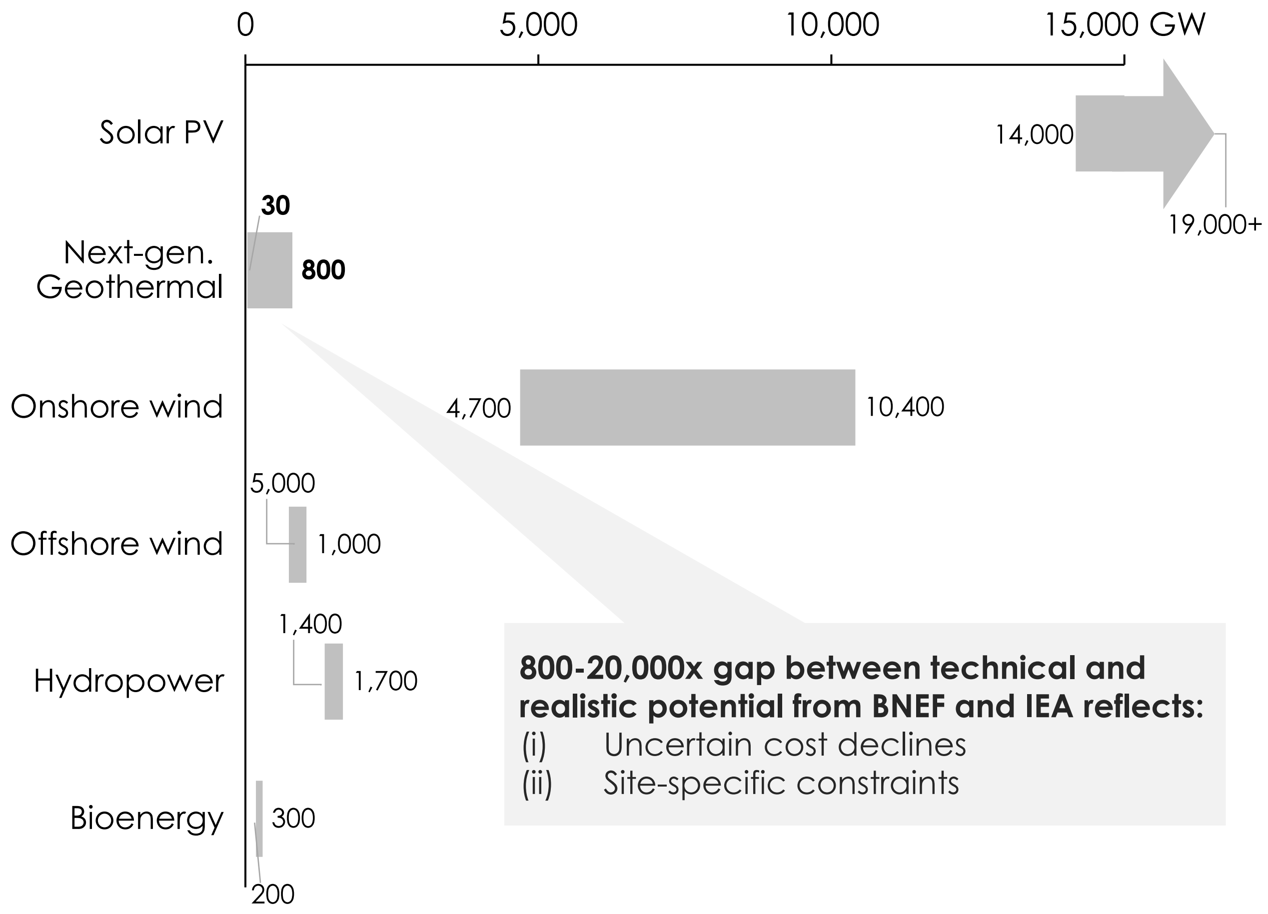
Note: Map shows depth to 450°C as a proxy for shallow heat resource
Source: Clean Air Task Force (2025), The Next Generation of Geothermal Energy. Available at: https://www.catf.us/shr-map/

4. Next-generation geothermal power has ~600 TW of technical potential globally but ~30–800 GW of realistic deployment by 2050 – a huge gap

Global technical potential of selected renewable energy technologies for electricity generation (IEA), TW



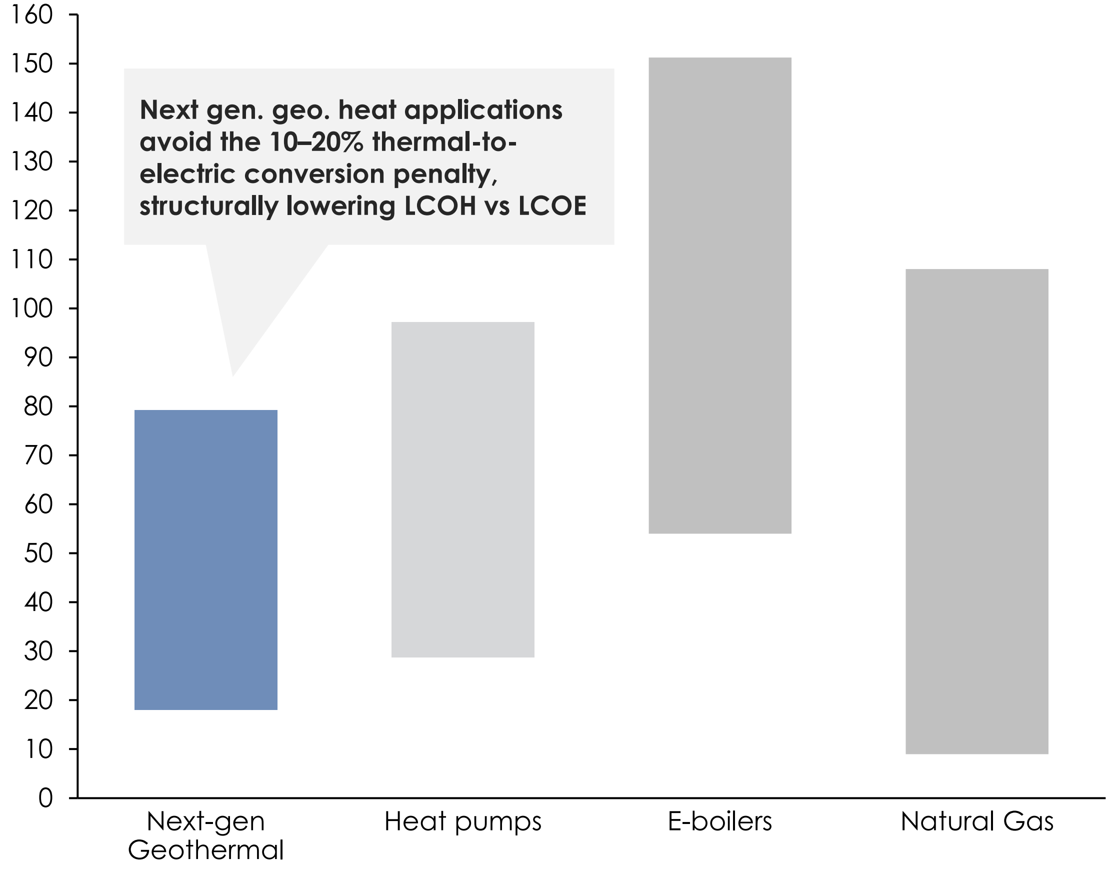
Indicative global 2050 economic power potential (BNEF, IEA)
GW



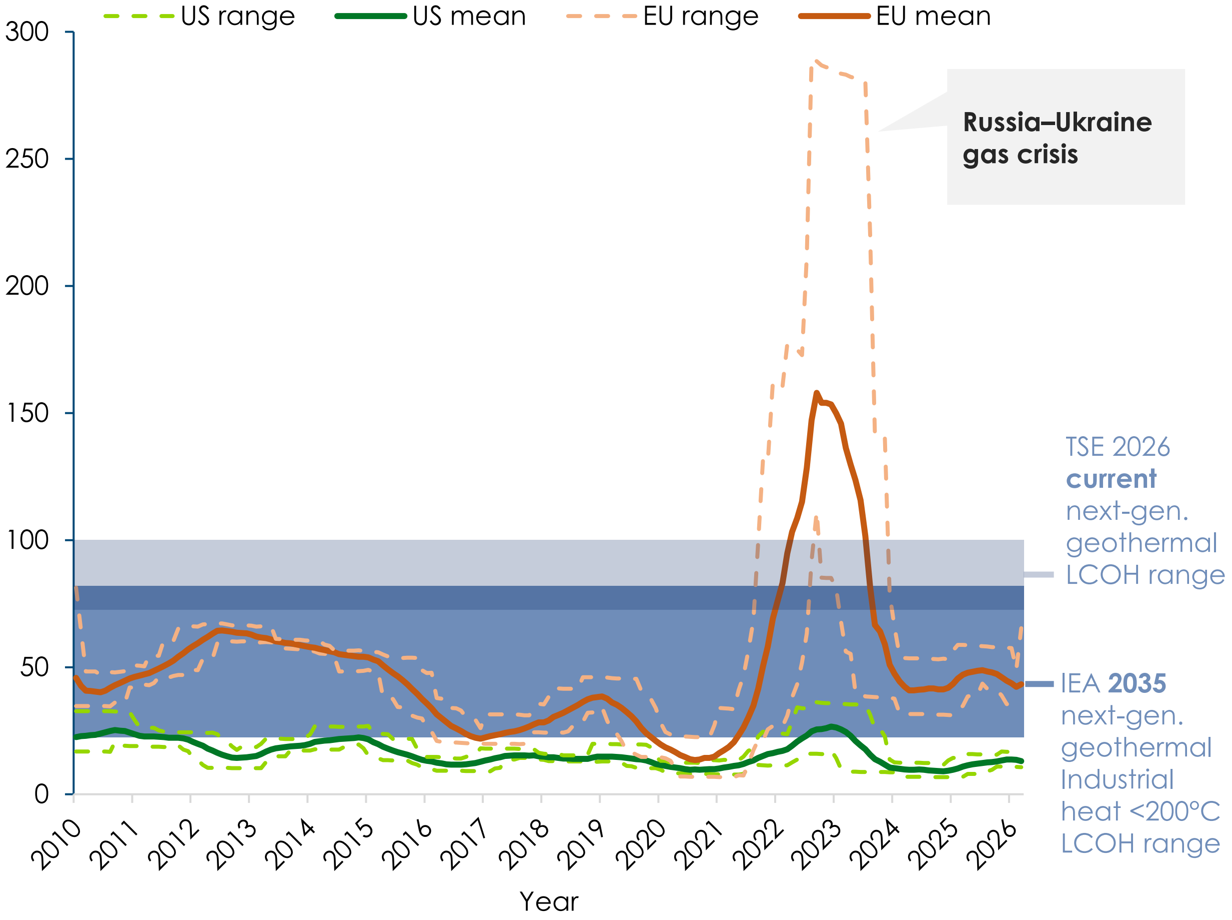
Notes: Technical potentials based on IEA / Project Innerspace estimates. Economic potential ranges taken from IEA for next-gen geo and BNEF New Energy Outlook for other technologies (taking the ETS as the lower bound and NZS as the upper bound).
Source: IEA (2024) *The Future of Geothermal Energy;* BNEF (2025), *New Energy Outlook 2025*

5. Next-generation geothermal could become competitive for low-temperature industrial heat in high gas price regions in the 2030s

LCOH for direct heat use in low temperature industrial heat (<200°C) in the IEA's Announced Pledges Scenario (APS), 2035, $/MWh$_{th}$ (real 2024)



Gas fuel cost per MWh-th delivered in US vs EU (rolling 12-month mean and ranges), $/MWh-th (real 2025)



Notes: Natural gas prices converted from $/MMBtu to $/MWh-th using 1 MWh-th = 3.412 MMBtu then converted to delivered cost of heat using an assumed modern industrial gas boiler efficiency of 90% and deflated to Real 2025 USD using US CPI (each month × 2025-avg CPI ÷ that month's CPI). Range reflects monthly high–low within the rolling 12-month window. Series tracks the IMF's European natural gas benchmark, historically anchored on Russian–Germany border pipeline prices and tracking closer to TTF spot prices from 2022 onwards. US series: Henry Hub. Source: IEA (2024) *The Future of Geothermal Energy;* International Monetary Fund, Global price of Natural gas, EU [PNGASEUUSDM], Available via FRED at: https://fred.stlouisfed.org/series/PNGASEUUSDM; International Monetary Fund, Global price of Natural gas, Natural Gas, US Henry Hub Gas [PNGASUSUSDM], Available via FRED at: https://fred.stlouisfed.org/series/PNGASEUUSDM; IEA (2024) *The Future of Geothermal Energy;* Thunder Said Energy (2026), Next-gen geothermal: progress update?

6. Geothermal environmental risks are technology and site-specific, but manageable with modern practices, and lower risk than fracking

Risk	Description	Risk level		
		Shallow Heat	Deep	Oil and gas fracking
		Ground source heat pumps	Conventional hydrothermal	
		Geothermal energy storage	Next-generation	
Groundwater pollution	Leakage of artificial fluids, drilling chemicals or refrigerant leakage	Low-Medium	Low–Medium	Medium-High
Toxic gases or contaminants entering water sources	Migration of arsenic, boron, or hydrogen sulfide into nearby waters	None	Medium	Medium-High
Disruption of local water supply	Alteration or depletion of aquifers from extraction	Low, none for closed-loop systems	Low–Medium	High
Release of gases locally	Emission of CO_2, H_2S, and trace gases during venting or maintenance	None	Medium	High
Induced seismicity	Small earthquakes triggered by injection or extraction	None	Medium	Medium
Land subsidence	Ground compaction due to pressure or fluid withdrawal	None	Low	Medium
Other local impacts	Noise, visual impact, or surface disturbance	Low	Low	High

Geothermal risks are low and can be well managed with modern monitoring and reinjection practices, particularly for shallow heat systems.

Note: **Risk levels reflect published reviews and regulatory assessments. Actual impacts depend on geology, design, regulation and operator practice.** Source: U.S. Department of Energy (2024) *Environmental Analysis of Geothermal Energy* Clean Air Task Force (2025) *Introduction to the Next Clean Energy Frontier: Superhot Rock Opportunities and Responsible Development;* Union of Concerned Scientists (2024) *Environmental Impacts of Geothermal Energy;* BKV Energy (2024) *Environmental Impact of Geothermal Energy;* Fiveable (2024) *Environmental Impacts of Geothermal Energy;* University of Texas (2023) *Geothermal Energy Systems: Environmental Considerations;* U.S. Geological Survey (USGS) – Induced Seismicity Studies (2015–2023); International Energy Agency (IEA 2012, 2020): "Golden Rules for a Golden Age of Gas"; Groundwater watch studies – Jackson et al. (PNAS 2014, 2015; Science 2013)

Agenda

- Key messages – nuclear
- Key messages – geothermal
- **Next steps**

We are developing separate reports for nuclear and geothermal, with a shared structure

Role of geo. in low-carbon power systems (~40 pg)

Role of nuclear in low-carbon power systems (~60 pg)

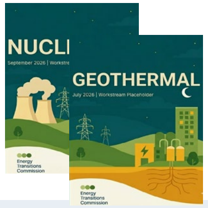
Context & introduction

Chapter 1:
Techno-economic outlook by sub-technology

Chapter 2:
System benefits

Chapter 3:
Country decision criteria and deployment guidelines

Next steps: parallel report production; geothermal launches first; nuclear follows



	Report drafting with member reviews	Report publication	Communications campaign, infographics, interactive models
Geothermal	• **Drafting:** May – June • **Member review:** Late May – Early June	**July**	**July onwards**
Nuclear	**Drafting:** June – July **Member review:** Late June – Early July	**September**	**September onwards**

What we need from members
Sign-off on draft chapters by end of review window

Where we want input
Expert analysis validation, policy-priority hierarchy, country-specific case studies,

How to get involved post-publication
Flag interest in involvement in the comms phase

Note: member review windows are still being finalised and will be confirmed in the coming weeks.

Discussion:
Comments & Reflections