RAF134/2223 Energy Innovation Needs Assessment: Nuclear Energy

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Mott MacDonald was the lead technical author for the nuclear technology theme report.

Views expressed in this report are those of the authors and not necessarily those of the UK Government.

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Abbreviations

AGR	Advanced gas-cooled reactor
AMR	Advanced modular reactor
DESNZ	Department for Energy Security and Net Zero
CAPEX	Capital expenditure
CAGR	Compound annual growth rate
COTS	Commercial off the shelf
FNEF	Future Nuclear Enabling Fund
FOAK	First of a kind
GBE-N	Great British Energy - Nuclear
GVA	Gross value added
HALEU	High assay low enriched uranium
HLW	High level waste
HPC	Hinkley Point C
HTTR	High Temperature Engineering Test Reactor
HTGR	High-temperature gas-cooled reactors
I&C	Instrumentation and control
NOAK	Nth of a kind
O&M	Operations and maintenance
OPEX	Operational expenditure
PWR	Pressurised water reactor
SMR	Small modular reactor
SZC	Sizewell C
TRL	Technology Readiness Level

Key findings

The Energy Innovation Needs Assessments (EINAs) have been developed and updated to identify key innovation needs across the UK's energy system, to provide an evidence base for the prioritisation of investment and support for clean energy innovation. This report summarises the analysis and findings from the EINAs across the nuclear technology theme, focusing on Small Modular Reactor (SMR) and High Temperature Gas Reactor (HTGR) technologies.

Nuclear is likely to play an important role in the UK's future energy system, providing low-carbon, baseload power to the grid. At this time, no land based SMRs have been constructed whilst the only operational HTGRs are located in China and Japan, with the only commercial HTGR being the HTR-PM demonstrator in China. Significant technological innovation impacting fabrication, CAPEX and OPEX is required if SMRs and HTGRs are to play an effective role in delivering net zero.

Energy system modelling to assess the potential impact of innovation in key net zero technologies was conducted using UK TIMES. Technologies were assessed at 3 levels of innovation (low, medium and high) and across three hypothetical scenarios: Minimally Constrained, High Hydrogen and High Diversification.[1] The key results from EINAs system modelling suggests that:

- Electricity generation from nuclear plants remains consistent across the innovation runs modelled, albeit marginally higher deployment is observed in 2035–2040 for high nuclear innovation runs, indicating that innovation in these technologies has little impact on their deployment, but makes this level of deployment significantly cheaper.
- As the electricity supply diversifies in the High Diversification scenario, generation from nuclear doubles in comparison to levels in Minimally Constrained and High Hydrogen in 2050. This aligns with the constraints on the scenarios enforcing a minimum nuclear capacity in these cost-optimal solutions. Reduction in the cost of nuclear, as a result of innovation, is particularly important in this High Diversification scenario.
- Given the constraint enforcing a certain level of nuclear capacity in the system, significant cost savings could be delivered by 2050 through innovation in nuclear technologies, £19.7 billion in High Diversification, £9.0 billion in Minimally Constrained and £9.1 billion in High Hydrogen.

To enable these cost savings, there are a number of potential areas for innovation across the nuclear energy technologies assessed. These innovation opportunities are outlined in Table 1.

[1] These scenarios do not represent government policy but were selected due to their differing constraints which provide a diverse set of outputs and insights. More information on the scenarios can be found in the Innovation Analysis section of this report and in the EINAs Methodology report.

Table 1: Innovation opportunities for the EINAs nuclear energy technologies

Innovation area	Description
Mining, processing, enriching and fabricating	Opportunities in fuels which remain in SMR and HTGR reactors for longer, increasing operational periods; fuels that can achieve higher burn-ups, producing less high-level waste and are compatible with earlier disposal in a geological disposal facility.
Components and systems	Adoption of standardised, modularised and productised design to maximise factory fabrication and minimise on-site installation; design simplification using safe and passive features and reduction in the quantity of nuclear-grade components; development and adoption of advanced machining, assembly, metrology, joining (e.g. local vacuum electron beam welding) and additive manufacturing to reduce cost, increase speed and reliability of components; use of robotics for in-service inspection, autonomous processes, remote handling in harmful environments, and size reduction..
Construction, installation and commissioning	Maximise use of Commercial Off the Shelf (COTS) components to reduce bespoke construction, installation and commissioning; develop a supply chain that can provide suitable COTS components for nuclear (through life availability, ability to maintain etc.).
Energy systems integration	Improve use of SMR energy generation with more flexibility and wider contribution to decarbonisation, such as: advanced power conversion cycles, district heating, hydrogen production, heat storage, and direct air capture of CO_2.
Operations and maintenance	Increased digitalisation, e.g. in instrumentation and control systems, enabling greater operational modes for SMRs. Equipment optimised for reduced maintenance (e.g. improved material, lubrication, electronics etc.)
Decommissioning	Use of robotics for in-service inspection, autonomous processes, remote handling in harmful environments and size reduction, which reduces reactor down time and allows in service component removal and inspection,

However, there are a number of non-innovation market barriers which must be addressed to enable scale up and deployment. These include:

- **Availability of investment:** Nuclear power plants require significant upfront investment in research, design and construction. The combination of capital cost with long delivery time can be a barrier to deployment.
- **Skills and training:** The workforce is currently insufficient to deliver the UK's 2050 nuclear power targets. This is compounded by the aging workforce, as a significant proportion of the civil nuclear workforce are nearing retirement.
- **Supply chain:** Nuclear plants require a number of specialist components, but there is currently a limited number of vendors in the UK with advanced manufacturing capabilities to meet these demands.

Overall, the key results from the business opportunities calculator suggest the following potential business opportunities from deployment of the nuclear technologies of focus:

- Annual GVA from SMRs and HTGRs reaches between £0.5bn and £1.75bn in 2050.
- A corresponding increase in supported (direct and indirect) employment to between 10,000 and 28,000 by 2050.
- Under a medium level of innovation, the systems modelling indicates that the projected economic contribution is derived entirely from SMRs. HTGRs only contribute under a high innovation scenario. However, even in this case, the contribution of HTGRs to both employment and GVA remains at 50% or lower compared to the contribution from SMRs throughout the assessment period.
- Across the three scenarios modelled, the High Diversification is associated with a significantly greater GVA contribution and supported employment than the other scenarios. This becomes over the 2045-2050 period when the systems modelling suggests a significant increase in the deployment of SMRs. Over the period as a whole, GVA in the High Diversification scenario is around 50% higher and employment around 30% higher than in the other two scenarios (medium innovation level).
- In all scenarios, the GVA and employment profile is quite uneven: high when the systems modelling implies assets will be under construction in the UK and significantly lower otherwise. This reflects the high capital intensity of the technology, with most of the economic activity and employment associated with asset construction, and substantially lower levels of economic activity during asset operation.
- Under these modelling assumptions, GVA and employment associated with exports helps to smooth out the lumpiness in GVA and employment associated with UK deployment. This is because global deployment is likely to be smoother than that of the UK, or any other specific country, as the peaks and troughs in different countries cancel each other out. Nonetheless, over the period as a whole, these results suggest that export markets are likely to make a relatively smaller contribution than domestic deployment to the GVA contribution of and employment supported in UK-based businesses (between 25-40% for both jobs and GVA, depending on the scenario). This reflects some of the challenges that UK-based firms may have in competing in global markets that have been discussed above.

Introduction

The Energy Innovation Needs Assessments

Achieving the UK's ambitious Clean Power 2030 and Net Zero by 2050 targets requires the accelerated scale up and deployment of innovative clean energy technologies. The UK government has a central role to play in supporting the research, development and deployment of these innovations to achieve global and national climate objectives. The decisions made now on the prioritisation and investment in crucial clean energy technologies will be pivotal to enable progress in the coming years and decades.

The Energy Innovation Needs Assessments (EINAs) have been developed and updated to identify key innovation needs across the UK's energy system, to provide an evidence base for the prioritisation of investment and support for clean energy innovation. The 2025 publications reflect an update on the 2019 exercise (link), accounting for the significant changes and progress both in the clean energy sector and wider economy. To complement and build on the UK's Net Zero Research and Innovation Framework, the updated EINAs will inform key decisions on clean energy innovation funding, by providing a structured evidence base, comparable across different technologies, which quantifies and assesses the role and scale of opportunities and considers the wider factors that may impact deployment and scale up.

The methodology followed is detailed in the EINAs Methodology report and is summarised below.

The EINAs technologies were decided through a prioritisation exercise, taking into account insights from key sector experts and prioritising against key DESNZ criteria. An initial longlist of technologies for analysis was put together based on:

- Previously published global and national scenarios (including the 2019 EINAs)
- DESNZ priorities
- Insights from DESNZ engagement activities
- Input from technical experts

This longlist was then assessed and prioritised to inform a shortlist of EINAs technologies, which were then taken forward for analysis including:

- An assessment of each technology's innovation needs, costs and barriers to deployment.
- Modelling, using the UKTIMES and HighRES models, to assess the impact of different levels innovation in these technologies on the UK's energy system in hypothetical Net Zero scenarios, including on system cost, capacity and energy security.
- Business opportunities analysis, including Gross Value Added (GVA) and employment, of the deployment of the technologies across scenarios and innovation levels.

This report summarises the findings across the nuclear energy technology theme.

The 2025 EINAs publications have been commissioned by DESNZ and produced by a consortium led by Carbon Trust, including Mott MacDonald, UCL and Pengwern Associates. Mott MacDonald was the lead technical author for the nuclear technology theme report.

Scope and limitations of the EINAs:

The EINAs project is a research exercise to evaluate the potential impact of technological innovations on the UK energy system and Net Zero targets, and help inform decisions on clean energy innovation funding.

A number of technologies were included as part of the prioritisation but were not included in the systems modelling due to limitations of the models used for the EINAs, data availability and resource constraints. The three hypothetical scenarios developed to represent potential routes to Net Zero were selected due to their differing constraints which provide a more diverse set of outputs and insights.

The technologies and scenarios selected do not represent UK Government policy.

The nuclear energy technology theme

Nuclear fission is a stable and secure source of low carbon electricity in the UK. In 2023, nuclear energy accounted for 13.9% of the UK's electricity generation.[2] As a source of reliable and low carbon electricity, nuclear energy can support the move to Net Zero by 2050. In its Clean Power 2030 Action Plan, Government has signalled its intentions to set out plans to streamline regulatory processes and foster innovation in nuclear technology, to ensure that nuclear power continues to play an important role in the net zero transition after 2030. Furthermore, the Great British Energy-Nuclear-led small modular reactor (SMR) competition reached a milestone in June 2025 with Rolls-Royce being selected as the preferred bidder to build the UK's first small modular reactors subject to final government approvals and contract signature. Sizewell C also reached Final Investment Decision in July-25.

The planned expansion of nuclear capacity considers the use of a number of technologies. Two large-scale reactors are currently under construction at Hinkley Point C in Somerset, with an above-ground replica station under development at Sizewell C in East Suffolk.

SMRs are generally reactors categorised as up to 300-500 MW in capacity based on modular design and off-site fabrication. Separate to GBE-N's competition, government support for SMRs has been provided through the Low-Cost Nuclear programme[3] and the Future Nuclear Enabling Fund.

[2] Department for Energy Security and Net Zero (2024) Digest of UK Energy Statistics (DUKES) 2024 Chapter 5: electricity
[3] UKRI (Accessed 12/02/2024) Low cost nuclear

High-Temperature Gas-cooled Reactors (HTGRs) are a type of Advanced Modular Reactor (AMR). They are capable of supplying high-temperature heat for industrial processes in addition to electricity generation. The UK aims to enable construction of a demonstration plant by the early 2030s. New AMR designs may utilise advanced forms of nuclear fuel, such as those utilising high assay low enriched uranium (HALEU).

A shortlisting and prioritisation exercise was conducted to determine the nuclear technologies to be modelled and studied in this update of the EINAs. This followed a framework which considered the following factors important to DESNZ:

- **Known net zero priority:** Technologies where there is a clear government direction or expert consensus.
- **Energy security:** Technologies necessary for system resilience (grid/import shocks).
- **UK relevance:** Technologies suitable for UK specific circumstances, and where the UK is likely to have an impact.
- **Technology Readiness Level (TRL) relevance:** Technologies close to commercialisation or likely to be commercially viable by 2040.

The nuclear technologies included as part of the EINAs are detailed in Table 2.

Table 2: Technologies in the nuclear technology theme prioritised for assessment as part of the EINAs

Technology	Description
Small Modular Reactors (SMRs)	SMRs are generally reactors up to 300-500 MW which are designed and built to take full advantage of modular techniques. Key features involve standardisation, modularisation, and factory-based construction. SMRs typically use Gen III technology. At this time, no land based SMRs have been constructed.[4] Three SMR designs are currently undergoing Generic Design Assessment in the UK. The Technology Readiness Level for SMRs is estimated to be 7.[5]

[4] Land based refers to reactors constructed on solid ground, as opposed to floating SMRs which may be installed on floating platforms or barges.
[5] National Nuclear Laboratory (2020) Identification of potential opportunities for development of UK R&D capability and strategic UK supply chain to the deployment of Advanced Modular Reactors

High Temperature Gas Reactors (HTGRs)	Advanced Modular Reactors (AMRs) are Generation IV reactors which use novel and innovative fuels, coolants, and technologies whilst taking advantage of the same modular-build principles as SMRs. HTGRs are a type of AMR. It is expected that HTGRs will make use of modularised design, in a similar manner to SMRs. HTGRs are capable of producing industrial heat and hydrogen in addition to electricity production. There have been several examples of prototype/test HTGRs, including the Dragon reactor in the UK. There are two HTGRs currently operational, one in Japan and one in China. In the UK, an HTGR design is undergoing Front End Engineering Design, supported by the Advanced Modular Reactor funding.[6] The UK government has also provided funding to Cavendish Nuclear through the Future Nuclear Enabling Fund to support X-Energy to undertake various studies and business development activities30. The Technology Readiness Level for HTGRs is estimated to be 5-7.[7]
High Assay Low Enriched Uranium (HALEU) fuel	HALEU fuel is an advanced type of fuel which contains an increased amount of uranium-235. HALEU fuel is commercially available, however pre-2022 supply was primarily from Russia which is now blocked. In addition, future reactor designs may require the development of new forms of HALEU fuel. New production facilities are planned in the UK and US.

[6] Department for Energy Security and Net Zero (2024) AMR Research, Development and Demonstration: Phase B (2023-2025): successful organisations
[7] National Nuclear Laboratory (2020) Identification of potential opportunities for development of UK R&D capability and strategic UK supply chain to the deployment of Advanced Modular Reactors

Nuclear energy in the UK energy system

The nuclear energy landscape in the UK

Nuclear power has been supplying power to the UK grid since the 1950s and accounted for 13.9% of electricity generation in 2023.[8] Worldwide, nuclear has an installed capacity of approximately 372 GW and supplied 2546 TWh of electricity in 2023[9]. This equates to approximately 9.1% of global electricity.[10]

There are currently nine operational nuclear reactors, across five power stations, in the UK.[11] Eight of these are advanced gas-cooled reactors (AGRs) and one pressurised water reactor (PWR). The number of operational reactors in the UK has been decreasing in recent years as early builds reach the end of their design life, with the 1.2 GW PWR at Sizewell B being the only existing plant expected to continue generating past 2030. The nuclear stations had a combined capacity of around 6 GW in 2023.[12] Nuclear reactors are typically run at nominal full load unless reduced for operational reasons or shut down for refuelling.

Nuclear research and development in the UK are undertaken by a range of organisations including reactor developers, universities and the UK National Nuclear Laboratory. Funding is through a combination of government awards and private sector investments. Areas of research include SMRs, HTGRs, fusion research, and waste management.

Future deployment of nuclear energy

The Government has stated its commitment to nuclear power beyond 2030, ensuring nuclear continues to provide clean, stable, and reliable power. Two Generation III+ pressurised water reactors are currently under construction at Hinkley Point C (HPC) in Somerset[13]. Once operational, HPC will generate 3.2 GW of electricity (equivalent to approx. 7% of Great Britain’s current demand)[11]. A sister project is planned to construct two reactors at Sizewell C (SZC) providing 3.2 GW. SZC reached Final Investment Decision in July-2025 and aims to be operational in the mid-2030s. Great British Energy-Nuclear (GBE-N) has selected Rolls-Royce as the preferred bidder to deploy SMR technologies in the UK.

SMRs aim to drive down the cost of nuclear power by reducing the overall delivery risk; this is achieved though employing highly modular designs and carrying out a greater proportion of the

[8] DESNZ (2024) Digest of UK Energy Statistics (DUKES) 2024 Chapter 5: electricity
[9] IAEA (2024) Nuclear Power Reactors in the World
[10] Ember (2023) Global Electricity Review 2024
[11] IEA (2024) United Kingdom 2024 Energy Policy Review
[12] DESNZ (2024) Digest of UK Energy Statistics, Plant capacity: United Kingdom (DUKES 5.7)
[13] Generation III reactor designs began development in the 1990s as an evolution of earlier designs, offering increased safety and economics. Generation IV covers a range of technologies that aim to be more economical, safer, with minimal waste and proliferation resistant. U.S Nuclear Energy Research Advisory Committee/Generation IV International Forum (2002), A Technology Roadmap for Generation IV Nuclear Energy Systems

construction work in factory conditions. It is anticipated that SMRs would have improved load following capability in comparison to legacy large-scale reactors due to inherent design features and optimisation of multi-module unit operation[14].

AMRs are Generation IV reactors which involve innovative designs and a significant level of modularity[15]. AMR vendors are targeting potential new uses of nuclear energy including hydrogen production, industrial heat, district heating, or nuclear waste management, in addition to electricity generation. The Advanced Modular Reactor Research, Development and Demonstration programme is focused on High Temperature Gas-cooled Reactor (HTGR) technology[16]. The high temperature output of HTGRs enables a range of potential industrial applications.

[14] OECD (2021) Small Modular Reactors: Challenges and Opportunities
[15] Department for Energy Security and Net Zero (2024) Advanced Nuclear Technologies
[16] Department for Energy Security & Net Zero (2024) Alternative Routes to Market for New Nuclear Projects

Nuclear energy: Innovation opportunities

Innovation opportunities in Small Modular Reactors (SMRs)

Overview of SMRs

SMRs are reactors up to 300-500 MW which are constructed using modular techniques[17]. They aim to maximise economies of series through implementation of modularisation and factory-based construction. This approach could reduce construction risks, once nth-of-a-kind (NOAK) efficiencies are realised, and makes the projects less capital-intensive. SMRs are typically Generation III+ technology. The designs considered as part of the GBE-N SMR competition have all been light water reactors. In the UK context, reactor designs utilising other coolants and fuel types fall under the AMR definition. SMRs are likely to be more suitable for integration into a grid featuring a significant amount of intermittent energy sources than legacy large-scale reactors due to incorporation of design features to enable load following and optimisation of multi-module unit operation.

SMRs generally have a smaller unit footprint than traditional scale nuclear power stations and could potentially enable development on a more diverse range of sites. The government's current draft EN-7 policy is designed to support siting on a more diverse range of sites than previously considered under EN-6 to support these advantages.[18,19,20]

EN-7 set out a refreshed planning framework for new nuclear reactors, including small and advanced modular reactors. The new planning framework proposes to empower developers to identify potentially suitable sites in real-time against a robust set of siting criteria. Following robust regulatory scrutiny and public engagement, this may enable new nuclear development at new sites.

Great British Energy - Nuclear was established in 2023 (originally as Great British Nuclear) as an expert nuclear delivery body that can provide the specialist capability and skills necessary to help deliver the government's nuclear programme.

GBE-N has acquired sites at Wylfa (Ynys Mon/Anglesey) and Oldbury-on-Severn (Gloucestershire), with currently 3 Rolls-Royce reactors planned for Wylfa with scope for 5 additional reactors in the future.

Mapping of innovation needs

This table details key components and areas of technology innovation required to reduce cost and accelerate the deployment of the nuclear technologies assessed in this report. This

[17] DESNZ (2019) Energy Innovation Needs Assessment – Nuclear fission
[18] DESNZ (2025) Draft – National Policy Statement for Nuclear Energy Generation EN-7
[19] Rolls Royce (2024) Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 1: Introduction,
[20] EDF Energy (2011) Environmental Statement – Volume 2

section draws from the previous EINAs research with updated assessments to reflect progression in innovation areas. The table details the direct technology impacts of innovations, as well as the other EINAs technologies that could benefit from innovation in these areas. Each innovation is assessed according to its likely impact on cost reduction and deployment for the relevant technology, with a qualitative assessed 1(very low) – 5 (very high) impact rating.. Column descriptors within the table are defined as following:

- Technology: technologies where the innovation is applicable.
- Cost reduction: how the innovation opportunity can reduce the overall costs of the technology, rated from 1 (low) to 5 (high).
- Barrier reduction: how the innovation opportunity can contribute to reducing barriers to deployment, rated from 1 (low) to 5 (high).
- Time frame: period over which the innovation could feasibly start to be adopted and have material implications for the UK energy system and Net Zero

Table 3: Innovation needs for SMRs

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Mining, Processing, Enriching, Fabricating	Fuels that remain in the reactor for longer increasing operational periods.	SMR, AMR	5 – Increased capacity factor and reduced re-fuelling costs. Potentially reduced volumes of radioactive waste	4 – Reduction in cost can contribute to greater market certainty	2040
Mining, Processing, Enriching, Fabricating	Fuels that can achieve higher burn-ups produce less high-level waste (HLW) per unit electricity generation and are compatible with earlier disposal in a geological disposal facility.	SMR, AMR	3 – Reduction in volume of HLW for disposal	4 – Reduction in cost can contribute to greater market certainty	2030

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
CAPEX – Components and systems	Adoption of a standardised, modularised and productised design25. Modularisation of systems to maximise factory fabrication and minimise on-site installation. Standardised and productised design allows for development of experienced staff and repeatable construction of multiple plants.	SMR, AMR	5 – Faster construction and higher quality first time, once NOAK efficiencies are realised	4 – Reduced construction times, de-risk of construction programme and reduced cost minimise financing risks	2030
CAPEX – Components and systems	Design simplification that uses inherently safe and passive features and reduction in the quantity of nuclear-grade components33	SMR, AMR	5 – Decrease in number of expensive components in comparison to active plants (newer GW scale plants may incorporate passive features)	5 – Reduced risk of a nuclear accident increases regulator and public acceptance	2025-30

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
CAPEX – Components and systems	Adoption/development of advanced manufacturing to reduce cost and increase speed and reliability of components: Advanced machining; Additive manufacturing; Advanced joining (e.g. local vacuum electron beam welding[21]); Advanced assembly, metrology, automation.	SMR, AMR	4 – Faster manufacture, reduction in material waste, increase in component quality	4 – Reduction in cost can contribute to greater market certainty	2030-40
CAPEX – Components and systems Decommissioning	Wider use of robotics for in-service inspection, autonomous processes, remote handling in harmful environments, and size reduction[22]. Reduces reactor down time, allows component removal to optimise waste stream, allows 'in service' component inspection which may underpin any life extension decisions.	SMR, AMR	5 – Increase in efficiency of inspections, reduced downtime, and earlier completion of decommissioning	4 – Improved economics. Shorter decommissioning timescales potentially contributes to public acceptance.	2040-50 for impact on operations Post 2050 for impact on decommissioning

[21] Cambridge Vacuum Engineering (CVE), Discover the factory of the future, accessed on 11/12/2024
[22] UK Atomic Energy Authority, Race, accessed on 11/12/2024

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
CAPEX – Construction installation and commissioning	Maximise use of Commercial Off the Shelf (COTS) components to reduce bespoke construction, installation and commissioning. Requires a supply chain that is engaged and understands what COTS means to nuclear (through life availability, ability to maintain etc.).	SMR, AMR	4 – Reduced cost and increased availability. Increased potential for multiple suppliers.	3 – Potential to strengthen the supply chain. Reduction in cost can contribute to greater market certainty.	2025-30
CAPEX – Components and systems Energy System Integration	Improved use of reactor energy generation with more flexibility and wider contribution to decarbonisation, such as: Advanced power conversion cycles, District heating, Hydrogen production, Heat storage, Direct air capture of CO2.	SMR	4 – Maximise usage of power plant and potential for new revenue sources	3 – Potential environmental benefits and greater public acceptance	2040-50

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Operations and Maintenance	Equipment that is optimised for reduced maintenance (routine and breakdown). Requires development of improved material, lubrication, electronics etc.	SMR	4 – Reduction in length of outages for maintenance	3 – Reduction in operational costs can contribute to greater market certainty and enable easier access to financing	2025-30
Operations and Maintenance	Increased digitalisation, e.g. upgrades in instrumentation and control systems. Digitalisation may enable greater supply chain integration, improved decision-making, and new operational modes.25	SMR	5 – Improved performance of the reactor	3 – Reduction in operational costs can contribute to greater market certainty	2025-30

Table sources[17, 21, 25, 33, Mott MacDonald]

Components and costs

While nuclear has been identified as a crucial technology in the UK's future electricity supply, the current capital costs and construction risks hinder the planned acceleration of nuclear plant construction.

There is no experience of SMR construction in the UK to use in developing cost estimates and cost estimates available in literature are subject to a range of uncertainties[23].

The following key cost components are significant to the cost of SMRs17 [24] [33]:

- **Mining, processing, enriching, fabricating (~10%):** Full treatment of fuel prior to its use in a reactor, from extraction through to fabrication.
- **Capex – Construction/installation and commissioning (~25%):** costs associated with construction such as contingency and owner's fee.
- **CAPEX – Components (~25%):** Main assemblies of the reactor system, e.g. reactor core.
- **CAPEX – Construction materials (~10%):** This covers costs of construction materials such as concrete and steel and access infrastructure.
- **O&M (~25%):** Operating costs including fixed costs and maintenance.
- **Waste management, processing, storage (~1.5%):** Processing of waste and packaging for storage, e.g. in a geological disposal facility.
- **Decommissioning (~1%):** Defueling and dismantling of the plant.

SMRs costs are driven by the CAPEX costs associated with construction, construction materials and components. CAPEX is estimated to represent 60% of the total costs[33], with operations and maintenance costs representing the second largest cost.

Financing is typically a large proportion of the CAPEX cost of nuclear power. For example, the financing costs relate to construction risk, interest, and return on equity and are approximately 67% of the levelised cost of electricity of large-scale nuclear power plants[25]. SMR designs aim to reduce financing costs through a number of mechanisms. As they are smaller than traditional Gen III plants, the associated risk for investors is reduced. The standardised nature of the design and factory-based construction reduces risks associated with inexperienced labour, weather and design changes, and shortens the construction period.

It is estimated that labour costs represent approximately 61% of the engineering, procurement and construction costs for typical large scale nuclear power plants[24]. SMRs aim to minimise labour costs by maximising the use of offsite module manufacturing, developing an

[23] Idaho National Laboratory (2023), Literature Review of Advanced Reactor Cost Estimates, INL/RPT-23-72972 Rev 3.
[24] Energy Technologies Institute (2020), The ETI Nuclear Cost Drivers Project – Full Technical Report
[25] OECD/NEA (2020), Unlocking Reductions in the Construction Costs of Nuclear: A Practical Guide for Stakeholders

experienced labour force, and by adopting advanced construction techniques, e.g. steel-plate composite.

High Temperature Gas Reactors (HTGRs)

Overview of HTGRs

High-temperature gas-cooled reactors (HTGRs) are a type of thermal reactor which typically use nitrogen or helium as the coolant and graphite as the moderator. HTGRs are one technology within the range of Generation IV reactors considered as Advanced Modular Reactors (AMRs). They are capable of generating electricity and supplying high-temperature heat for hydrogen generation and other industrial processes. This provides an advantage over other AMR technologies in decarbonising hard to abate sectors which require industrial process heat. Typical HTGR designs produce coolant outlet temperatures of 750°C to 950°C.[26, 27]

Currently the only operational HTGRs are located in China and Japan, with the only commercial HTGR being the HTR-PM demonstrator in China. The HTR-PM has a net capacity of 150 MWe. HTGRs have previously been operated in the UK (Dragon), Germany and the US[28]. The Dragon reactor was an experimental reactor with a thermal output of 20 MW, which ran from 1966 to 1975.[29] Cavendish Nuclear have been awarded funding under the Future Nuclear Enabling Fund (FNEF) to evaluate the potential development of 16X-Energy's Xe-100 HTGR design in the UK. X-Energy have proposed a 12-reactor plant, each outputting approximately 80 MWe, at Hartlepool.[30]

Mapping of innovation needs

Refer to table 3 for components which relate to both HTGRs and SMRs. Column descriptors within the table are defined as following:

- Technology: technologies where the innovation is applicable.
- Cost reduction: how the innovation opportunity can reduce the overall costs of the technology, rated from 1 (low) to 5 (high).
- Barrier reduction: how the innovation opportunity can contribute to reducing barriers to deployment, rated from 1 (low) to 5 (high).
- Time frame: period over which the innovation could feasibly start to be adopted and have material implications for the UK energy system and Net Zero

[26] IAEA (2001) IAEA-TECDOC-1198 Current status and future development of modular high temperature gas cooled reactor technology
[27] IAEA, Technical Data, accessed on 22/10/2024
[28] Dragon was an early HTGR research and development reactor, owned and operated by UKAEA at their Winfrith site in Dorset, England.
[29] Nuclear Energy Agency, https://www.oecd-nea.org/jcms/pl_51567/dragon-project, accessed on 10/12/2024
[30] X-Energy, https://x-energy.com/media/news-releases/uk-government-selects-x-energy-and-cavendish-nuclear-for-first-advanced-modular-reactor-award-from-future-nuclear-enabling-fund, accessed on 10/12/2024

Table 4: Innovation needs for HTGRs

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Mining, Processing, Enriching, Fabricating	Important innovations are in fuel cycle, proliferation resistance, and accident tolerant fuels (including fuel cladding that does not produce hydrogen in fault conditions, have a lower failure rate, reduce primary circuit activity and produce less HLW through optimisation of fuel enrichment and fabrication).	AMR	2 – Reduction in volume of HLW	3 – Reduction in cost can contribute to greater market certainty. Reduced risk of a nuclear accident increases regulator and public acceptance.	2030-40
Mining, Processing, Enriching, Fabricating	Development of fuel technologies that: enable lower cost and safer waste management, reduce the period that HLW remains active from hundreds of thousands of years to hundreds of years, and that deliver improved raw material utilisation.	AMR	2 – Reduction in storage requirements for HLW	2 – Reduction in cost can contribute to greater market certainty. Reduced risk of a nuclear accident increases regulator and public acceptance.	2030-40

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
CAPEX – Components and systems	Choice of coolant that in AMRs: a) operate at higher temperatures giving higher efficiency and a wider range of applications; b) have improved safety characteristics in loss of coolant accidents or large void reactivity coefficients; c) have lower environmental impact if released into the atmosphere or on final disposal.	AMR	4 – Increased efficiency and access to new markets	3 – Reduced risk of a nuclear accident increases regulator and public acceptance	2030-40
CAPEX – Components and systems	Develop and nuclear qualification of materials for use in high temperatures[32]	AMR	2 – Reduction in cost due to minimised need for cooling of components	3 – Reduction in cost can contribute to greater market certainty	2030-40
CAPEX – Components and systems	Instrumentation and Control (I&C): The elevated temperatures in HTGRs require the development and qualification of suitable sensors.[32]	AMR	2 – Increased efficiency in operation of reactor	3 – Reduced risk of a nuclear accident increases regulator and public acceptance	2030-40

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Decommissioning	Waste packaging and storage: Current disposal approaches require modification to account for possible variations in heat generation, volume, behaviour of coated particle fuels etc.[31], [32].	AMR	3 – Decrease in storage requirements	3 – Reduction in cost can contribute to greater market certainty	2030-40
Regulatory	Streamlined assessment of technology – time to deployment reduced.	AMR	3 – Reduction in deployment timeline	3 – De-risking of deployment programme minimises financing risks	2030-40
Regulatory	Aligned regulation in moving from “first of a kind” to ”nth of a kind” (FOAK to NOAK)	AMR	2 – Potentially reduced costs of redesign work	3 – De-risking of deployment programme minimises financing risks	2040-50

Table sources[17, 31, 32, 32, Mott MacDonald]

[31] US Department of Energy (2023), Advanced reactors spent fuel and waste streams dispositions strategies – Spent fuel and waste disposition
[32] Nuclear Innovation and Research Office (2021), Advanced Modular Reactors Technical Assessment

Components and costs

The key cost components for AMRs are the same as those for SMRs[17].

HTGRs are subject to capital costs and construction risks similar to those affecting SMRs. CAPEX is the primary cost driver for HTGRs, estimated as 83% of the total costs.

It is likely that design development costs for HTGRs will exceed those for Gen III plants or SMRs (on a per MW basis) due to the inherent design challenges, the relatively lower technology maturity level and regulatory uncertainty. It is also expected that HTGR costs will be impacted by first-of-a-kind cost overruns. However, published cost estimates show a significant overlap between water cooled and gas cooled reactor costs[23]. Indeed, Japan's High Temperature Engineering Test Reactor (HTTR) shows the potential viability of a low-cost HTGR design[33].

Reprocessing of HTGR fuels can be difficult and spent fuel may be sent for direct disposal[34]. HTGRs are expected to produce a larger volume of spent fuel in comparison to Gen III reactors/SMRs, although the impact of the larger volume is offset by a lower rate of heat generation.

HALEU fuel

Overview of HALEU fuel

High Assay Low Enriched Uranium (HALEU) fuel typically ranges from greater than 5% to 19.75% uranium-235[35], above the 5% level used in most nuclear power plants currently in operation. The use of HALEU may reduce operating costs by increasing cycle length and decreasing the volume of high-level waste, through enhanced burnup of the fuel. HALEU fuel can enable the use of smaller reactors due to the higher concentration of fissile U-235[36]. HALEU fuel may also support the development of fuel designs more tolerant of accident conditions.

Demand for HALEU fuel will largely come from AMRs[37]. Use of HALEU fuel in existing reactors would require major redesign and re-licensing work. Outside of energy generation, HALEU is also used in research reactors and in medical radioisotope production. Existing conventional light water reactors may opt to use HALEU fuel over conventional fuel to achieve cost savings, subject to regulatory approval. AMR designs however have a variety of different fuel requirements, including HALEU fuel. A steady and secure supply of HALEU fuel is required for

[33] Energy Technologies Institute (2018), The ETI Nuclear Cost Drivers Project: Summary Report
[34] Department of Energy & Climate Change (2016), SMR Techno-Economic Assessment Project 1: Comprehensive Analysis and Assessment, Techno-Economic Assessment Final Report Volume 1.
[35] IAEA (2020) Light Water Reactor Fuel Enrichment beyond the Five Per Cent Limit: Perspectives and Challenges
[36] Centrus Energy, https://www.centrusenergy.com/what-we-do/nuclear-fuel/high-assay-low-enriched-uranium/, accessed on 12/02/2024
[37] World Nuclear Association (2023) High-Assay Low-Enriched Uranium (HALEU), accessed 10/10/2024

the deployment of AMR projects[38]. Until recently, the primary source of HALEU fuel on a commercial scale has been from within the Russian Federation. Limited supplies of HALEU fuel are produced by the US Department of Energy, however these are not on a commercial scale. The UK government is committed to establishing front-end fuel cycle capabilities for enriched uranium up to 19.75%[39]. The government has awarded funding for the construction of a uranium enrichment facility in the UK, with further funding to be allocated to support deconversion capability. This funding aims stand up this capability by the early 2030s, and includes provision for transportation, regulation and skills.

Cost estimates for HALEU fuel production are limited and depend on input assumptions such as production method and market size. The Nuclear Innovation Alliance have estimated that of the total HALEU fuel production costs, LEU fuel cycle related activities represent 65% of the total, HALEU-specific production activities represent 33% of the total and overheads representing the final 2% of total production costs[40].

[38] OECD/NEA (2022), High-temperature gas-cooled reactors and industrial heat applications, https://www.oecd-nea.org/jcms/pl_70442/high-temperature-gas-cooled-reactors-and-industrial-heat-applications?details=true
[39] Department for Energy Security and Net Zero (2024) Civil Nuclear: Roadmap to 2050
[40] Nuclear Innovation Alliance (2023), Characterizing an Emerging Market for High-Assay Low-Enriched Uranium Production, https://nuclearinnovationalliance.org/characterizing-emerging-market-high-assay-low-enriched-uranium-production

Table of innovation needs

Table 5: Innovation needs for HALEU fuel

Component	Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Mining, Processing, Enriching, Fabricating	Important innovations are in fuel cycle, proliferation resistance, and accident tolerant fuels (including fuel cladding that does not produce hydrogen in fault conditions, have a lower failure rate, reduce primary circuit activity and produce less HLW).	AMR, SMR	2 – Reduction in volume of HLW	3 – Reduction in cost can contribute to greater market certainty. Reduced risk of a nuclear accident increases regulator and public acceptance	2030-40

Energy System Modelling

System modelling to assess the potential impact of innovation in key net zero technologies was conducted using UK TIMES, an energy system model of the UK that was developed by UCL and the UK Department of Business, Energy and Industrial Strategy (now the Department for Energy Security and Net Zero or DESNZ). For each of the selected technologies, three levels of innovation were developed representing a low, medium and high innovation case for the technology. The low innovation level represents a business-as-usual case where innovation follows recent trends or is generally limited, whilst the high innovation case represents significant innovation in the technology to decrease costs and improve efficiencies.

The low, medium and high innovation cases were each run against three different hypothetical scenarios which were developed by DESNZ to represent potential routes to net zero for the UK, namely Minimally Constrained, High Hydrogen and High Diversification. They do not represent government policy but were selected due to their differing constraints which provide a more diverse set of outputs and insights. A summary of each is presented below, a more in depth description can be found in the EINAs Methodology report.

- **Minimally Constrained:** Designed to show the largest potential impacts from innovation investments by minimising the number of constraints on the energy system. UK Government data assumptions are used across the scenario.
- **High Hydrogen:** Based on the Minimally Constrained scenario, with a range of constraints added to force hydrogen use across the economy. These constraints are based on estimates of H2 demand ranges in the DESNZ Hydrogen transport and storage networks pathway policy paper published in 2023, and provisional figures from DESNZ sector teams that are set to be refined further for CB7. A maximum hydrogen consumption in each sector and a minimum overall level of consumption is applied in each year from 2035 to 2050.
- **High Diversification:** Based on the minimally constrained scenario, this scenario aims to be more energy secure through two means, 1) limiting imports of key commodities to reduce UK reliance on overseas resources, and 2) diversifying resource and technology use across the economy to limit the impacts of any supply interruptions, price rises or technology failures.

The results presented below demonstrate the potential impact of innovation for a specific technology on achieving net zero within the confines of the scenario. In each model run for a specific technology, all other technologies are held at their low innovation case so that the impact on the UK energy system of that technology can be isolated. Changing the costs and performance of technologies through innovation can have both direct and indirect consequences:

- Direct consequences are a reduction in cost or an improvement in the quality of the energy service supplied by the technology. Only cost reductions are examined in the UK TIMES energy system model.

- Indirect consequences are changes to the wider system caused by a relative change of cost of a technology relative to other technologies. If the deployment of a technology increases due to a lower cost and the deployment of alternative technologies reduces then a cost reduction will be realised. This cost reduction will be lower than the direct cost reduction would have occurred if the new technology had already been used at lower innovation levels. More profound changes could also occur across the energy system, for example changes in total electricity consumption or in the relative rate of decarbonisation between sectors of the economy.

We have not considered rebound effects where lower costs of energy due to innovation investments lead to higher energy service consumption. An elastic demand version of UK TIMES could be used to explore potential rebound effects of innovation investments.

The below analysis refers to only SMRs and HTGRs. It should be noted that, given these results are an output of the system modelling and the three hypothetical scenarios developed for the EINAs, that they do not necessarily reflect UK government deployment targets and ambitions.

In Minimally Constrained and High Hydrogen, nuclear capacity remains unchanged across all innovation runs. This aligns with the constraints on these scenarios enforcing a minimum nuclear capacity in these cost-optimal solutions. Installed capacity for the High Diversification scenario is higher due to the key assumptions within this scenario, namely higher domestic generation as well as higher diversification of generation sources.

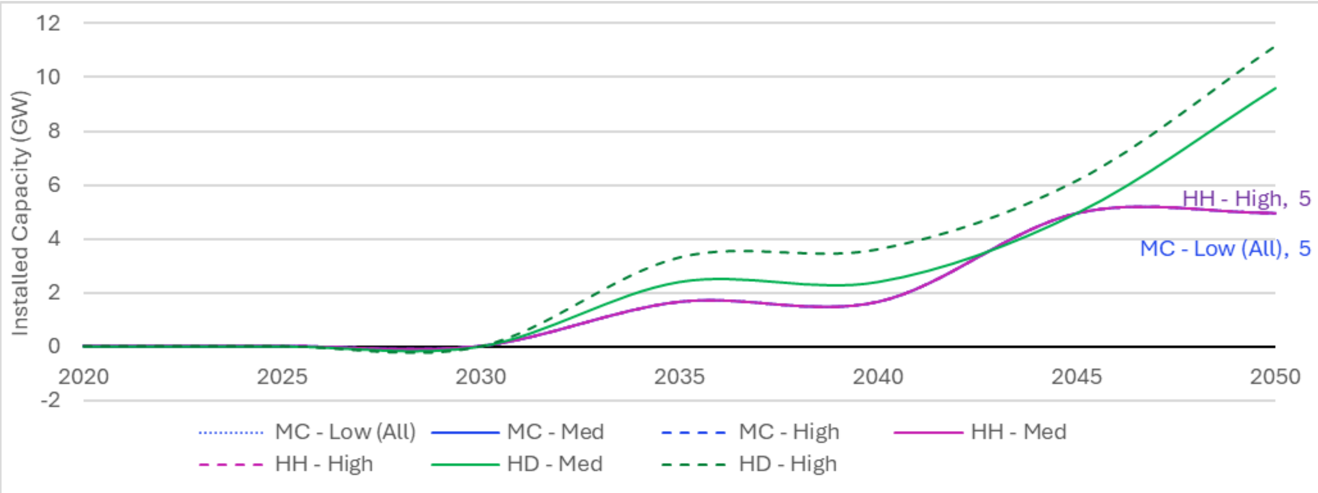

Figure 1: Installed capacity (GW) of SMRs and HTGRs by innovation level and scenario

Electricity generation from nuclear plants also remains consistent across innovation runs in Minimally Constrained and High Hydrogen, albeit marginally higher deployment is observed in 2035–2040 for with some increase in deployment in the high innovation nuclear runs. Innovation in nuclear technologies has very limited to no impact on other technologies within Minimally Constrained and High Hydrogen scenarios, while similarly innovation in other technologies had no impact on nuclear deployment. As the electricity supply diversifies in High Diversification, generation from nuclear doubles in comparison to levels in Minimally Constrained and High Hydrogen in 2050. The high innovation run in the High Diversification leads to the highest electricity generation from nuclear, reaching 87 TWh by 2050 and hitting the imposed capacity limit.

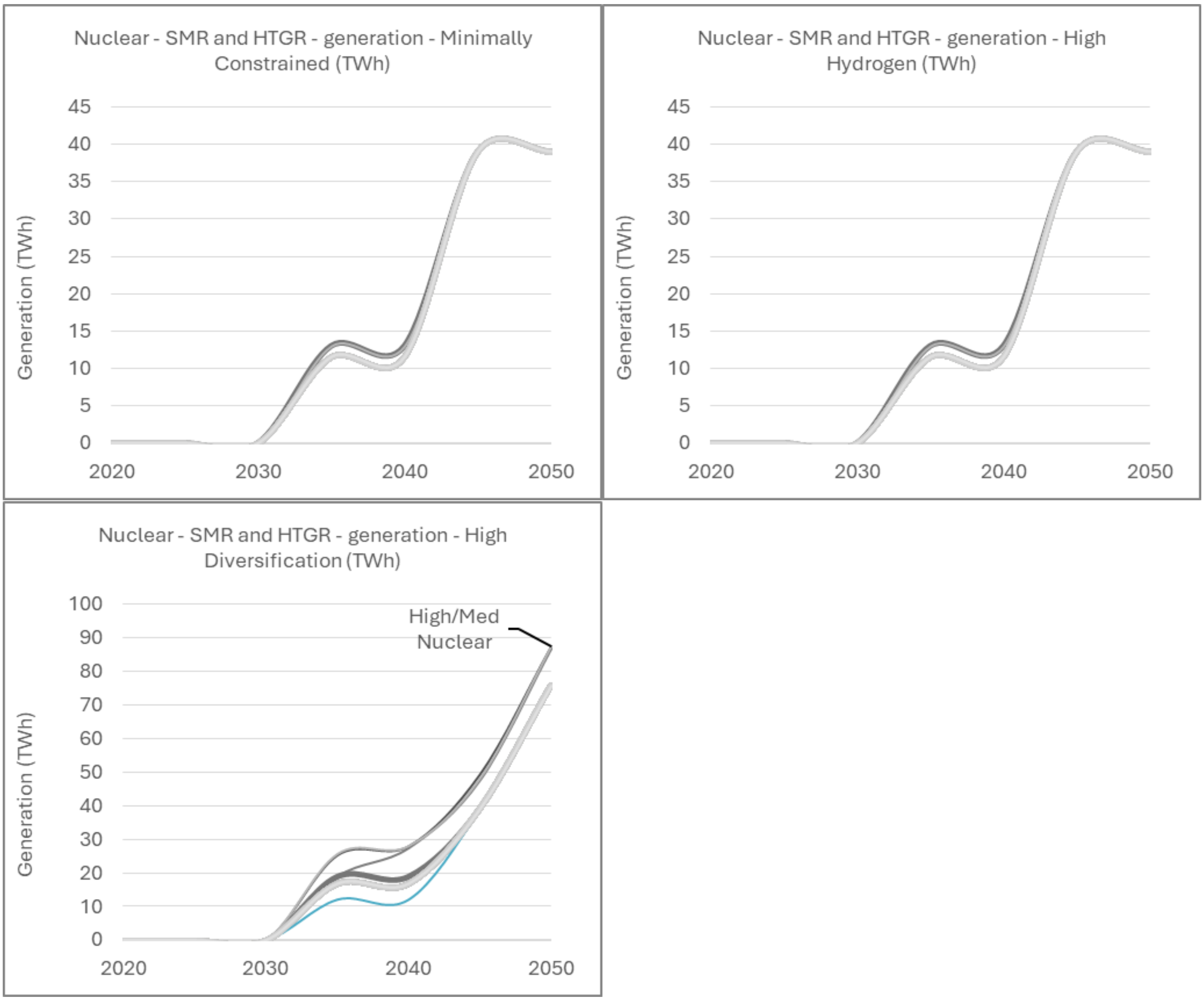

Figure 2: SMRs and HTGRs generation (TWh) over time across different innovation runs (low, medium and high levels for each technology) in all three scenarios

Cost savings through high innovation levels in nuclear technologies are significantly higher in the High Diversification (£19.7 billion) than the other two scenarios (£9.0 billion for Minimally Constrained and £9.1 billion for High Hydrogen) due to the higher rates of deployment and consequent system cost savings from innovation.

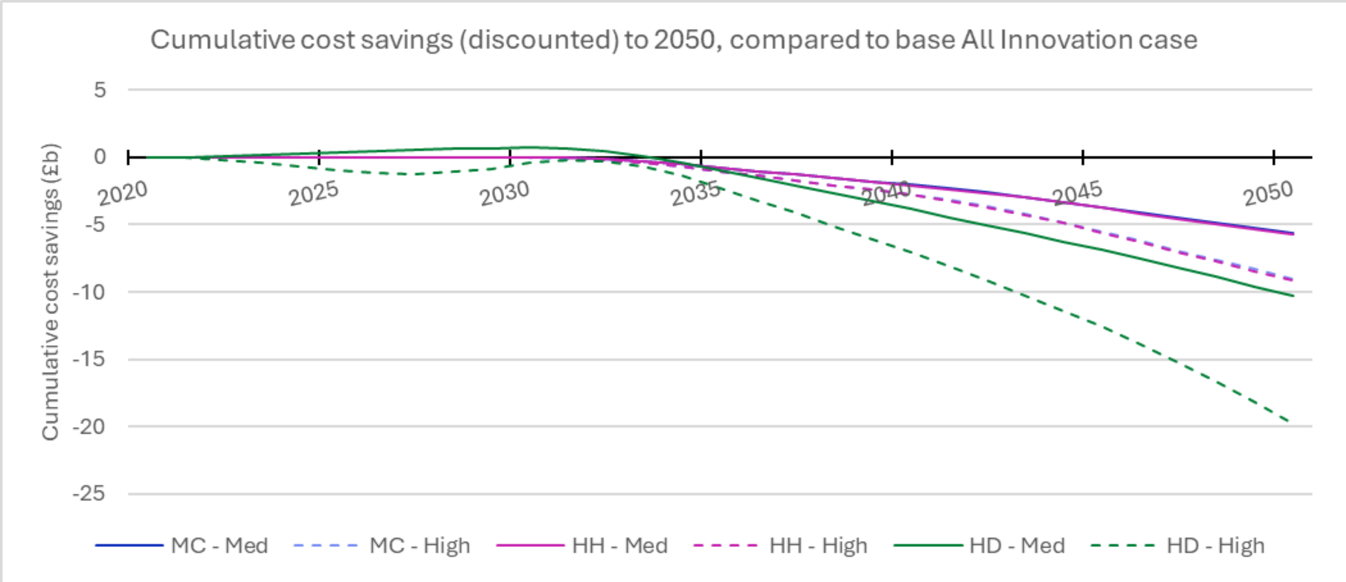

Figure 3: Cumulative cost savings (in real 2022 £) to 2050 for differing levels of innovation in SMRs and HTGRs, compared to base all low innovation case

Market innovation barrier and enabler deep dives

As part of the EINAs project, a barriers and enablers assessment was carried out across the prioritised technologies to understand the factors which should be considered for each technologies in additional to technology innovation. This included qualitative analysis across eight variables with a low/medium/high rating for each element to indicate the relevance and risk of each barrier to the deployment and scale up of the technology.

- **Enabling infrastructure:** The supply chain for HTGRs and SMRs needs investment in the UK. Some enablers that need some support include TRISO/fuel manufacturing, reactor vessel manufacturing, and Reactor Pressure Vessel forging.
- **Regulatory environment:** There are two major regulatory barriers to deploying HTGRs or other AMRs: Sites defined by National Policy Statements and nuclear regulatory experience. Deploying SMRs across the UK would benefit greatly from more sites available than are prescribed in NPS EN-6.
- **Stakeholder acceptance:** HTGRs face high barriers to stakeholder acceptance and it is clear that power technologies must compete on price. SMRs have a slightly better public acceptance than GW scale reactors due to better perception on build time and cost.
- **Availability of funding and investment:** The nuclear industry has struggled with access to private financing and the majority of NPPs deployed in the past decade have been publicly funded.
- **Business model viability:** NPPs are generally a long-term investment with a long construction period. SMRs aim to reduce the debt build up during construction which could enhance the business model.
- **Resource availability:** Nuclear power in general is not resource intensive, with low land, fuel and water use, whilst raw materials are available.
- **Supply chain:** Deployment of HTGRs in the UK would need to rely on international supply chains. Companies interested in deploying SMRs in the UK have made partnerships with international suppliers of the long lead items to help mitigate risks.
- **Skills and training:** The UK has experience operating gas cooled reactors. This could be used as a base for the operating skills and training of HTGRs. Manufacturing and construction of HTGR sites would inevitably be different than other nuclear power technologies.

This section summarises and expands on the key barriers and enablers for the nuclear energy technologies, which can be considered alongside the priorities for technology innovation.

Deep dive 1: Upfront costs

One of the primary barriers to the increased deployment of nuclear energy are the upfront costs. Nuclear power plants require significant upfront investment in research, design, and construction with capital costs representing approximately 72% of the total production costs[25]. The construction of a nuclear power plant is also accompanied by significant risks, e.g. regulatory approval, construction issues, inflation, electricity price uncertainty. The combination of upfront investment, long delivery times and potential risks reduces the attractiveness of nuclear as an investment and increases the cost of finance, thus discouraging innovation and hindering deployment. Lowered deployment would in turn affect the potential for SMRs to achieve lower costs through standardisation.

There are a number of approaches to reducing upfront costs of nuclear. New funding models, such as Regulated Asset Base, may reduce the risk associated with a project by providing a revenue stream during the construction period.

It is recognised that the level of design maturity and of the supply chain have a significant impact on the construction costs. Reactor vendors are pursuing a number of innovations to reduce the construction cost of nuclear reactors. These include:

- Modularisation and factory build: can reduce costs by utilising a fully developed standardised design, avoiding the impacts of inclement weather, and increase productivity by developing an experienced workforce. International deployment of a standardised design would provide further opportunities to reduce costs. A standardised design should accommodate differences in the international market to maximise efficiencies, e.g. 50 Hz or 60 Hz grid frequency.
- Advanced manufacturing: covers a range of processes with the potential to produce reactor components with reduced material and labour costs, e.g. automated welding, high energy density welding, etc.
- Building Information Modelling (BIM): allows designers to develop and share accurate design information through detailed models of nuclear facilities. It allows for the design to be developed to a greater level of detail and incorporate scheduling into the model, improving project management and planning for construction, maintenance and decommissioning.
- Advanced construction methods: allow for quicker construction by simplifying construction access and by allowing multiple activities to be undertaken simultaneously, for instance Diaphragm Plate Steel Composite (DPSC) construction and use of 3D printing for concrete moulds or structural components.
- Co-siting of multiple reactors: Co-siting is expected for SMRs and has the potential to reduce costs by sharing a number of indirect costs among multiple reactors. Examples of shared costs include site licensing and site infrastructure. Co-siting also has the potential to improve productivity by retaining experienced contractors on-site.

The potential worldwide investment in SMRs alone may reach USD 670 billion by 2050.[41] The UK has an existing nuclear industry supply chain with experience in the design, build, operation and decommissioning of nuclear reactors. The UK currently has the capability to produce a number of the systems required by SMRs, although further investment is required in areas to increase capacity. Several of the companies involved in the GBE-N nuclear technology competition are looking to develop factories in the UK to support the deployment of SMRs, with Holtec Britain having selected South Yorkshire as the location for their planned factory.[42]

Deep dive 2: Skilled workforce

The wider civil and defence nuclear workforce was estimated to support around 96,000 jobs in 2024.[43] Based on the same industry-led workforce assessment exercise, approximately 120,000 employees would be needed by the early 2030s in order to deliver the UK's civil and defence nuclear programmes. This will require continued momentum in implementing strategic workforce initiatives to attract and train new entrants to the industry. [50]

The UK's aging workforce is part of this challenge. A significant proportion of the civil nuclear workforce are approaching retirement age, with approximately 10% aged 60 or above.[44] An increasing number of workers must be recruited even if the industry undergoes no expansion. Additionally, the existing workforce may not have the right skills for construction and commissioning on new nuclear reactors with much of the workforce involved in operations, maintenance and decommissioning. This risk is increased with SMRs and AMRs as they use different techniques for delivery than previous new build projects.

Addressing the skills shortage requires collaboration from government, reactor developers, supply chain companies, education providers, and institutes of higher education. An example includes the industry-led Nuclear Skills Plan, which outlines actions to build a skilled workforce for the UK's nuclear ambitions, delivering nearly 4,000 early-careers starters entering the sector in 2024/2025,[45] launching the first ever national recruitment campaign 'Destination Nuclear' to ensure opportunities in nuclear are visible and attractive to job seekers,[46] and establishing the Regional Skills Hubs to align workforce planning with regional skills needed. The Plan is also delivering a bespoke nuclear doctoral funding award to grow the UK PhD ecosystem, creating a pipeline for future sector specialists. Such initiatives will also benefit from targeting populations who have not traditionally considered the sector to ensure increased demand can be met.

[41] IEA (2025), The Path to a New Era for Nuclear Energy, https://www.iea.org/reports/the-path-to-a-new-era-for-nuclear-energy
[42] BBC, https://www.bbc.co.uk/news/articles/cvglxne40p4o, accessed on 10/12/2024
[43] Cogent Skills (2025) Nuclear Workforce Assessment
[44] NSSG (2023), A scenario-based approach to nuclear workforce planning
[45] Explore the Skills Plan - Nuclear Skills Plan
[46] DDestination Nuclear - Start your career in nuclear | Destination Nuclear

Deep dive 3: Supply chain

Nuclear power plants require a number of specialist components such as reactor pressure vessels, reactor vessel internals, nuclear steam supply system, etc. The widespread deployment of nuclear power requires a reliable supply chain with the capability and capacity to meet demand. There are currently a limited number of nuclear vendors in the UK with advanced manufacturing capabilities, with Sheffield Forgemasters being the only supplier capable of producing large nuclear components at the time of writing. New entrants to the market may be dissuaded by the high barriers to entry and uncertain future demand.

An example of supply chain challenges is forging capacity. A number of components in reactors utilise forging during manufacture, including component parts of the reactor pressure vessel, steam generators and hot legs. The UK is unable to produce a number of the components required for large reactors but is capable of producing components for smaller reactors. The UK has experience of developing innovative technologies relating to forging[47]. The forge capacity in the UK is limited and would not be able to support a widespread deployment of reactors without additional investment in capacity. There is competition for resources internationally, where the expansion of nuclear programmes in other countries draw on the same nuclear supply chain.

There is an opportunity to capture a greater percentage of the value of the supply chain, both for domestic construction and for the export market. Large scale reactor vendors typically have existing preferred supply chain partners; the choice of Rolls-Royce in delivering the UK’s first SMRs provides an opportunity to further develop domestic supply chains and enable further expansion in the future.[48] A clear and sustained commitment to increasing nuclear reactor deployment in the UK is required encourage the supply chain to invest in increasing capacity. Delays in funding decisions and a lack of commitment to future deployments have previously resulted in a weak demand signal to suppliers and dented confidence in relation to future investments.[49]

[47] Nuclear AMRC (2020), Intelligent Fixtures for Optimised and Radical Manufacture (InFORM)
[48] UK Government (2025) Rolls-Royce SMR selected to build small modular nuclear reactors - GOV.UK
[49] House of Commons Science, Innovation and Technology Committee (2023), Delivering nuclear power, Eighth Report of Session 2022-23, https://committees.parliament.uk/publications/41092/documents/200324/default/

Business opportunities in novel nuclear energy

Introduction

The purpose of this section is to explore the potential scale of the business opportunities for the UK associated with the national and global development of two of the key technologies discussed in this report: SMRs and HTGRs. This incorporates the business opportunities associated with the production of HALEU fuel to the extent that it is used as an input by SMRs or HTGRs. Innovation has the potential to be a key driver in supporting the growth of this sector in the UK and realising these business opportunities, and therefore an important element to capture as part of this innovation assessment.

The section summarises the key findings from the development of a series of 'business opportunities calculators'. These calculators integrate projections of domestic deployment of the two technologies derived from scenario-based systems modelling, with assessments of the UK's potential market share in overseas markets, informed by global modelling and literature reviews. They combine this understanding of potential deployment with assumptions about the cost structure and employment intensity of the different activities required for the manufacturing, deployment, operation and decommissioning of each technology to generate an understanding of the potential business opportunities in terms of:

- Gross Value Added (GVA) – a measure of the value generated by the production of goods and services. GVA can be thought of as broadly equivalent to the contribution of that sector/activity to Gross Domestic Product.
- Employment – Employment is measured in terms of jobs and includes both direct employment – the jobs associated with the construction, operation and decommissioning of the assets – and indirect employment – the jobs associated with the production of the goods and services needed by the workers with direct jobs, i.e. jobs associated with the supply chain needed to construct, operate and decommission the assets.

All results are illustrative of potential business opportunities of technological innovation. They are generated using a particular set of technologies, hypothetical deployment scenarios, modelling outputs and other assumptions to help inform UK Government decision making.

The modelling outputs on which the results are based include modelled expectations for deployment in both 2020 and 2025. While efforts have been taken to calibrate these modelled outcomes with existing deployment data, some inconsistencies will remain. Looking forward, results do not reflect UK government targets/ambitions regarding neither deployment of these technologies nor the business opportunities that might be realised.

It is also important to stress that the results are specific to the particular technologies of focus for the report, rather than the GVA and employment for the wider sector within which these technologies may often be categorised. As such, care should be taken when comparing the figures presented below with estimations which cover the entire sector, and use different scenarios and models.

Results do not reflect UK government targets or ambitions for either deployment or the business opportunities that might be realised. All monetary values in this section refer to 2022 GBP unless otherwise specified.

Nuclear energy market landscape

UK market position

The earlier discussion in this report outlines the mixed landscape regarding the ability of UK-based companies to leverage the business opportunities associated with emerging nuclear technologies. The UK possesses several key strengths, including a well-established track record in the construction and operation of nuclear reactors. Nuclear energy currently contributes approximately 14% of the UK's electricity generation, which is above the global average, and, in combination, the civil and defence components of the nuclear sector support an estimated 83,000 jobs.[50] Additionally, the UK benefits from strong government support for the future expansion of the nuclear industry, as well as a robust ecosystem of institutions dedicated to research and development in advanced nuclear technologies.

Despite these strengths, challenges remain that may constrain the sector's growth. A recent lack of investment has contributed to several structural weaknesses. In particular, the UK's indigenous nuclear supply chain is relatively limited, with only a small number of domestic vendors possessing advanced manufacturing capabilities. Furthermore, differences between conventional nuclear technologies and emerging SMRs or HTGRs could hinder the direct transferability of skills from the existing workforce to new technological applications. Addressing these challenges will be critical to ensuring the UK remains competitive in the evolving nuclear energy landscape.

Global nuclear energy market

To achieve global net zero targets, the demand for new nuclear energy technologies is expected to expand significantly over the next 30 years. Analysis from the International Energy Agency (IEA) suggests that reaching net zero by 2050 will require a near doubling of total global nuclear capacity, increasing from approximately 415 GW in 2020 to 812 GW by 2050.[51]

At the time of developing the calculators, there was limited analysis available on the share of this capacity increase that might be met by SMR/HTGR technologies. However, there has been, and continues to be, significant interest in these technologies, particularly in SMRs. A 2024 Wood Mackenzie report identified a global pipeline of approximately 22 GW of planned

[50] NSDG (2024) National Nuclear Strategic Plan for SKills
[51] IEA (2021) Net Zero by 2050: A Roadmap for the Global Energy Sector, https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

SMR capacity, representing a 65% increase since 2021. Market interest is particularly strong in the United States, which has 4 GW of announced SMR projects and an additional 3 GW in early or pre-development stages. Other key markets include Poland and Canada, each of which has approximately 2 GW of planned capacity.[52]

The analysis below is based on the global expansion of nuclear capacity projected in the IEA's Net Zero scenario. It assumes that SMR and HTGR technologies will penetrate the global market at the same rate as is projected for the UK market.[53] Additionally, it is assumed that UK-based firms could capture approximately 3–5% of the global market for both SMR and HTGR technologies, while securing between 50–80% of the market associated domestic deployment of these technologies. These assumptions are consistent with those used in previous EINA studies for nuclear generation technologies.

Nuclear energy business opportunity analysis

Gross Value Added (GVA)

All GVA and Jobs analysis has been produced on the basis of technologies assessed in the scope of the EINAs (i.e. SMRs and HTGRs). Jobs and GVA estimates presented reflect only these technologies and should not be interpreted as whole nuclear sector jobs and GVA estimates. The report has noted significant existing activity and employment within the UK nuclear sector, which is not reflected in the figures below. This explains why GVA and employment impacts are only observed from 2035 onwards, as they only relate to deployed SMRs and HTGRs within modelled scenarios.

As Figure 4 shows, the business opportunities calculators suggest that, assuming a 'medium' level of innovation, the GVA contribution of these nuclear technologies will increase broadly over the period, but with a sawtooth profile. The profile reflects when the systems modelling suggests that generation capacity will be under construction, which provides an additional 'pulse' of economic activity reflecting the importance of capital costs for these technologies. The figure also shows that the GVA contribution is highest in the High Diversification scenario, reaching around £1.8 billion per year by 2050, and tends to be lower in the alternative scenarios, for example reaching only £0.5 billion per year by 2050. This reflects assumptions underlying the High Diversification scenario, which favour domestic energy supply and a higher level of diversity in electricity generation technologies.

[52] Utility Dive (2024) Global small modular reactor pipeline hits 22 GW, with US leading the market: WoodMac

[53] After the completion of the business opportunities calculators, the IEA released a report 'The Path to a New Era for Nuclear Energy' which projects total SMR capacity of 120GW in 2050 in its Announced Pledges Scenario. This compares with around 170 GW using the assumptions on which the calculator is based. As discussed below, in most scenarios, they systems modelling does not suggest that HTGR will penetrate the UK market and so it is also assumed that this will not penetrate the global market.

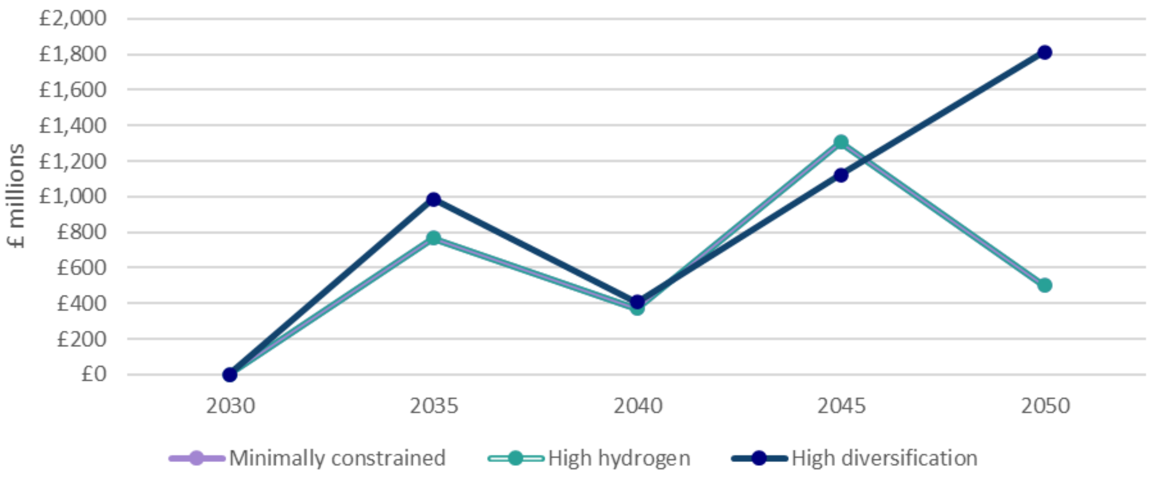

Figure 4: GVA by scenario for SMRs and HTGRs
Notes: The figure reports outputs associated with a medium level of innovation. The systems modelling suggests an identical deployment of these technologies in the Minimally Constrained and High Hydrogen scenarios, leading to an identical GVA contribution. As such the line for the Minimally Constrained scenario is not visible.

In the medium innovation level, all GVA is derived from SMRs, with the systems modelling suggesting that the high cost of HTGRs at this level of innovation throughout the period means that it is unlikely to be deployed. It therefore generates no GVA. HTGR technologies only get deployed and generate GVA in the high innovation/High Diversification scenario. However, even in this scenario/innovation level combination, the GVA contribution of HTGRs is only around 50% that of SMRs in 2035, falling to around 10% in 2050.

Figure 5 shows the relative importance of the domestic and export markets in generating GVA under the agreed assumptions. It suggests that successfully harnessing export market opportunities can provide a degree of stability if UK deployment of these technologies follows the irregular deployment pattern suggested by the systems modelling. GVA associated with export markets is expected to contribute to 20% or less of the total GVA from these technologies in 2035 and 2045, when the systems modelling suggested construction activity associated with UK-based deployment may be peaking. By contrast, in 2040 and – for the Minimally Constrained and High Hydrogen scenarios in 2050 – export markets account for a much greater share of the expected GVA[54].

[54] As noted above, some recent analysis from the IEA suggests that the global deployment of SMRs may be more modest than assumed in this analysis. Keeping everything else the same, this smaller global deployment would reduce the proportion of jobs associated with the export market.

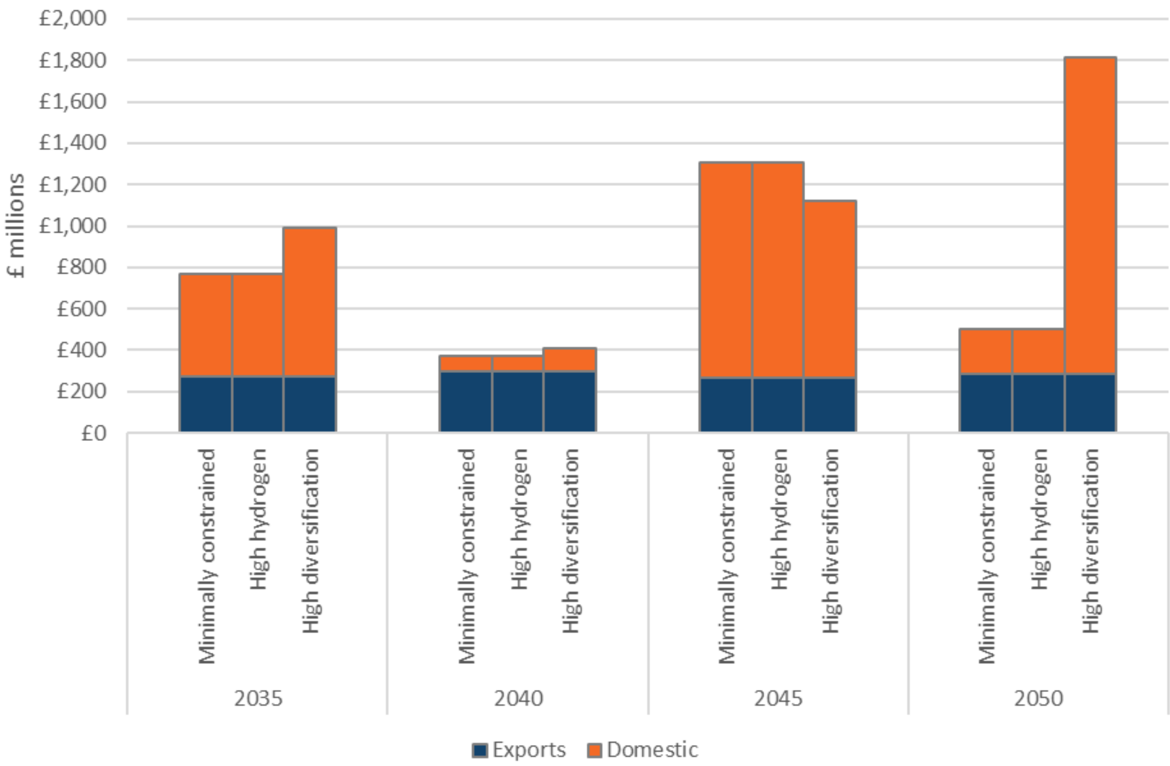

Figure 5: GVA by scenario by market for SMRs and HTGRs
Notes: The figure reports outputs associated with a medium level of innovation.

Figure 6 illustrates the projected variation in GVA contributions over time across different scenarios and levels of innovation. The analysis indicates that in certain years, there is minimal difference in GVA between innovation levels—for example, across all three scenarios in 2040 and within the Minimally Constrained and High Hydrogen scenarios in 2050. In some cases, higher levels of innovation correlate with greater GVA contributions, as observed in the High Diversification scenario in 2035. However, there are also instances where lower innovation levels are associated with higher GVA contributions, most notably in 2045 and in 2050 under the High Diversification scenario.

This counterintuitive outcome in these years/scenarios is driven by the relationship between costs and economic activity. Higher costs, provided they continue to be met by consumers, imply a higher level of economic activity per unit of electricity generated, which shows up as a higher GVA contribution. In the years and scenarios for which the GVA contribution in the low innovation level is larger than the high innovation levels, the cost reductions associated with high innovation does not result in a sufficiently large increase in deployment to offset this effect.

It should be noted that the potential impact that higher or lower electricity system costs may have on the output, and hence GVA contribution, of other sectors in the economy is not captured in this analysis.

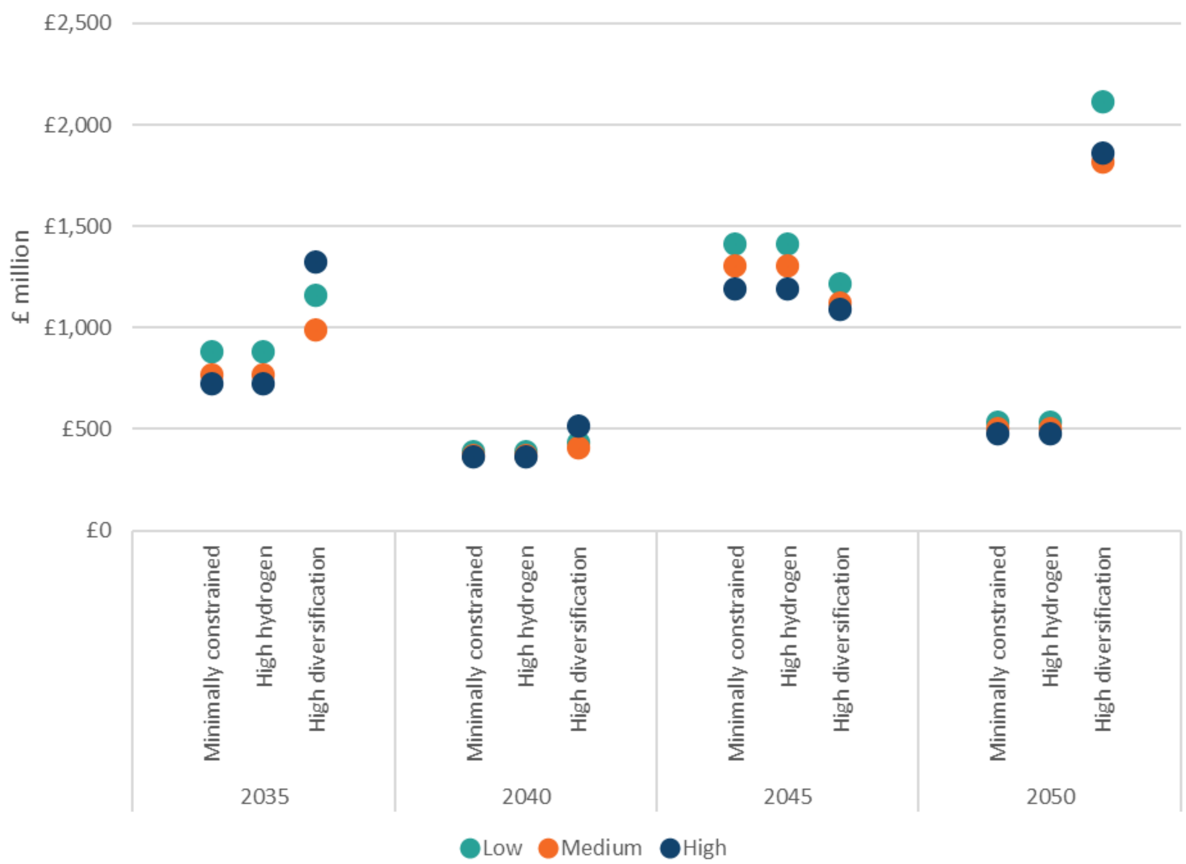

Figure 6: GVA by scenario for low, medium and high innovation levels for SMRs and HTGRs

Direct and indirect jobs

Figure 7 shows that supported employment follows the same general trend as for GVA. By 2035, assuming a medium level of innovation, these technologies are expected to support between 10,000 – 15,000 jobs in the UK. This falls as the systems modelling analysis suggests new deployment falls in the period to 2040, before picking up in the period to 2045 when supported employment is between 17,000 and 19,000. In the Minimally Constrained and High Hydrogen scenarios, there is a second drop in employment between 2045 and 2050 as construction and related jobs associated with new deployment are no longer required, but the additional deployment of these technologies in the High Diversification scenario takes supported employment to a peak of around 28,000 people in 2050. In those years/scenarios where employment is high – because of the construction activity associated with new deployment – direct jobs account for a relatively larger share of jobs of between 50-60%. This falls to closer to 35-50% in years/scenarios where absolute employment is lower and mainly related to operation and maintenance activity. This reflects the greater employment intensity of the supply chain for operation and maintenance activities compared to construction activities.

As with the GVA analysis, with a medium level of innovation, all the supported employment is associated with the deployment and operation of SMRs. The only case where employment is supported by HTGRs is in the high innovation cases, where employment supported by the HTGRs varies between around 1,500 (in 2040) and 6,500 (in 2035) jobs over the period between 2035 and 2050. In these cases, the employment supported by HTGRs is never more than around 50% of that supported by SMRs, and by 2050 is only around 12% of the SMRs supported employment level.

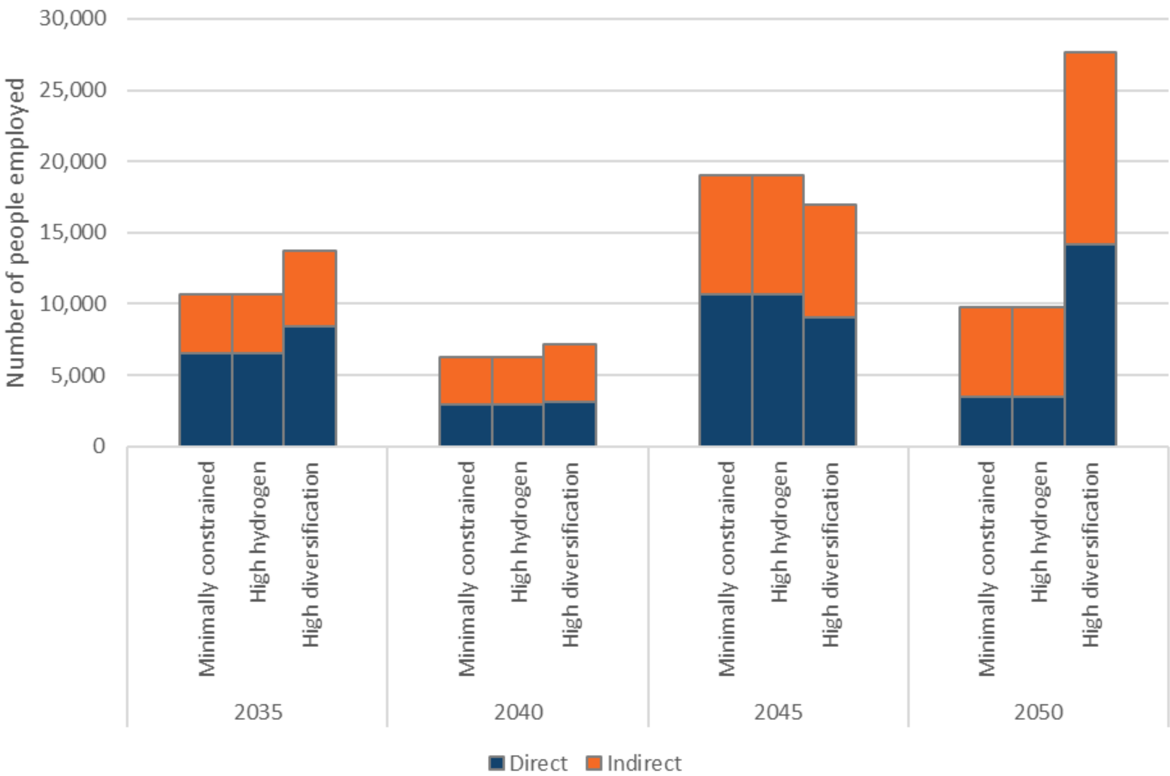

Figure 7: Total jobs supported by scenario by direct vs indirect for SMRs and HTGRs

Figure 8 shows the breakdown of employment by domestic/export market looking specifically at 2040 and 2050 and for the medium innovation level. It shows that, across the three modelled scenarios, at least 50% of employment (equivalent to at least 5,000 jobs in both years) is associated with domestic deployment of SMRs. In the High Diversification scenario, where nuclear contributes more to the UK electricity mix, this rises to 70%/85% of the total number of jobs in 2035, falling to ~40% in 2040 as limited UK deployment takes place in that year, and increasing back up to ~85% in 2050. This is equivalent to around 10,000, 3000 and 24,000 jobs being supported by the domestic market in these three years.

Building on the discussion above, Figure 9 illustrates the projected distribution of employment across cost categories, in 2040 and 2050. In 2035, all employment is expected to be associated with construction activities, as the systems modelling indicates that investments will not yet be operational at this stage. In 2040 CAPEX accounts for approximately 65% of employment with about 4,000 jobs supported. By 2050, employment related to operation and maintenance is projected to account for approximately 5,500 jobs, representing more than half of total employment in the Minimally Constrained and High Hydrogen scenarios. However, under the High Diversification scenario, additional investment in this technology between 2045 and 2050 results in a significantly greater share of construction-related jobs in 2050. In this scenario, construction-related employment is expected to reach approximately 22,000 jobs, accounting for around 80% of total employment.

It is important to note that the variation in deployment between the High Diversification scenario and the Minimally Constrained and High Hydrogen scenarios is much more evident in the differences in construction employment between these scenarios, with the differences in employment associated with operations and maintenance across scenarios being much less marked. This highlights the capital-intensive nature of this technology, which in turn translates into a high employment intensity during the construction of these assets.

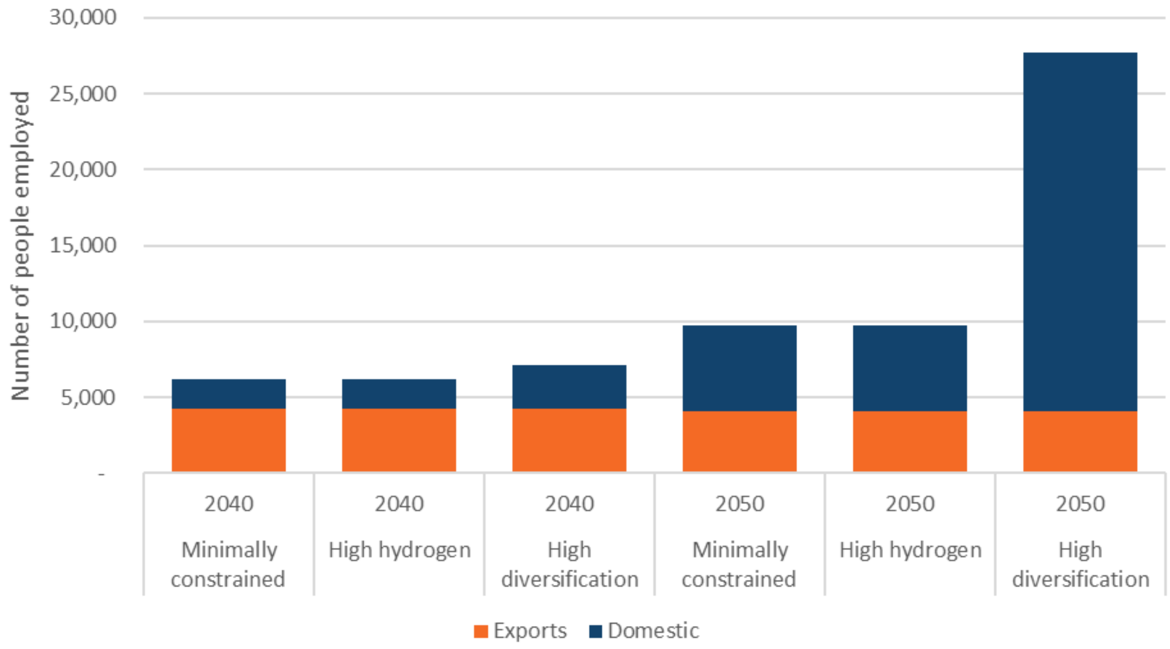

Figure 8: Total jobs supported (direct + indirect) by scenario by market for SMRs and HTGRs

Notes: The figure reports outputs associated with a medium level of innovation.

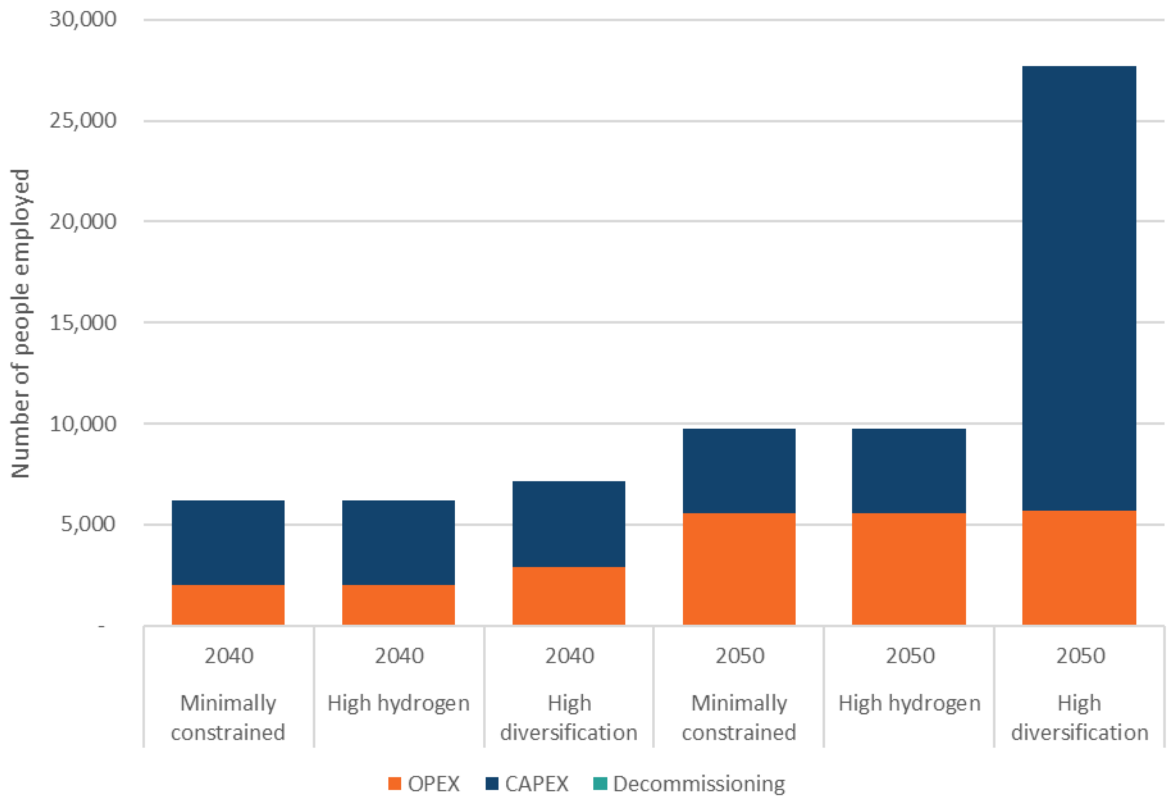

Figure 9: Total jobs supported (direct + indirect) by scenario by cost category for SMRs and HTGRs

Notes: The figure reports outputs associated with a medium level of innovation.

Finally, Figure 10 below, shows the possible distribution of supported direct jobs in 2050, illustrates that the development of this technology can support jobs across wide range of different occupations. The three occupations which account for the largest number of supported jobs are managers, directors and senior officials, those in the skilled metals trade, and process, plant and machine operatives. In the High Diversification scenario, the result suggests there could be more than 2,500 people in each of these occupation categories in 2050[55].

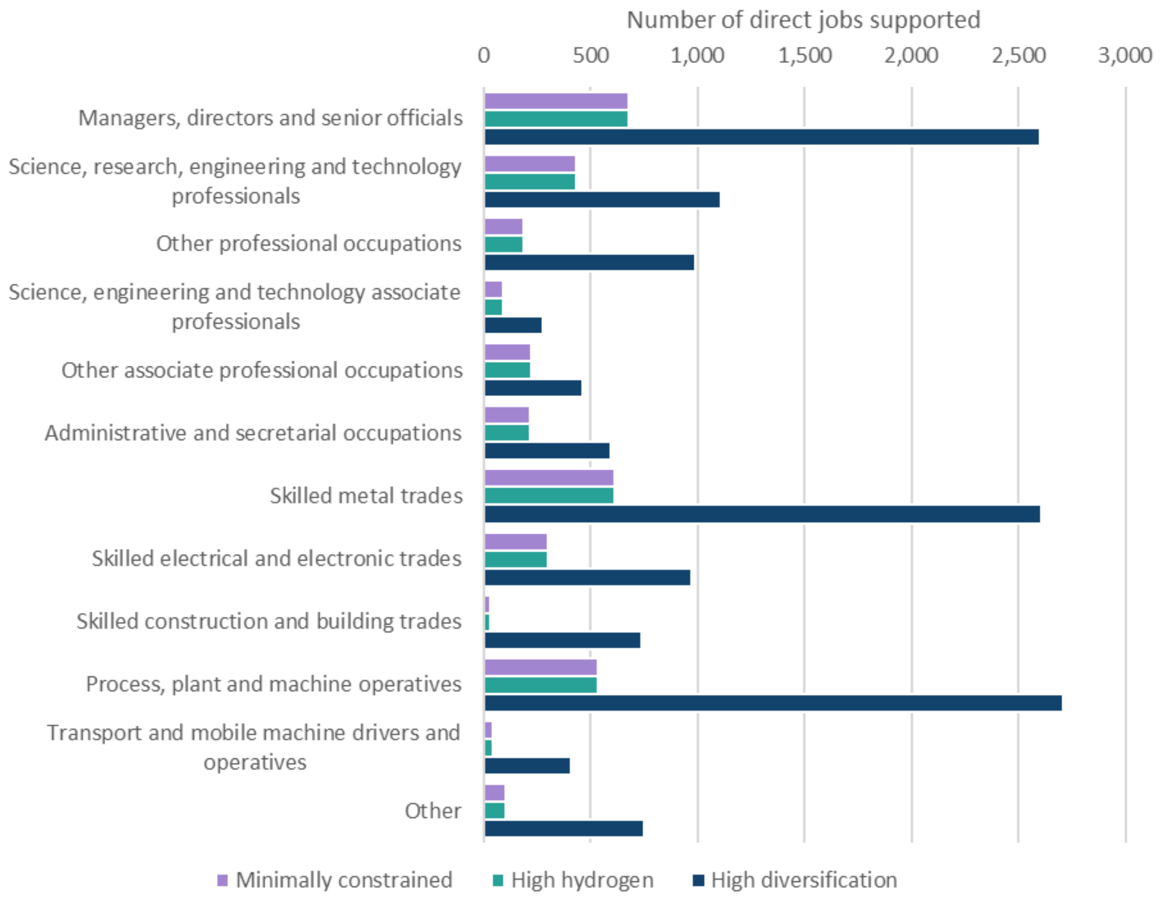

Figure 10: Direct jobs supported by scenario by occupation type in 2050 for SMRs and HTGRs

Notes: The figure reports outputs associated with a medium level of innovation. For the purposes of this analysis, the 412 4-digit SOC codes have been aggregated to 15 SOC groupings. See EINAs Technical Methodology note for more details on this aggregation. In Figure 10 the heading ‘other’ covers the following 4 SOC groupings: elementary occupations, other skilled trade occupations, sales and customer service occupations and caring, leisure and other service occupations.

[55] Note that this analysis assumes that the construction, operation and maintenance of SMR will require the same occupational profile throughout the period.

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