Energy
Transitions
Commission

Topical debate on The role of nuclear power in the energy transition

ETC Commissioners meeting

26 June 2025

Guiding questions for the nuclear workstream

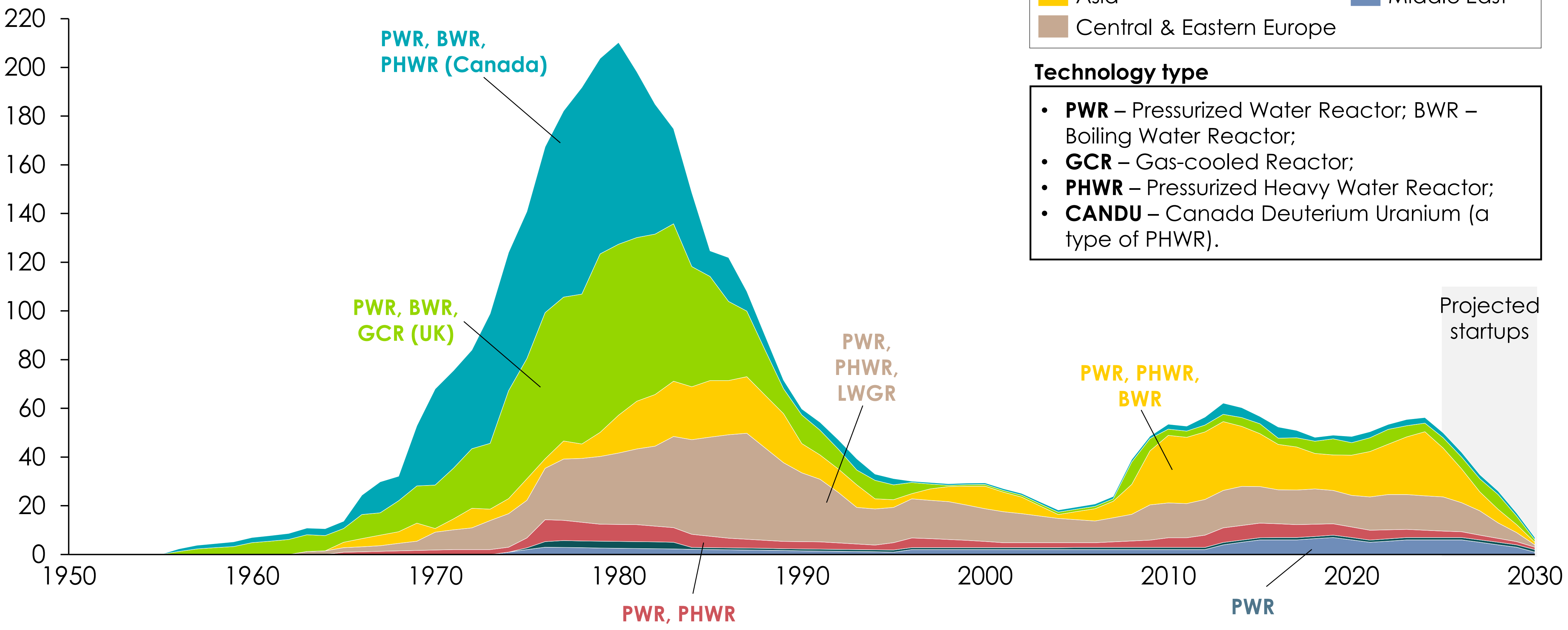
1. What is the role of nuclear in future energy systems?

2. What lessons can be learnt from how nuclear technology has developed over time?

3. How can cost effective nuclear deployment be achieved?

Nuclear power deployment peaked in the 1980s in the West, with a recent peak in Asia

Reactors under construction by year by region
GW (dominant reactor types annotated)



Region

- North America
- Western Europe
- Asia
- Central & Eastern Europe
- Latin America
- Africa
- Middle East

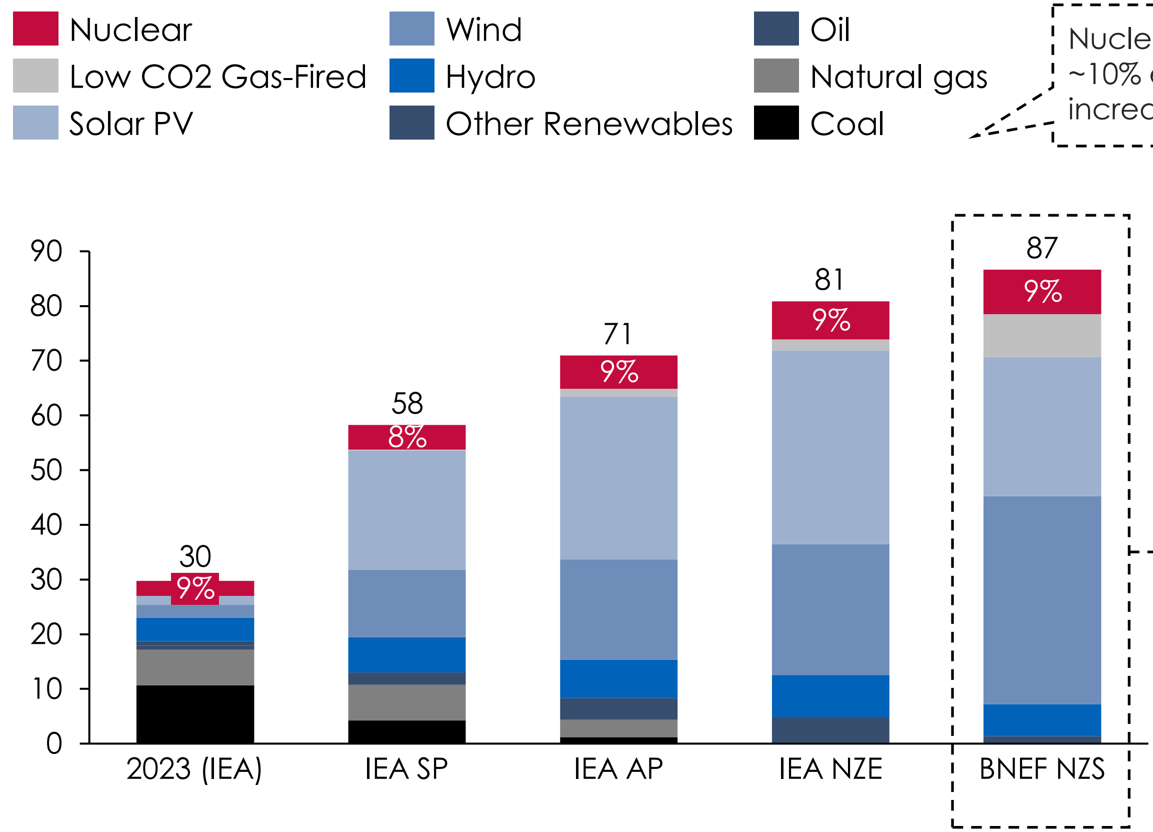
Technology type

- **PWR** – Pressurized Water Reactor; BWR – Boiling Water Reactor;
- **GCR** – Gas-cooled Reactor;
- **PHWR** – Pressurized Heavy Water Reactor;
- **CANDU** – Canada Deuterium Uranium (a type of PHWR).

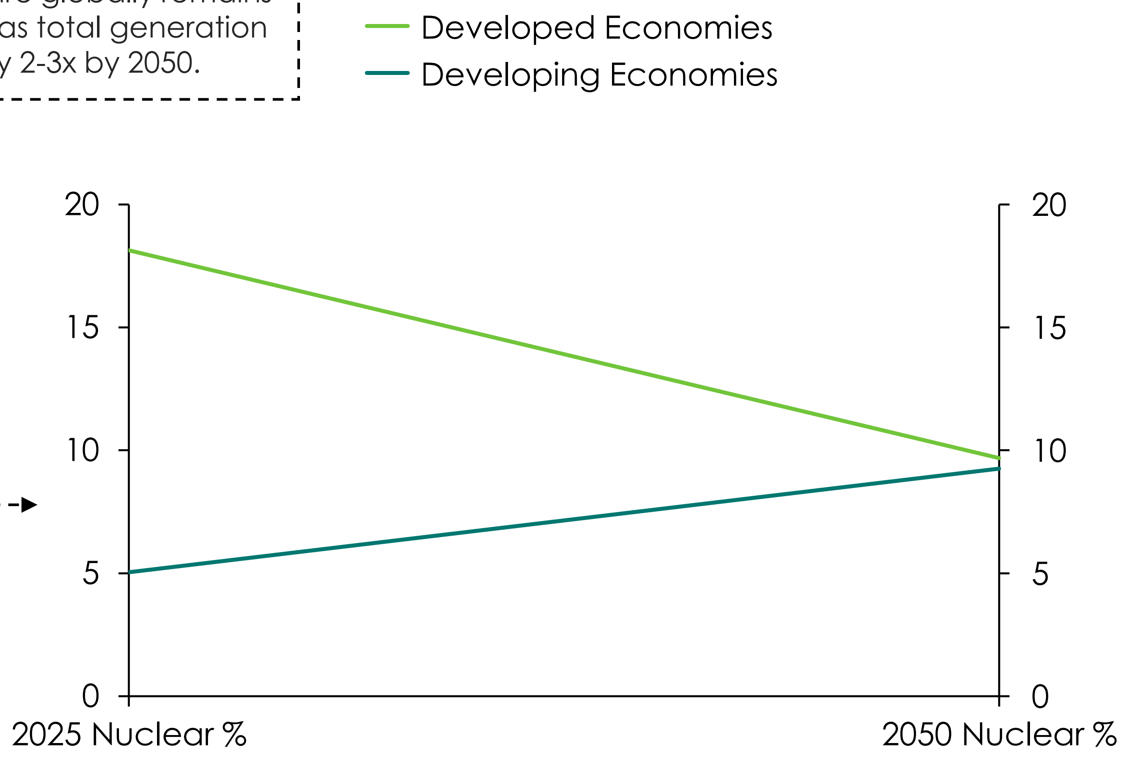
Source: adapted from Mycle Schneider Consulting (2024), *The World Nuclear Industry Status Report 2024*; World Nuclear Association (2025), *Reactor Database*

Selected future power system scenarios suggest that nuclear will remain at ~10% of total generation

Global nuclear vs non-nuclear generation by scenario (2023 and 2050)
'000 TWh



Average nuclear share of generation by region in BNEF NZS
% of Generation

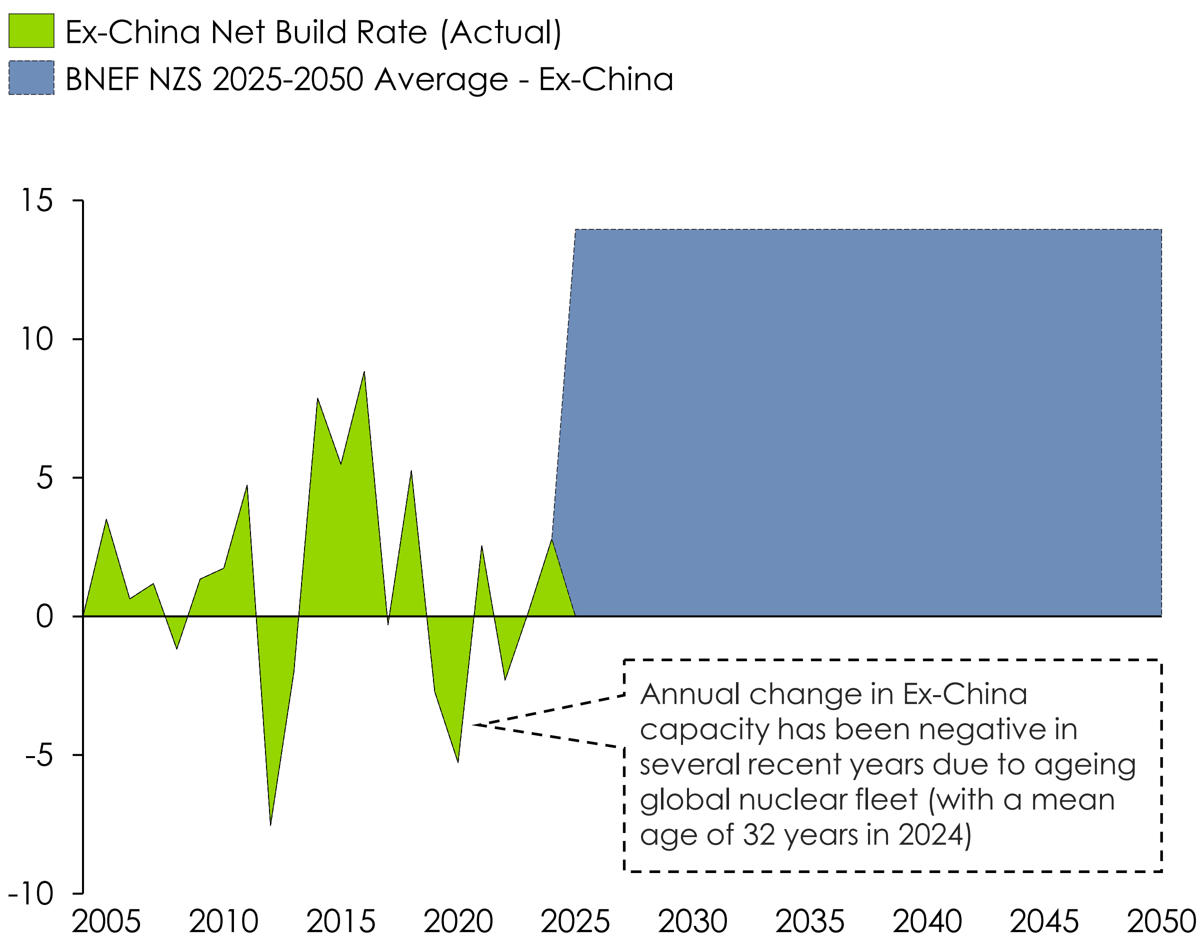


In many cases, nuclear plant lifetimes can and should be extended safely. Nuclear plant lifetime extensions are frequent but do present some risks (e.g. structure/component ageing, technical limitations and physical ageing of system design).

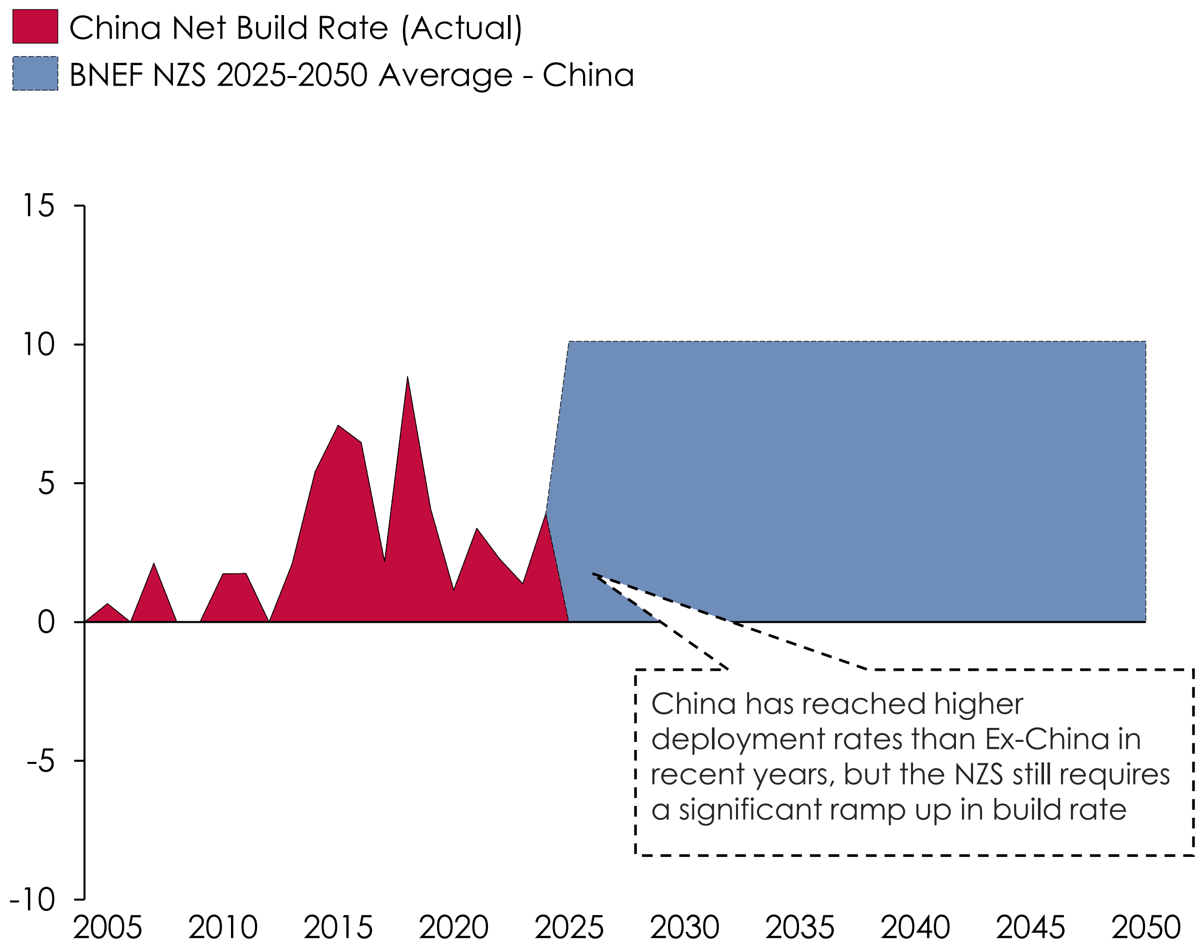
Notes: Nuclear generation includes conventional and SMR. SP = Stated Policies, AP = Announced Pledges, NZE = Net Zero Emissions, ETS = Economic Transition Scenario, NZS = Net Zero Scenario, MENAT = Middle East, North Africa, and Turkey.
Sources: BNEF (2025), *New Energy Outlook 2025*, IEA (2024), *World Energy Outlook 2024*

Nuclear build rates lag far behind what is indicated in most Net Zero scenarios

Ex-China nuclear annual change in nuclear installed capacity, 2005 - 2050
GW/y



China nuclear annual change in nuclear installed capacity, 2005 - 2050
GW/y



Source: Ember (2025), Electricity Data Explorer; BNEF (2025), *New Energy Outlook 2025*

Reactor technologies vary by technology readiness level (TRL)

Decreasing TRL

Conventional reactors (Gen III)

- Global standard for commercial nuclear energy since the 1960s.
- The main types are Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs).

TRL 9

Advanced reactors (Gen IV+)

Next generation of nuclear fission technologies which use novel coolant including:

- High-temperature gas reactors
- Liquid metal reactors
- Molten salt reactors

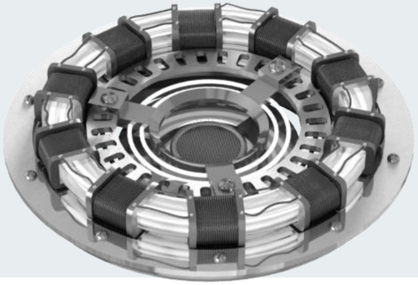
TRL 6-8

Small Modular Reactors (SMR)

- SMRs are compact reactors (10 – 350 MW) built in factories and shipped for assembly
- Growing commercial interest due to scalability and flexibility

TRL 5-7

Fusion



- Fusion joins light atomic nuclei like hydrogen into heavier ones to release energy
- Massive clean energy potential with minimal long-lived radioactive waste
- Remains in early-stage R&D

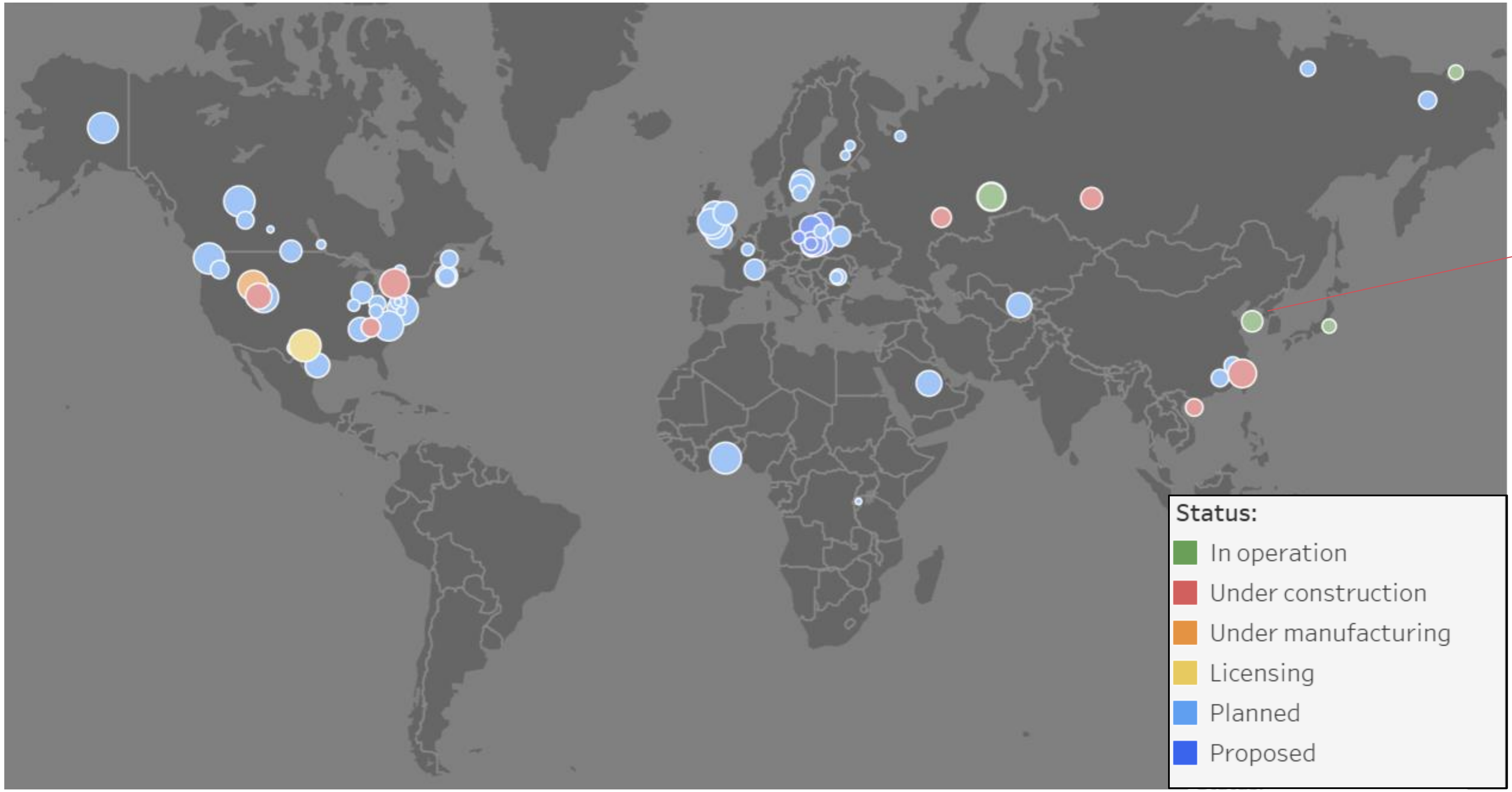
TRL 3-5

Notes: 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. Sources: US DoE (2024), *Pathways to Commercial Liftoff: Advanced Nuclear*; Mycle Schneider Consulting (2024), *The World Nuclear Industry Status Report 2024*; Third Way (2024), *The Global Race for Advanced Nuclear Is On*; Ben James (2024), *The Big Guide to Fusion*; Nuclear Innovation Alliance (2025), *Advanced Reactor Deployment Map*

Advanced nuclear reactors are starting to be operated or constructed across North America, Europe, and Asia

Global advanced nuclear reactor demonstration deployment map

Circle colour denotes status and size denotes capacity



While some of the operational projects are pre-Gen-IV reactors with some advanced features, China Huaneng Group's **200 MW High-Temperature Reactor – Pebble-bed reactor demonstration project** in China is considered the most advanced Gen IV design in full operation globally

Sources: US DoE (2024), *Pathways to Commercial Liftoff: Advanced Nuclear*; Mycle Schneider Consulting (2024), *The World Nuclear Industry Status Report 2024*; Third Way (2024), *The Global Race for Advanced Nuclear Is On*; Ben James (2024), *The Big Guide to Fusion*; Nuclear Innovation Alliance (2025), *Advanced Reactor Deployment Map*

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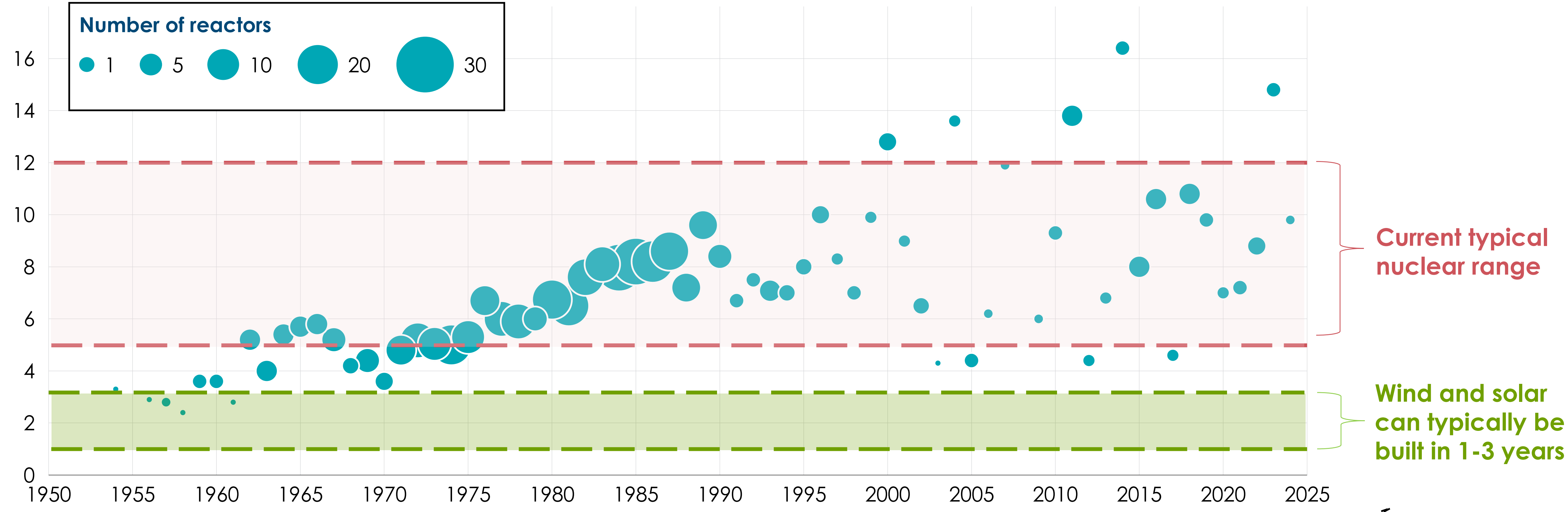
1. What is the role of nuclear in future energy systems?
2. **What lessons can be learnt from how nuclear technology has developed over time?**
3. How can cost effective nuclear deployment be achieved?

Average nuclear construction times have trended upwards, in contrast to renewables that can be built in under three years

Average annual durations from construction start to grid connection over time

Years



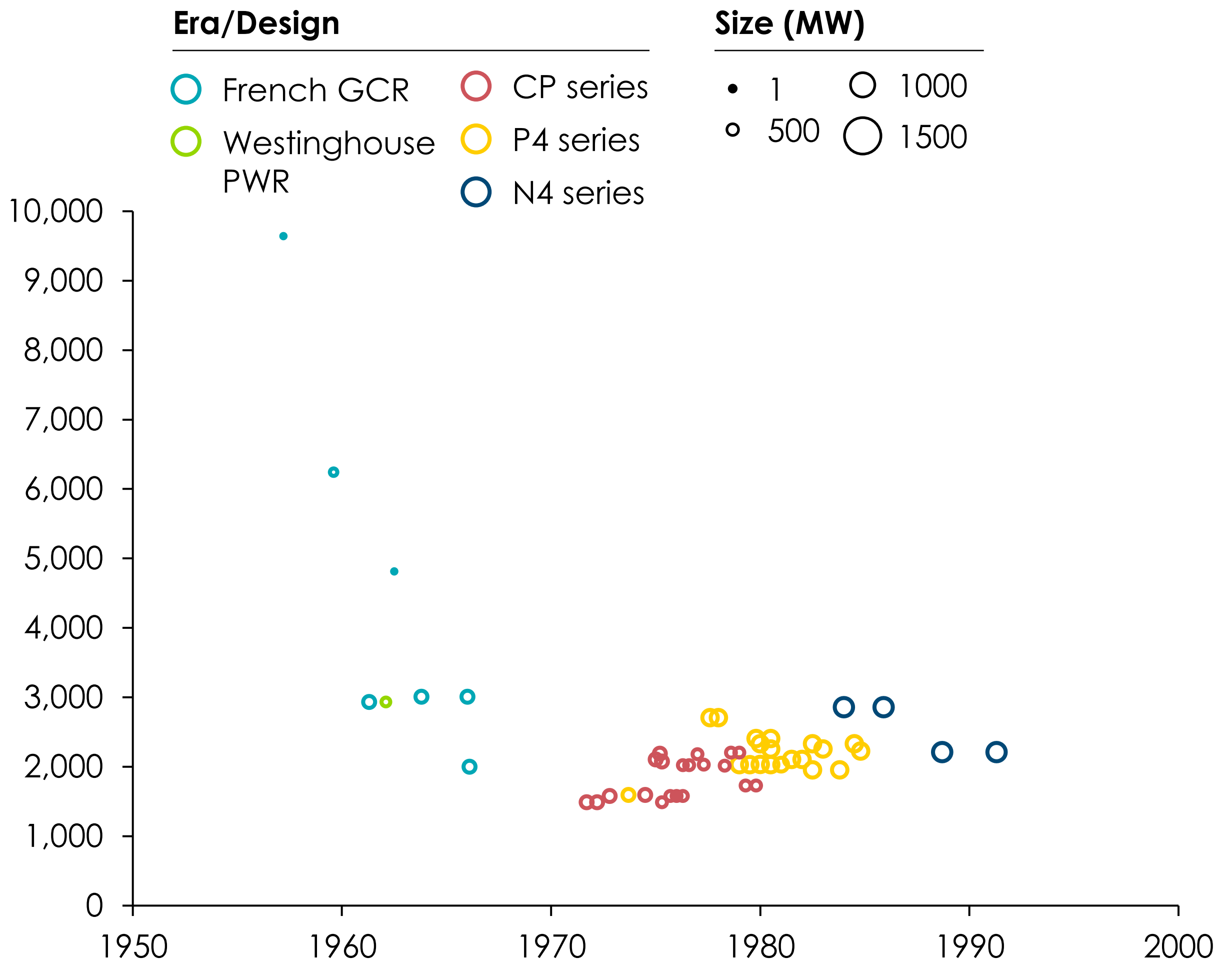
Average construction times have increased significantly, particularly in the West

New nuclear will add 1,000 TWh in the next 10 years while solar will add 10,000 TWh

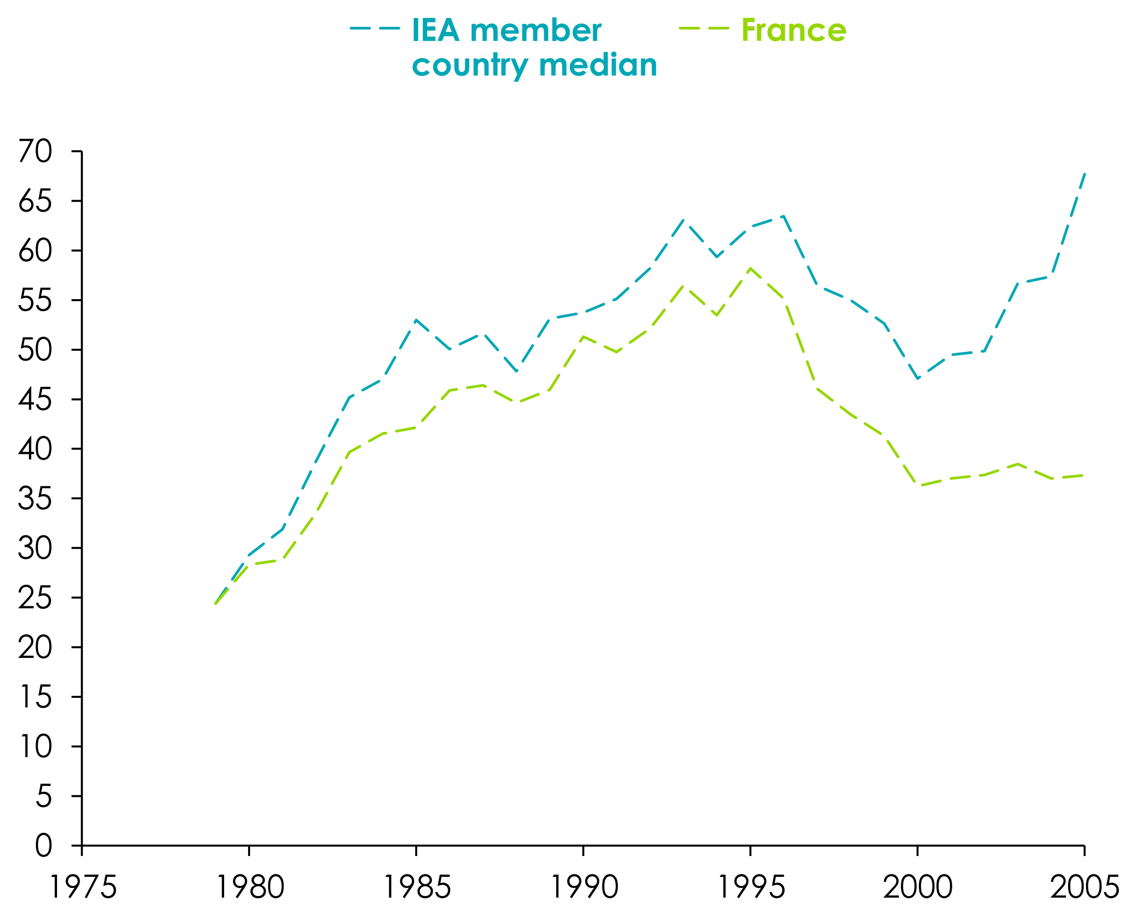
Sources: Adapted from Mycle Schneider Consulting (2024), *The World Nuclear Industry Status Report 2024*; Financial Times (2025), Can the nuclear industry find a better way to build?; A. Gumber (2024), *A global analysis of renewable energy project commissioning timelines*

France’s large-scale nuclear programme in the 1970s and 1980s helped to slash power prices

Overnight CAPEX for French nuclear fleet
$/kW, real 2024



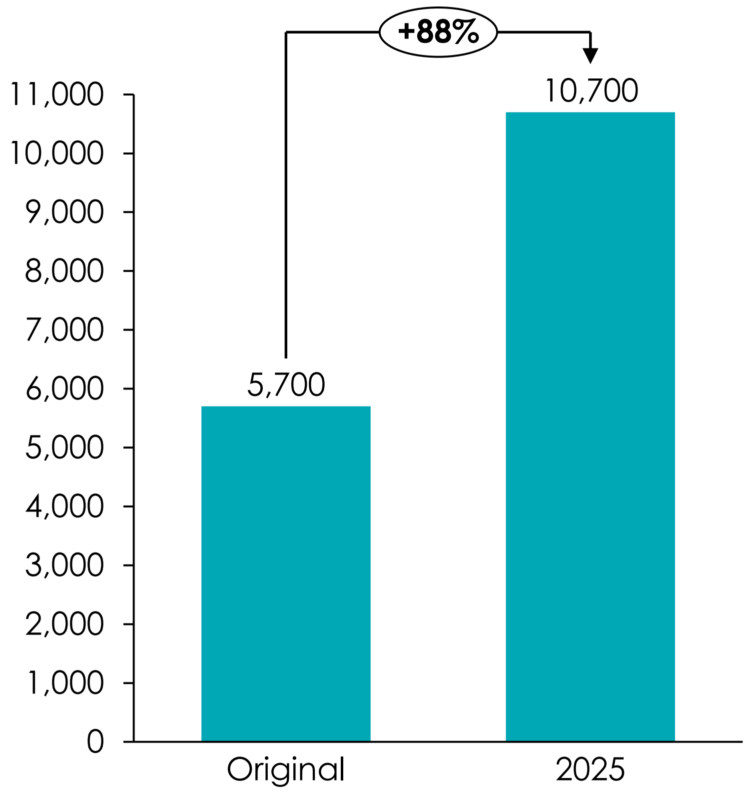
France vs other countries industrial electricity prices
$/MWh, real 2024



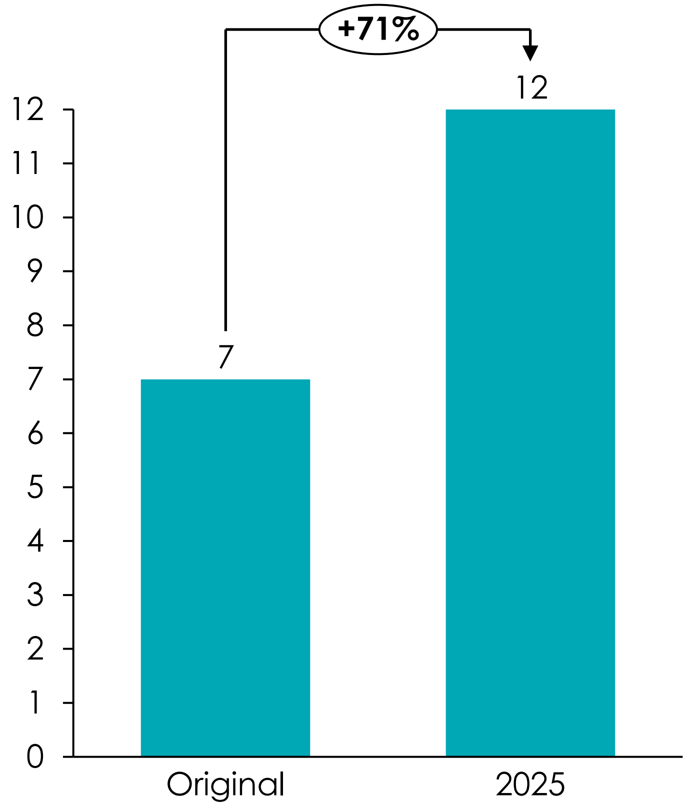
Notes: All nuclear power stations in France are pressurized water reactors (PWR). French GCR refers to gas-cooled reactors, CP, P4, and N4 refer to specific types of PWR designs. Source: J. R. Lovering (2016) *Historical construction costs of global nuclear power reactors*; UK Department for Energy Security and Net Zero (2024) *Energy Prices International Comparisons*

Recent UK projects show first of a kind (FOAK) reactor construction increasing in cost and duration

Hinkley Point C CAPEX estimate
$/kW, real 2024



Hinkley Point C construction duration estimate
Years



Increases have been driven by:

1. **Lack of replication due to FOAK project design in UK**, limiting learning-by-doing and productivity gains
2. **Long construction timeline**, has increased exposure to long-tail risks (e.g. geopolitical, financial, regulatory)
3. **Safety-driven overengineering**, adding complexity, cost, and regulatory burden
4. **High capital costs** with delayed returns, increasing cost of capital and investment risk

Source: Financial Times (2025), *Cost of Sizewell C nuclear project expected to reach close to £40bn*

Levelised cost of energy (LCOE) is diverging across regions and alternative technologies

NUCLEAR: China and UK indicative LCOE breakdown
$/MWh, real 2024

OFFSHORE WIND: China and UK indicative LCOE breakdown
$/MWh, real 2024

China vs Ex-China

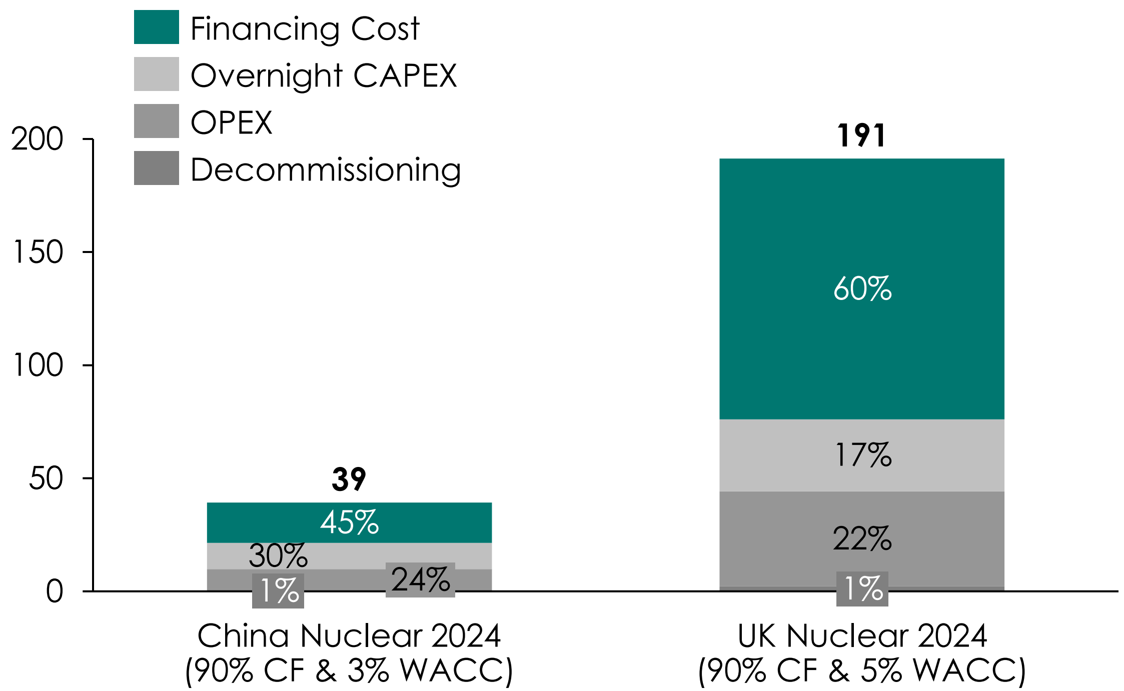
- **Lower-cost capital in China** (state-backed, low risk)
- **Lower overnight CAPEX** in China due to lower labour costs, more design standardization and replication
- **Greater share of OPEX in China's LCOE**

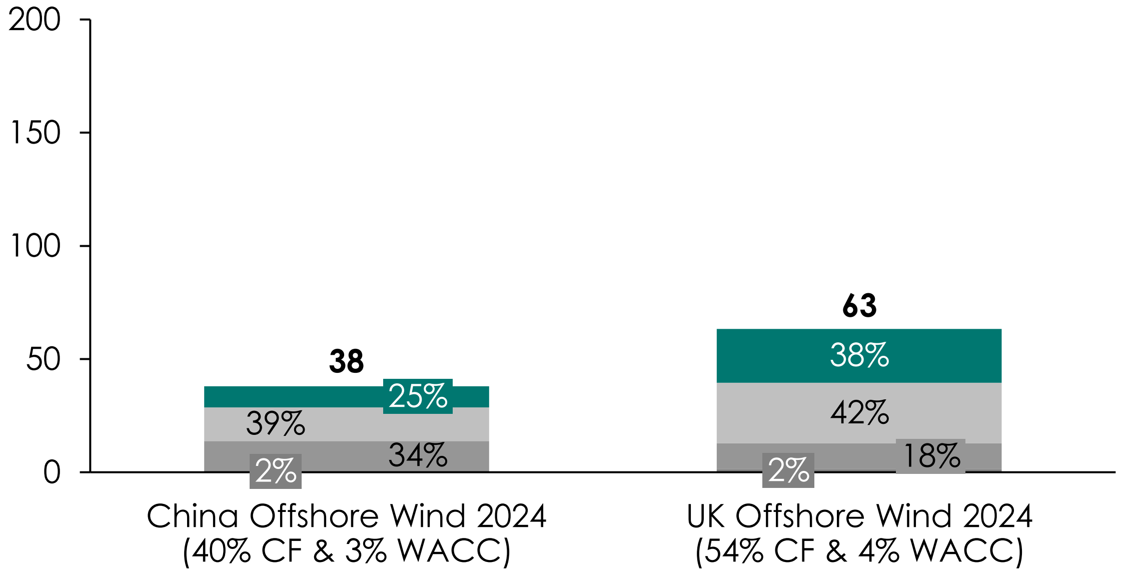
Nuclear vs Offshore Wind

- **Shorter build times reduce offshore wind financing differences** between China and Ex-China

China vs Ex-China

- Offshore wind generally has **lower CAPEX, OPEX, DECEX, and WACC** than nuclear, driving lower LCOE contributions across all project lifecycle stages

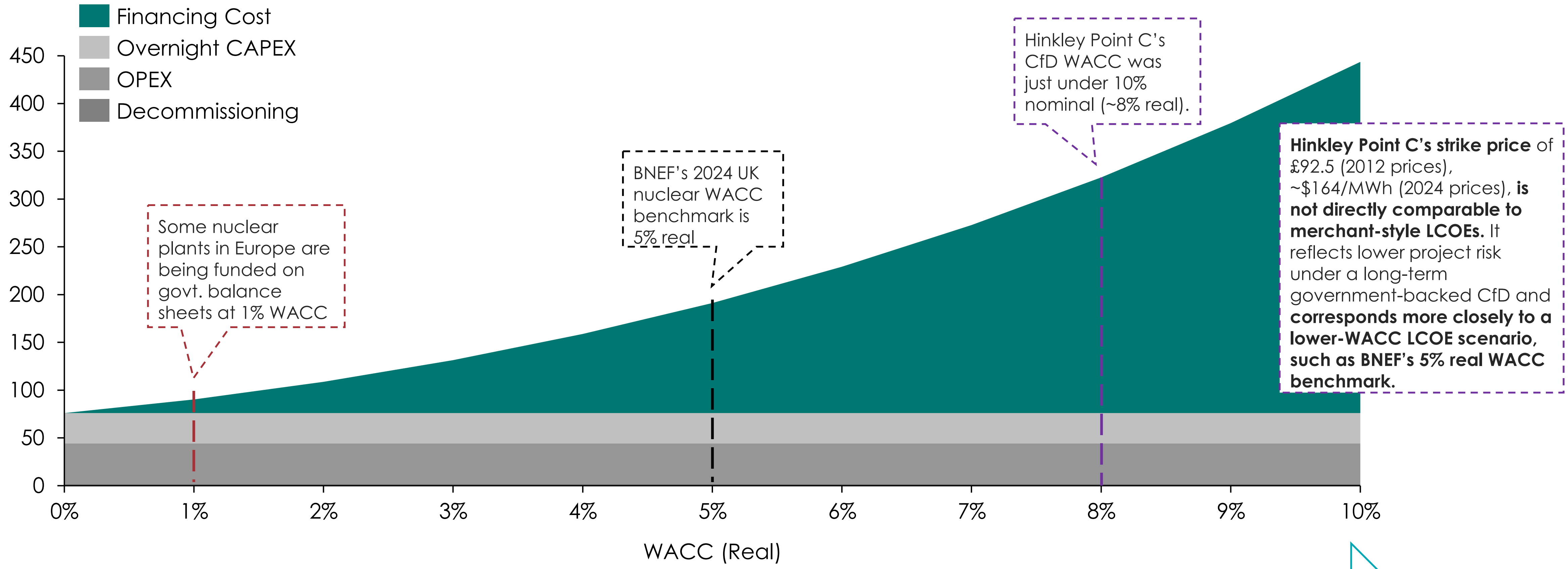




Notes: CF = Capacity Factor, WACC = weighted average cost of capital (real), CAPEX = Capital Expenditure, OPEX = Operating Expenditure (incl. fueling), DECEX = Decommissioning Expenditure. Overnight CAPEX is the total CAPEX excluding financing costs.
Source: BNEF LCOE Data Viewer, Nuclear Energy Cost Estimates for Net Zero World Initiative, ORE Catapult (2021), *End-of-life planning in offshore wind*

The weighted average cost of capital (WACC) is a key nuclear LCOE sensitivity

UK conventional nuclear 2024 sensitivity to WACC
$/MWh, real 2024



Higher risk = higher investor returns = higher WACC = higher LCOE

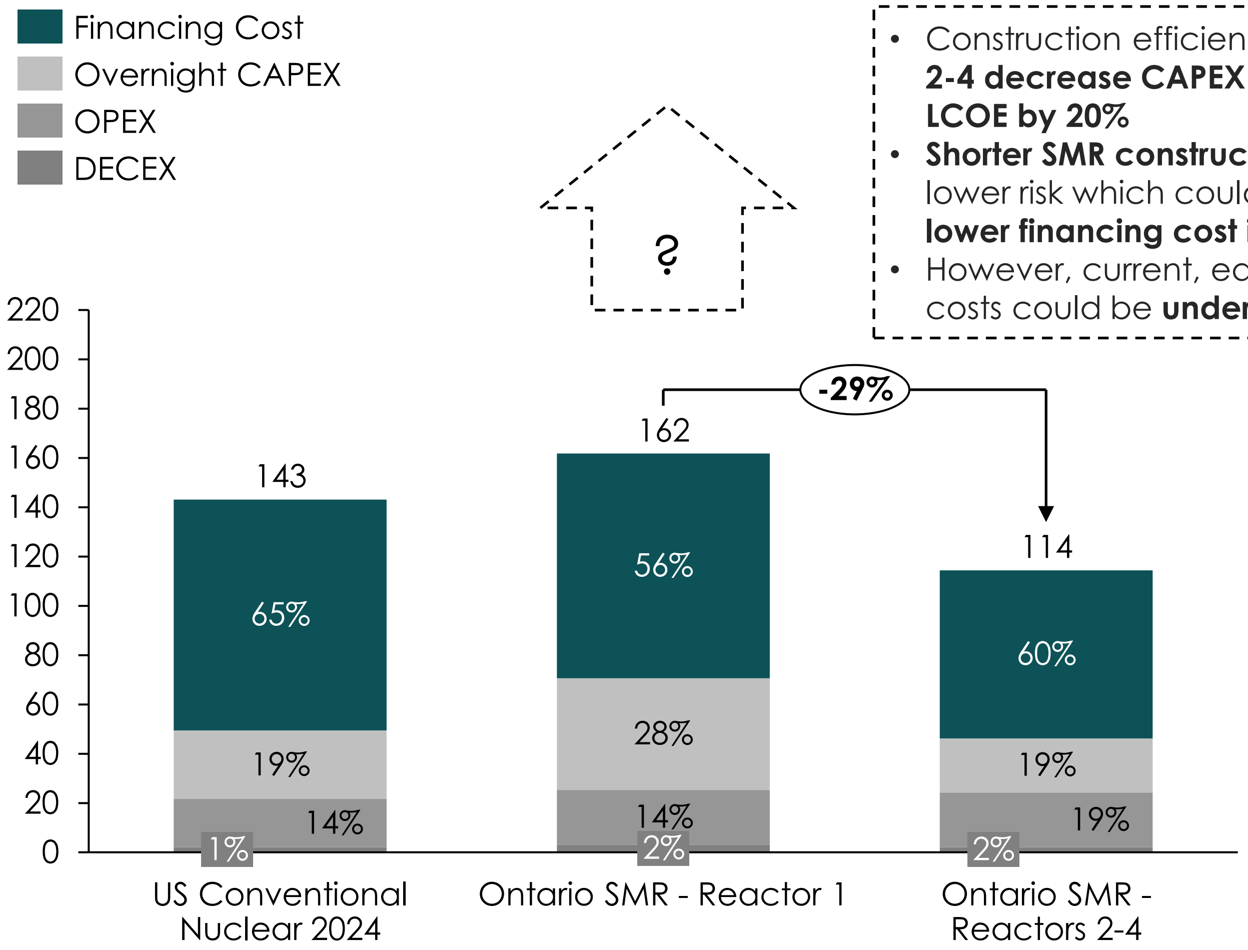
Notes: CfD = Contracts for Difference, CAPEX = Capital Expenditure, OPEX = Operating Expenditure (incl. fueling), DECEX = Decommissioning Expenditure. Overnight CAPEX is the total CAPEX excluding financing costs. Only WACC varies as a sensitivity.
Source: BNEF LCOE Data Viewer, Nuclear Energy Cost Estimates for Net Zero World Initiative

SMRs are purported to delivery faster builds, lower interest costs during construction, and cost reductions from standardisation

- >80 SMR designs and concepts globally, with operational demonstration projects in China and Russia
- Modularisation could eventually bring costs down
- Government approval for the construction of an SMR farm in Ontario, aiming to be online by 2030
- **BUT** real world experience so far suggests costs remain high

Conventional and SMR estimated LCOE breakdown

$/MWh, real 2024

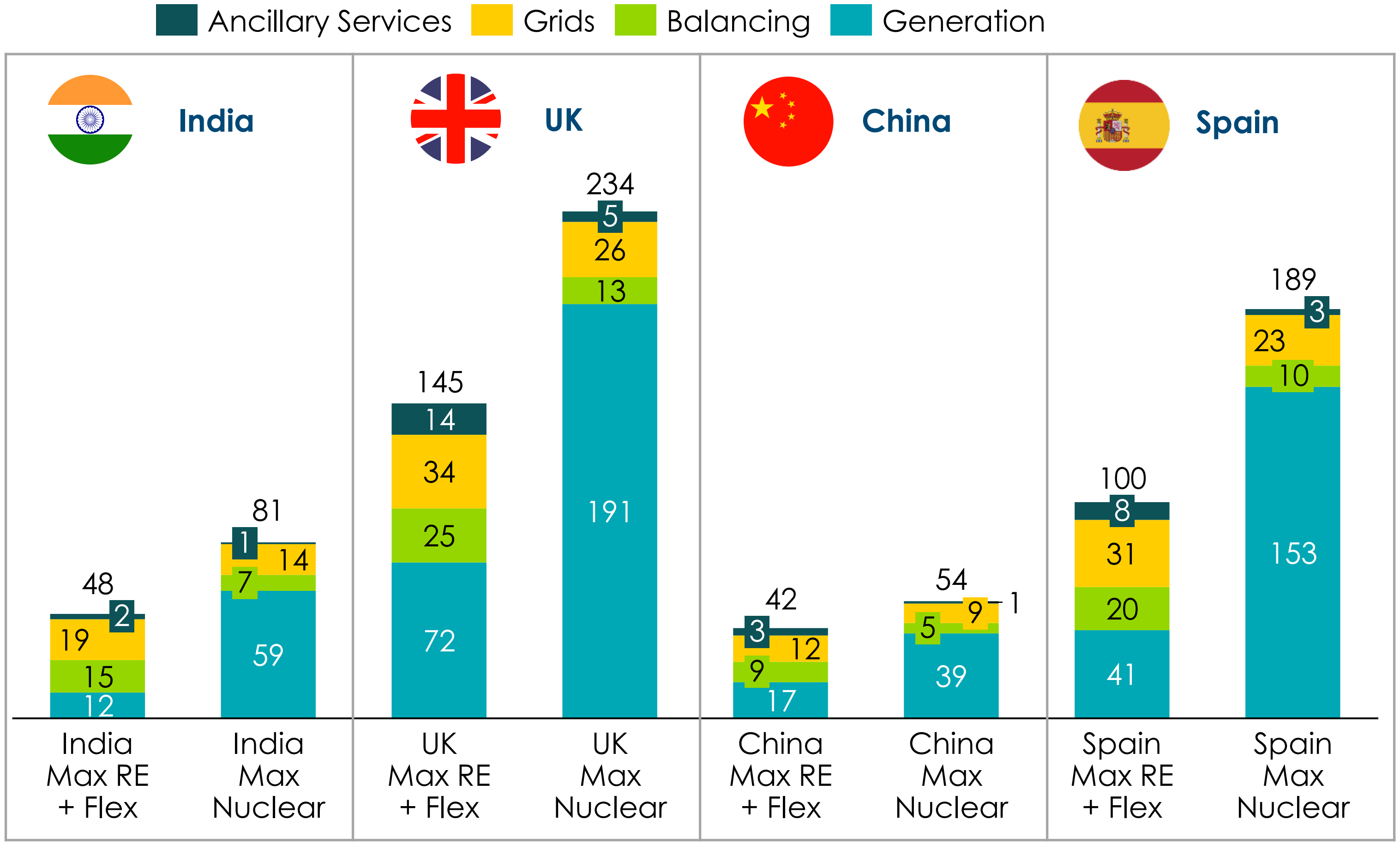


- Construction efficiencies in **SMRs 2-4 decrease CAPEX by 30% and LCOE by 20%**
- **Shorter SMR construction window** = lower risk which could lead to **lower financing cost impact**
- However, current, early stage SMR costs could be **underestimated**

Notes: CF = Capacity Factor, CAPEX = Capital Expenditure, OPEX = Operating Expenditure (incl. fueling), DECEX = Decommissioning Expenditure. Overnight CAPEX is the total CAPEX excluding financing costs.
Source: Carbon Commentary (2025), The first test for new Small Modular Reactors (SMR); IAEA (2025), *Small modular reactors: flexible and affordable power generation*

Given current projections of future cost, a nuclear dominated system would likely be more expensive than a wind+solar+storage dominated system

Illustrative 2050 system costs for 'Max Renewable Energy (RE) + Flexibility' and 'Max Nuclear'
$/MWh, real 2024



Key questions for analytical workstream:

a. Identify regions where firm resources are especially valuable
b. Should we oversize renewables/storage or rely on nuclear?
c. Deployment considerations of building out VRE vs nuclear (land use, speed of deployment)
d. Test flexibility of nuclear and consequent balancing needs
e. What is the opportunity cost of nuclear investments?
f. Impacts of DSF in Max VRE vs Max Nuclear scenarios

Notes: Preliminary assumptions (based on available BNEF data): generation cost equates to nuclear 2024 LCOEs for Max Nuclear scenario (due to lack of data on future projections, however significant cost declines outside of China are unlikely based on current deployment trends), balancing cost reduction of 50% for Max Nuclear vs Max Wind & Solar, grid cost reduction of 25% for Max Nuclear vs Max Wind & Solar, Ancillary Services costs of 20% of generation, balancing and grid costs for Max Wind & Solar and 1/3 of Max Wind and Solar's Ancillary Services cost for Max Nuclear, respectively. India nuclear LCOE assumed to be 1.5x China's and Spain nuclear LCOE assumed to be 0.8x the UK's.

In some geographies, nuclear is likely to have a more significant role to play

Geographies where nuclear may play a more significant role include countries with…

	Constrained land / resources	Public opposition to renewables	Wind-dominated systems
Representative of:	Singapore, Bangladesh, Japan	UK, France	UK, Germany, Canada
Key characteristics:	Population density constraint Cloud cover and topography limiting solar resource (Japan)	NIMBYism limits renewables deployment	High costs of last mile decarbonisation in wind belt systems

Potential system operation benefits from nuclear:

1. Supply of spinning inertia to maintain system stability
2. Diversity of supply is important principle for energy security and system stability
3. Reducing the size of balancing challenge
4. Lower grid costs as generation located closer to demand
5. Renewables integration, if nuclear can be economically / technically run flexibly

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What's holding nuclear back? Key barriers span safety, development risk, environmental impacts, and resource use

Issue	Summary of Debate
Cost	• Nuclear is capital-intensive, with high upfront costs and long payback periods. • Cost overruns and schedule delays have plagued many projects. • Financing costs are a major LCOE driver.
Construction times	• Long timelines (often 8–15 years) undermine competitiveness and increase financing risk. • SMRs claim faster build times but lack commercial proof.
Safety (incl. lifetime extensions)	• Public concern persists over core meltdowns, aging reactor components, and incident history (e.g. Fukushima, Chernobyl). • Lifetime extensions raise questions about material degradation and safety margins.
Security of uranium supply	• Uranium is globally available, but conversion/enrichment is geographically concentrated. • Dependence on Russia for enrichment is a rising concern.
Environmental impact (waste/disposal)	• High-level waste remains a politically and technically unresolved issue in most countries. • Volumes are low, but long-lived and require deep geological storage.
Water use	• Nuclear plants are water-intensive, particularly those using once-through or wet cooling. • Local environmental impacts (e.g. thermal pollution) are a concern.