Energy Innovation Needs Assessment

Sub-theme report: Nuclear fission

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Contents

The views expressed in this report are the authors' and do not necessarily reflect those of the Department for Business, Energy and Industrial Strategy.

Acronyms and abbreviations

Table 1. **Key acronyms and abbreviations**

Acronym/abbreviation	Definition
AMR	Advanced Modular Reactor
BEIS	Department for Business, Energy & Industrial Strategy
CAPEX	Capital Expenditure
CCUS	Carbon Capture, Usage and Storage
EINA	Energy Innovation Needs Assessment
EPCm	Engineering, Procurement, and Construction Management
ESC	Energy Systems Catapult
ESME	Energy System Modelling Environment
EU	European Union
Gen III	Generation III
GHG	Greenhouse Gas
GVA	Gross Value Add
HTGR	High-Temperature Gas-Cooled Reactor
IEA	International Energy Agency
LCOE	Levelised Cost of Energy
MW	Megawatt
NDA	Nuclear Decommissioning Authority
O&M	Operations and Maintenance
OPEX	Operating Expenditure
RCA	Revealed Comparative Advantage
RD&D	Research, Development and Demonstration
RoW	Rest of the World
SFR	Sodium-cooled Fast Reactors
SMR	Small Modular Reactor
TINA	Technology Innovation Needs Assessment

Glossary

Table 2. **Key terms used throughout this report**

Term	Definition
Learning by doing	Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards which tend to increase in direct proportion to capacity increases.
Learning by research, development and demonstration	Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D); increases with spend in RD&D and tends to precede growth in capacity.
Sub-theme (relevant level for optional EINA reports)	Groups of technology families which perform similar services which allow users to, at least partially, substitute between the technologies. For example, a variety of technology families (heat pumps, district heating, hydrogen heating) have overlapping abilities to provide low-carbon thermal regulation services and can provide flexibility to the power system.
System value and Innovation value	Estimates of change in total system cost (measured in £ GBP, and reported in this document as cumulative to 2050, discounted at 3.5%) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies are compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas targets. Energy system modelling is a vital tool in order to balance the variety of interactions determining the total system costs. Innovation value is the component of system value that results from research and development (rather than from 'learning by doing').
Technology family	The level at which technologies have sufficiently similar innovation characteristics. For example, heat pumps are a technology family, as air-source, ground-source and water-source heat pumps all involve similar technological components (compressors and refrigerants). Electric vehicles are also a technology family, given that the battery is a common component across plug-in hybrids and battery electric vehicles.
Gross Value Add	Gross Value Add (GVA) measures the generated value of an activity in an industry. It is equal to the difference between the value of the outputs and the cost of intermediate inputs.

Introduction

Box 1. **Background to the Energy Innovation Needs Assessment**

The Energy Innovation Needs Assessment (EINA) aims to identify the key innovation needs across the UK's energy system, to inform the prioritisation of public sector investment in low-carbon innovation. Using an analytical methodology developed by the Department for Business, Energy & Industrial Strategy (BEIS), the EINA takes a system-level approach, and values innovations in a technology in terms of the system-level benefits a technology innovation provides.[1] This whole system modelling in line with BEIS's EINA methodology was delivered by the Energy Systems Catapult (ESC) using the Energy System Modelling Environment (ESME^{TM}) as the primary modelling tool.

To support the overall prioritisation of innovation activity, the EINA process analyses key technologies in more detail. These technologies are grouped together into sub-themes, according to the primary role they fulfil in the energy system. For key technologies within a sub-theme, innovations and business opportunities are identified. The main findings, at the technology level, are summarised in sub-theme reports. An overview report will combine the findings from each sub-theme to provide a broad system-level perspective and prioritisation.

This EINA analysis is based on a combination of desk research by a consortium of economic and engineering consultants, and stakeholder engagement. The prioritisation of innovation and business opportunities presented is informed by a workshop organised for each sub-theme, assembling key stakeholders from the academic community, industry and government.

This report was commissioned prior to advice being received from the CCC on meeting a net zero target and reflects priorities to meet the previous 80% target in 2050. The newly legislated net zero target is not expected to change the set of innovation priorities, rather it will make them all more valuable overall. Further work is required to assess detailed implications.

[1] The system-level value of a technology innovation is defined in the EINA methodology as the reduction in energy system transition cost that arises from the inclusion of an innovation compared to the energy system transition cost without that innovation.

The nuclear sub-theme report

The nuclear energy sub-theme analysis focusses exclusively on nuclear energy, covering three categories of nuclear power: Generation III (Gen III), Small Modular Reactors (SMRs) and Advanced Modular Reactors (AMRs). These technologies, with different deployment timelines and energy system benefits, present important innovation opportunities to bring system benefits. Nuclear fusion is out of scope as technology remains in early development and experimental phase.

Gen III reactors are advanced versions of Generation II designs, which were built in the UK until the 1990s and are currently in use. Gen III reactors typically have improved fuel technology, superior thermal efficiency, passive safety systems and standardised design for reduced maintenance and capital costs. Gen III+ reactors are similar in design to Gen II but have more advanced safety systems.

SMRs are reactors under 300-500 MW which have been built using modular techniques. The ideal size is a balance between manufacturing needs and economies of the reactor. SMRs typically use Gen III technology and have deployment times estimated around 2030.

AMRs are considered "revolutionary" in design, as opposed to "evolutionary", and as such qualify as a new technology. They can be of small capacity, or full-scale nuclear plant projects, and can be modularised. Reactor types and types of fuel vary significantly depending on the design. AMRs differ from conventional reactors, which use pressurised or boiling water for primary cooling. AMRs aim to maximise the amount of off-site factory fabrication and can also provide different benefits:

- Low-low cost electricity generation.
- Increased flexibility.
- Increased functionality (heat output for district heating or production of hydrogen).

There is a variety of technologies within AMRs and some are closer to deployment than others. Some reactors could be deployed in the 2030s while others such as sodium-cooled reactors could become operative from the 2040s onwards.

This report has four sections:

- **Nuclear and the whole energy system:** Describes the role of nuclear fission in the energy system, based on ESME modelling performed by the ESC.
- **Innovation opportunities:** Provides lists of the key innovations available within nuclear fission, and their approximate impact on costs.
- **Business opportunities:** Summarises the export opportunities of biomass and bioenergy, the GVA and jobs supported by these opportunities, and how innovation helps the UK capture the opportunities.

- **Market barriers to innovation:** Highlights areas of innovation where market barriers are high and energy system cost reductions and business opportunities significant.

Key findings

Innovation areas in nuclear fission

The main innovations for the nuclear sector are identified below. The list is not a substitute for a detailed cost reduction study. Rather, it is a guide for policymakers on key areas to be considered in any future innovation programme design.

The innovation priorities below select individual or groups of the top scoring innovations. Table 3 maps the top scoring innovations to individual technology components, and Table 6 sets out the full list of innovations and their scores.

- **Digitisation (Gen III, SMRs, AMRs):** Using the most appropriate digital technology at each life cycle stage, from design to construction to operation to decommissioning. Rapid data collection and analysis through digital deployment can lead to improved diagnostics which enhance the understanding of operations and safety. Digitisation can also inform design optimisations early, thus reducing the embedment of issues throughout the nuclear power plant fleet.
- **Modularisation (SMRs, AMRs):** This innovation reduces risk and costs in manufacturing and construction, improving the route to build and diminishing the overall cost.
- **Design simplification (SMRs, AMRs):** Plant design completion prior to starting construction provides significant opportunities for certainty of cost forecast. Risks can also be designed out at an early stage, by incorporating inherent safety features such as eliminating a core meltdown scenario in simplified plant designs. Design simplification can be enriched by innovations in digitisation and modularisation.
- **Reduced downtime fuels and components (Gen III, SMRs, AMRs):** Innovative fuels that last longer and components and systems designed to maximise productivity all reduce downtime of nuclear plants.
- **Flexible output (AMRs):** Nuclear energy has traditionally been used as a baseload source of energy. Innovations in different types of AMR reactor allow for a range of different benefits including output flexibility and functionality (including heat output and/or production of hydrogen).

Business opportunities for the UK

Innovation provides a business opportunity to grow nuclear-related exports, contributing up to £1.3 billion of GVA per annum in the 2030s, and £0.7 billion of GVA per annum by 2050. In the business opportunities section below, GVA and jobs results are set out by component (Table 7).

- Two key strengths for the UK are exports related to the fuel cycle and decommissioning, which combined are roughly half the business opportunity. Although decommissioning is expected to peak in the 2030s given the age profile of the current nuclear fleet.
- To fully unlock the export opportunity around nuclear technology, the broader UK nuclear supply chain must be developed, likely through the export of a UK reactor design, possibly an SMR.
- Domestic business opportunities can contribute around £9.6 billion per annum in GVA and support 130,000 jobs by 2050 (Table 8). This is significantly larger than export opportunities primarily because of the GVA from services that are not traded extensively, such as decommissioning and waste management.

Market barriers to innovation in the UK

Opportunities for HMG support exist when market barriers are significant, and they cannot be overcome by the private sector or international partners. In the market barriers section below, the barriers are set out by component, where possible (Table 9). The main market barriers identified by industry relate to:

- The UK National Policy Statement only provides cover to seek development consent for Gen III reactors deployable by 2025 and needs more clarity for non-Gen III reactors. This reduces incentives for UK firms to develop SMRs, as securing developing consent for a project in the UK is riskier.
- Any uncertainty over future fuel cycles may reduce incentives for innovation in waste management and storage.
- For newly designed plants, decommissioning activities occur far in the future, beyond 45 years, and are therefore heavily discounted. This discourages innovation for cost reduction in the design stage.
- Site-specific certification is an important cost driver and streamlining or standardising certain processes where possible would contribute to the timely development of nuclear reactors in the future.
- The high capital cost nature of nuclear technology and long timescales involved discourage private sector investment in innovation. A high market perception of risk in the sector further increases the cost of finance and de-risking is difficult to demonstrate.

Key findings by component

Government support is justified when system benefits and business opportunities are high, but market barriers prevent innovation.

Table 3. **Cost and performance of fixed nuclear fission (see key to colouring below)**

Overall statistics for nuclear fission: System value = £18.8 billion (range: £14.9-29.4 billion), 2050 export opportunity (GVA) = £0.7 billion, 2050 potential direct jobs supported by exports = 8,300				
Component	**Main innovation**	**Business opportunities**	**Market barriers**	**Strategic assessment**
Mining, processing, enriching, fabricating	Development of new fuel concepts	Medium-low	Moderate	Innovations in fuels complement reactor development and offer opportunities for cost reduction and increased operational efficiencies. Development of niches in the fuel cycle is a significant business opportunity for the UK (maintaining the current comparative advantage). Without government intervention, innovation will likely occur at lower scale and speed.
Capex– component	Modularisation and design simplification	Low	Severe	Innovations in modularisation and design simplification allow for reductions in risks and costs early on. Standardisation of requirements across different sites would allow standardisation of components, and other measures to reduce financial risk will reduce costs. Without government intervention, innovation will likely occur far below the optimal level with few commercial examples.
Capex – materials	Construction materials optimisation	N/A	N/A	Innovations in construction material optimisation offer cost reduction in plant build and waste minimisation. Innovation requirements are low priority, and business opportunities and market barriers are more directly related to the wider construction industry and hence not assessed.
Capex – construction	Modular and digital construction techniques. Optimised Commercial Off the Shelf engineering	Low	Severe	Innovations in construction techniques optimise the route to build and allow for more efficient resources use. Key areas of innovation lie in Capital Expenditure (CAPEX) construction, including modularisation and digitisation. Without government intervention, innovation will likely occur far below the optimal level with few commercial examples.

Component	Main innovation	Business opportunities	Market barriers	Strategic assessment
Operations and maintenance (O&M)	Digitisation	Low	Low	Innovations in digitisation can lead to improved diagnostics, operability and performance monitoring. Innovation in O&M will likely continue without government intervention.
Decommissioning	Autonomous robotics, processes & thermal technologies	Low	Moderate	Innovations in robotics and processes allow for more efficient decommissioning operations and innovations in thermal technologies can speed up waste decomposition. Decommissioning is a meaningful UK strength, particularly in services. Without government intervention, innovation will likely occur at lower scale and speed.
Waste management	Advanced fuel recycling, reprocessing and assessment.	Low	Low	Innovations in fuels offer opportunities for more efficient waste management. Without government intervention, innovation will likely continue.

Source: *Vivid Economics, Carbon Trust*

Note: *The main innovations per component are the innovations that score highest in the innovation inventory. This table only includes component-specific market barriers. Cross-cutting barriers are included in the market barriers section below.*

Table 4. **Key to colouring in the key findings per component**

Business opportunities	**Market barriers**
High: more than £1 billion annual GVA from exports by 2050	**Critical:** Without government intervention, innovation, investment and deployment will not occur in the UK.
Medium-High: £600-£1,000 million annual GVA from exports by 2050	**Severe:** Without government intervention, innovation, investment and deployment are significantly constrained and will only occur in certain market segments / have to be adjusted for the UK market.
Medium-Low: £200-£600 million annual GVA from exports by 2050	**Moderate**: Without government intervention, innovation, investment and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
Low: £0-200 million annual GVA from exports by 2050	**Low:** Without government intervention, innovation, investment and deployment will continue at the same levels, driven by a well-functioning industry and international partners.

Source: Vivid Economics, Carbon Trust

Box 2. **Industry workshop**

A full-day workshop was held on 14th December 2018 with key delegates from the nuclear industry, academic community and research agencies. Key aspects of the EINA analysis were subjected to scrutiny, including innovation opportunity assessment, and business and policy opportunities assessment. New views and evidence were suggested; these have been incorporated into an update of the assessments.

The views of the industry experts were included in the innovation's assessment. In addition, several contextual issues were raised at the workshop:

- The key categories of nuclear include legacy nuclear (Gen II), the current Gen III of new build, SMRs and AMRs. SMRs are based on existing and AMR technology, and there is a big role for innovation in their design. For AMRs, it is not yet clear what the objectives of this technology are in terms of their role in the energy system. Aspects such as heat generation capabilities and flexibility are being assessed as the technology develops, and therefore innovations could be tailored to meet broad energy system objectives.
- Innovation is broader than technology and includes areas that raise productivity and increase efficiency, such as delivery models, contracting mechanisms and high performing culture among others. These innovations can lead to cost reductions on a shorter timescale than new technology.
- The cost and performance assumptions that went into the energy system modelling for this study (to derived system-level innovation value) were based on January 2018 data and therefore do not reflect more recent research that might suggest lower nuclear costs over time.
- Business opportunities come from having a national reactor design and the complete supply chain to sell overseas. It is difficult to develop export markets in isolation from this.

These overarching messages, while not fitting within the limited scope of the EINA framework, are important for consideration in setting innovation policy.

Nuclear fission and the whole energy system

Current situation

Old nuclear stock is currently decommissioned. Nuclear power currently supplies around 20% of the UK's electricity demand. Fifteen nuclear reactors, totalling 9.3 GW capacity accounted for 11.5% of total generation capacity in 2017.[2] However, all this capacity will be decommissioned in the 2020s and early 2030s, unless the licences of currently operating plants are extended. The Nuclear Decommissioning Authority (NDA) owns 17 sites across the UK. Estimated costs of decommissioning are £121 billion spread across the next 120 years.[3] Decommissioning also affects skills capability as the workforce retires. The necessary skilled workforce requires a long time to reach maturity and is vulnerable to high turnover rates and obsolescence.

New Generation III nuclear plans are being rolled out. Construction has commenced on the first-Generation III plants. Hinkley Point C is currently being built by EDF Energy. The company's estimates suggest that on completion it will create over 25,000 job opportunities and avoid 9 million tonnes of carbon dioxide emissions a year.[4] Hinkley Point C is currently the only plant with uninterrupted construction plans in the UK, as Hitachi's Wylfa Newydd plant suspended construction in January 2019. Sizewell C and Bradwell, proposed by EDF Energy and China General Nuclear Power Corporation, are both under final investment decision.[5]

Future deployment scenarios

Under the high innovation scenario for nuclear (per BEIS's EINA analytical methodology), whole systems analysis indicates that:

[2] BEIS (2018) Energy Trends https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770773/Energy_Trends_December_2018.pdf
3 Nuclear Decommissioning Authority (2018) Nuclear Provision corporate report https://www.gov.uk/government/publications/nuclear-provision-explaining-the-cost-of-cleaning-up-britains-nuclear-legacy/nuclear-provision-explaining-the-cost-of-cleaning-up-britains-nuclear-legacy
[4] EDF Energy Hinkley Point C https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c and https://www.edfenergy.com/about/climate-change-solutions/hinkleypointc
[5] https://www.edfenergy.com/energy/nuclear-new-build-projects/sizewell-c and https://bradwellb.co.uk/

- **35 GW of Gen III nuclear fission would be deployed by 2050.** Nuclear fission is a core component in decarbonising the electricity system in ESME model runs.[6] Under this EINA high innovation scenario the ESME modelling implies system-optimal deployment levels of circa 7 GW of Gen III by 2030, 22 GW by 2040 and 35 GW by 2050. This constitutes a build-out rate of up to 1.5 GW per annum between 2030 and 2050, equivalent to approximately one Hinkley Point C plant every two years between 2030 and 2050.

- **Initial SMR deployment would be expected by 2030.** Prototypes are already being developed in the worldwide stage and some designs are very advanced. Under the EINA high innovation scenario for SMRs, the ESME modelling implies a build-out rate of 0.8 GW per annum between 2030 and 2040, increasing to around 1.1 GW per annum between 2040 and 2050. Design could address future system requirements including flexibility and heat.

- **AMRs would be expected to be deployed earlier than 2050.** However, evidence of current developments internationally indicates that some high-temperature gas-cooled reactors (HTGRs) and sodium-cooled fast reactors (SFRs) could be operative earlier.[7] Nuclear is also an important provider of power system inertia, which is an important electricity system need. However current/Gen III technologies in the UK may be poorly suited for dealing with power fluctuations on the grid and complement intermittent renewable sources. SMRs and AMRs are being designed considering flexibility of supply and are expected to compensate for renewables' intermittency.

[6] It also features significantly in CCC analysis.
[7]There are prototypes under development in other countries such as the USA, China and South Korea https://www.nrc.gov/docs/ML1035/ML103560222.pdf; https://www.gen-4.org/gif/upload/docs/application/pdf/2017-11/gif-sfr-safetyassessment-20170427_final.pdf, https://www.sciencedirect.com/science/article/pii/S1738573316000140

Box 3. **System modelling: nuclear power in the UK energy system**

Following the BEIS EINA methodology, whole energy system modelling was conducted using the ESME^{TM} Version 4.4 to estimate where innovation investments could provide most value to support UK energy system development.

ESME is a peer-reviewed whole energy system model (covering the electricity, heat and transport sectors, and energy infrastructure) that derives cost-optimal energy system pathways to 2050 meeting user-defined constraints, e.g. 80% greenhouse gas (GHG) emissions reduction.[8] The model can choose from a database of over 400 technologies which are each characterised in cost, performance and other terms (e.g. maximum build rates) out to 2050. The ESME assumption set has been developed over a period of over 10 years and is published.[9] ESME is intended for use as a strategic planning tool and has enough spatial and temporal resolution for system engineering design.

Like any whole system model, ESME is not a complete characterisation of the real world, but it is able to provide guidance on the overall value of different technologies, and the relative value of innovation in those technologies.

The EINA Methodology prescribes the approach to be taken to assess the system-level value of technology innovation. This involves creating a baseline energy system transition without innovation (from which a baseline energy system transition cost is derived), and on a technology-by-technology basis assessing the energy system transition cost impact of “innovating” that technology. Innovation in a technology is modelled as an agreed improvement in cost and performance out to 2050.

For the EINA analysis, the technology cost and performance assumptions were derived from the standard ESME dataset[8] as follows:

- In the baseline energy system transition, the cost and performance of all technologies is assumed to be frozen at their 2020 levels from 2020 out to 2050.
- The “innovated” technology cost and performance for all technologies are assumed to follow the standard ESME dataset improvement trajectories out to 2050 (these are considered techno-optimistic).
- In the case of nuclear technologies, the assumed “innovated” installed cost reduction is around 16% between 2020 and 2050 values for Gen III systems, and 25% for SMRs.

Whole system analysis using the BEIS EINA methodology described above shows that there is significant value to the UK in continued (and accelerated) innovation in nuclear technology:

- Nuclear fission's role in the energy system is predominantly as a firm source of low-carbon power that can be provided at a large scale. Nuclear can also provide broader system services to the power grid (e.g. power system inertia), which are valuable in a system with high shares of variable renewables (wind and solar).
- An additional role for nuclear could be as a provider of heat, by capturing the waste heat from the nuclear power generation process and using it in, for example, district heating schemes. This is particularly relevant to SMRs where there is potentially greater locational flexibility than larger-scale reactors. In addition, some AMR technologies could provide high-temperature industrial process heat.
- Modelling conducted for this project suggests that innovation in SMRs (in combined electricity and heat delivery mode) could provide over three times more energy system value than innovation in Gen III technologies, ~£14 billion cumulative to 2050 (discounted at 3.5%).
- Some AMR technologies could generate hydrogen – this system value is not reflected in the current version of ESME and therefore not reflected in the deployment scenarios nor system benefit calculations.

The build-out of current/Gen III nuclear reactors is facing challenges. Reactors currently being built are facing cost increases, delays and/or suspensions in installation. Some suppliers have withdrawn from the UK market. These challenges reflect tensions between costs and deployment and the prices and stakes that HMG is willing to provide to industry.

Further work is required to estimate the value of innovations in nuclear technology, or how these estimates may change in the case of different energy system scenarios.

[8] More details of the capabilities and structure of the ESME model can be found at eti.co.uk/programmes/strategy/esme. This includes a file containing the standard input data assumptions used within the model.
[9] The ESME assumption set has been developed is published with data sources at https://www.eti.co.uk/programmes/strategy/esme

Box 4. **Learning by doing and learning by research**

The total system value follows from two types of technology learning:

- **Learning by doing** improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors such as the impact of standards which tend to increase in direct proportion to capacity increases.
- **Learning by research:** improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development and demonstration (RD&D). It increases with spend in RD&D and tends to precede growth in capacity.

The EINAs are primarily interested in learning by RD&D, as this is the value that the government can unlock as a result of innovation policy. Emerging technologies will require a greater degree of learning by RD&D than mature technologies. Academic work suggests that for emerging technologies around two-thirds of the learning is due to RD&D, and for mature technologies around one-third is due to RD&D.[10]

To reach a quantitative estimate of the system value attributable to RD&D, these ratios are applied to the system value. This implies that, as an emerging technology, around £12.4 billion of £18.8 billion system value for new nuclear follows from RD&D efforts. Note, this is an illustrative estimate, with the following caveats:

- The learning type split are intended to apply to cost reductions. However, in this study, they are applied to the system value. As system value is not linearly related to cost reduction, this method is imperfect.
- In practice, learning by research and learning by doing are not completely separable. It is important to deploy in order to crowd-in investment to more RD&D, and RD&D is important to unlock deployment.

These estimates are used in the EINA Overview Report to develop a total system value that results from innovation programmes across the energy system.

[10] Jamasb, Tooraj (2007). "Technical Change Theory and Learning Curves", The Energy Journal 28(3).

Innovation opportunities within nuclear fission

Introduction

Box 5. **Objective of the innovation opportunity analysis**

The primary objective is to identify the most promising innovation opportunities within nuclear fission and highlight how these innovations may be realised and contribute to achieving the system benefit potential described above. This section provides:

- A breakdown of the costs within nuclear energy across key components and activities.
- A list of identified innovation opportunities, and an assessment of their importance to reducing costs and deployment barriers.
- Deep dives into the most promising innovation opportunities.

In nuclear technology, innovation is crucial not only to reduce the present and future costs of the Gen III reactors which are expected to be deployed in the short- to medium-term, but also to allow the development of SMRs and AMRs. Without enough R&D investment to retain and expand UK expertise, it is unlikely that the country will be able to deploy and manage AMRs and SMRs effectively or enter into any strategic partnerships with other leading nuclear nations to develop joint IP and new technologies.

Despite the stigma that nuclear power carries in some segments of society due to concerns about safety, it retains majority support in the UK. However, the size and scope of nuclear endeavours makes it hard for any single nation to pursue them entirely on its own. The UK currently enjoys a position of possessing strong skills and knowledge with which to collaborate with other leading nuclear nations. These skills are expected to keep strengthening following government support to the sector through the Nuclear Innovation Programme.[11]

[11] BEIS, Funding for nuclear innovation https://www.gov.uk/guidance/funding-for-nuclear-innovation https://www.gov.uk/guidance/funding-for-nuclear-innovation

Cost breakdown

The price agreed for Hinkley Point C was £92.50/MWh over 35 years – higher than the latest offshore wind farms at £57.50/MWh. HMG has signed a 35-year contract to pay EDF's Hinkley Point C £92.50/MWh. This price is higher than the latest offshore wind farms at £39.65/MWh. However, nuclear has fewer balancing costs than renewables given its provision of base load electricity and it is a developed and known technology as opposed to recently developed offshore wind technology. Since signing the contract, EDF has signalled an increase in costs of around 8% and indicated that completion could be delayed 15 months for unit 1 and 9 months for unit 2. Hitachi was in negotiations HMG to agree a price of £75/MWh for their Wylfa Newydd site but has since halted construction in the face of a lack of agreement on project funding.

Seven key components of cost are identified for nuclear[12]:

- **Mining, processing, enriching, fabricating:** Full treatment of fuel prior to its use in a reactor, from extraction through to fabrication.
- **Capex - Components:** Main assemblies of the reactor system – reactor core, heat exchanger, containment vessel, pumps, turbines etc.
- **Capex - construction materials:** This refers to the costs of materials, principally steel and concrete, the building frame, and access infrastructure.
- **Capex - construction/installation and commissioning:** This covers the remaining capital costs of the build, including contingency and owner's fee.
- **O&M:** Operating costs including fixed costs and maintenance.
- **Waste management, processing, storage:** Long-term waste management.
- **Decommissioning:** Defueling and dismantling of the plant and the costs of the full decommissioning process.

The key Gen III and SMR cost components are construction and installation. Costs in Gen III and SMRs are mainly driven by CAPEX in construction, construction materials, and components. In the case of Gen III, they represent 79% of total costs, with the biggest contribution in construction, installation and commissioning, accounting for 41%. Similarly, in SMRs, total CAPEX represents 80%, with construction, installation, and commissioning arising to 41%. The rest of the cost structure has a similar distribution in both technologies.

AMRs' biggest cost is CAPEX. Total CAPEX is the most relevant cost group for AMRs, accounting for 83%. The driver in the category for AMRs in general is CAPEX on the reactor, representing 44% of the total cost structure. However, as AMR technology is varied, so are the reactors for each technology, which may have different impacts in the overall capital cost.

[12] Based on EIA (2013), Gen IV Forum (2013), DECC (2013), NNL (2014), Carbon Trust analysis.

The rest of the cost breakdown follows a similar structure for all technologies. The second biggest cost after CAPEX is operations and maintenance, ranging from 9% to 13% for the three nuclear categories. These costs were followed by mining, processing, enriching and fabricating, decommissioning, and finally waste management, processing and storage.

Table 5. **Cost of fixed nuclear fission (% Levelised Cost of Energy (LCOE))**

	Component	Gen III	SMR	AMR
Component-specific	**Mining, Processing, Enriching, Fabricating**	5.5%	6.0%	6.4%
	Capex – Components	26.7%	26.9%	43.9%
	Capex - Construction materials	11.5%	11.6%	14.1%
	Capex – Construction/installation and Commissioning	40.9%	41.3%	24.9%
	O&M	13.2%	11.9%	9.1%
	Decommissioning	1.5%	1.6%	1.1%
	Waste Management, Processing, Storage	0.7%	0.7%	0.5%

Source: EIA (2013), Gen IV Forum (2013), DECC (2013), NNL (2014), Carbon Trust analysis

Decommissioning costs might be under-represented. There is some concern about the discounted rates usually utilised to calculate costs for decommissioning. Workshop feedback has suggested that the rates tend to be too low and lack accurate reflection of final costs at the end of nuclear life.

Costs are sensitive to construction timelines. Construction delays are the main reason behind nuclear cost increases. Advanced modelling and simulation, digitisation, Non-Destructive Testing, and other innovative technologies can help mitigate the risk of construction delays and overruns. Modular construction techniques can reduce the overall construction time, reducing nuclear costs considerably.

Unlike most technologies, nuclear costs have historically risen in the West. Nuclear cost reductions have always been contentious, with some studies indicating possible negative learning-by-doing, resulting in cost increases rather than decreases with additional deployment.[13] This can be partially explained by the increased safety requirements of new reactor models and can hopefully be ameliorated by advances in passive safety features, thermal efficiency, modularity, and other characteristics of all Gen III, SMR and AMR reactors. One should note that this phenomenal is predominantly associated with the West, with Japan and South Korea being able to realise cost reduction.[14]

ESME estimates potential for significant nuclear cost reductions. Based on ESME inputs there are cost reductions of 16% in Capex for both Gen III and AMR by 2050, while operating expenditure (OPEX) remains the same. However, in absolute terms, AMR is regarded to be more expensive with a Capex of £3,648/kW in 2050 versus £3,610 Capex for Gen III in 2020 and £3,040/kW in 2050. On the other hand, ESME assumes SMRs to reduce 25% of Capex by 2050 while OPEX also remains the same. Capex by 2050 is estimated at £3,525/kW. The system-level innovation values that are derived using BEIS's EINA Methodology are only realised if these levels of cost reduction are achieved in practice. The Nuclear Sector Deal targets a 30% cost reduction of nuclear new build projects by 2030.[15] ESME doesn't include this scenario, which shows higher cost reductions may be achieved at a sooner date than assumed by the model.

Inventory of innovation opportunities

Innovation opportunities in nuclear energy are highly dependent on the technology. Some cost-reducing innovations and innovations that overcome barriers are identified and grouped below within each category. These innovations do not represent an exhaustive list.

Gen III reactors provide limited technical innovation opportunity. This is because the design of the reactor is already locked in. The most promising cost reduction opportunities are:

- Operations and maintenance: innovations in monitoring, instrumentation, control systems, modelling techniques and data mining.

[13] Arnulf Grubler, The costs of the French nuclear scale-up: A case of negative learning by doing. Original Research Article, Energy Policy, Volume 38, Issue 9, September 2010, Pages 5174-5188.
[14] Local country specific benefits in cost reductions may not be transferrable to projects in the UK. Energy Technologies Institute ETI, (2018). The ETI Nuclear Cost Drivers Project: Summary Report. https://www.eti.co.uk/library/the-eti-nuclear-cost-drivers-project-summary-report
[15] Industrial Strategy: Nuclear Sector Deal https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/720405/Final_Version_BEIS_Nuclear_SD.PDF Industrial Strategy: Nuclear Sector Deal https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/720405/Final_Version_BEIS_Nuclear_SD.PDF

- Installation: Optimised Commercial-Off-The-Shelf (COTS) engineering helps reduce bespoke installation, bringing a unit into service promptly; building multiple units on a single site.
- Digitisation.

Innovations that improve safety are most significant in:

- Fuels: Gen III reactors can adopt advanced fuels, including accident tolerant, that are temperature resistant.
- Waste management: innovations allow for advanced qualification of waste forms, packing density, fuel recycling and assessment.
- Digitisation.

SMRs present their biggest cost reducing potential in innovations in:

- Design that addresses risk: simplicity of design allows for cost reduction.
- Modularisation: modular construction techniques and offsite construction reduce costs significantly compared to other technologies.
- Line manufacture: line manufacture of components yields economies of scale.
- Digitisation.

SMRs size de-risks deployment barriers are:

- The smaller scale of SMRs de-risks project planning and accelerates construction timelines.[16]

SMRs can also provide opportunities to address energy system needs:

- De-centralisation and off-grid energy generation capabilities: their smaller size allows for a more decentralised energy system including off-grid applications for remote communities.
- Heat co-generation for district heating.

Innovations adopted in SMRs, particularly modularisation, can be applied to AMRs.

Uses of AMRs are thought to be wide ranging. Uses range from on-grid and off-grid electricity generation at a lower cost than current nuclear, to broader system applications. These include heat co-generation for district heating, the ability to produce baseload heat for industrial applications, and hydrogen production.

AMR technology innovations offer opportunities for reducing costs and delivery risk in:

[16] Market framework for financing small nuclear https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/732220/DBEIS_11_-_Market_Framework_for_Financing_Small_Nuclear_EFWG_Final_Report_.pdf Market framework for financing small nuclear https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/732220/DBEIS_11_-_Market_Framework_for_Financing_Small_Nuclear_EFWG_Final_Report_.pdf

- Design simplification: key elements of design, such as safety, reuse, and construction modularity, allow to design-out risks and cut costs at an early stage. The requisite level of safety is achieved with fewer components, and hence lower costs.
- Reduced downtime: improvement in inspection techniques, monitoring and equipment optimisation (possible for Gen III and SMRs but most realisable for AMRs).
- Digitisation.
- Modularisation: as per SMRs, modular construction techniques and offsite construction reduce costs significantly compared with other technologies.

Innovations in AMR can also address energy system needs as follows:

- Flexible output, where thermal energy storage systems could be capable of storing heat output for many hours, hence allowing for system flexibility like those of gas boilers or gas turbines.
- Co-generation of heat for district heating.
- High-temperature heat for industry, where some AMRs could produce heat at high temperature, both improving electricity generation and facilitating industrial processes such as hydrogen production.
- Energy benefits through fuel use, where some AMRs could improve energy yield up to 300 times from the same amount of fuel use by earlier technologies. Also, spent fuel in Gen II and III can be used as new fuel in AMRs.[17]

Innovations in AMR can also provide opportunities to address deployment barriers through improved safety and security including:

- Accident tolerant: AMRs allow for the use of a variety of accident tolerant fuels in different reactors types. Some of them may not allow for any airborne release of radioactivity in the event of an accident.
- Some AMRs may offer the option to reuse their own spent fuel or consume the fuel of other nuclear reactors.
- Reduced operational waste discharge.
- Reactors could be designed to be factory sealed, delivered and retrieved after fuel depletion. Fuel cycles could also be inherently more proliferation-resistant.

Representatives of the nuclear sector discussed innovation opportunities.
Table 6 below contains examples of technical innovation opportunities in the nuclear sector. It groups technical innovations by broad category, describing which technology it applies to and the approximate timeframe for deployment. It was first

[17] Low-carbon Coordination Innovation Group: Technology Innovation Needs Assessment, Nuclear Fission (2016).)

developed by Frazer-Nash as a proposal of innovations mapping for nuclear fission. It is indicative and not exhaustive.

The industry experts attending the workshop discussed the contents of the table and offered feedback. The updated table was afterwards circulated amongst industry experts with the opportunity to provide further comments, which were included.

Prioritisation of cost reduction and barrier deployment was elaborated by the **Carbon Trust to reflect the importance of some innovations in the workshop interaction.** The magnitude of the contribution to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

An indicative timeframe for each innovation is provided. The timeframe given relates to the year the technology is deployed commercially at scale (gaining 10-20% market share).

Table 6. **Innovation mapping for nuclear fission**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Timeframe
Mining, Processing, Enriching, Fabricating	Fuels that remain in the reactor for longer increasing operational periods and require fewer nuclear power plants to deliver energy needs.	5	4	AMR, SMR	2030
	Fuels that can achieve higher burn-ups produce less high-level waste (HLW) per unit electricity generation and are compatible with direct disposal in a geological disposal facility.	3	4	AMR, SMR	2030
	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).	2	3	AMR	2030-40
	Development of fuel technologies that: reduce existing stocks, reduce the period that HLW remains active from hundreds of thousands of years to hundreds of years, and that deliver improved raw material utilisation.	2	3	AMR	2030-40
CAPEX – Components and systems	Advanced digital design, modelling and virtual reality with link to digital manufacturing.	5	3	SMR, AMR	2025-30
	Modularisation of systems to maximise factory fabrication and minimise on-site installation.	5	4	SMR, AMR	2030
	Design simplification that uses inherently safe and passive features and minimise engineered safety systems.	5	5	SMR, AMR	2025-30
	Advanced manufacturing to reduce cost and increase speed and reliability of components: Advanced machining; Additive manufacturing; Advanced joining; Advanced assembly, metrology, automation and virtual reality.	4	4	SMR, AMR	2030-40

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Timeframe
CAPEX – Components and systems	Reactor internals optimised for decommissioning: Can decay in ~35 years to low-level waste (LLW), does not contain long lived radionuclides, are able to outlast the reactor (operation and decommissioning phases) leading to no in-service interference.	2	3	SMR, AMR	2040-50
	Components and systems designed to maximise productivity: • Digitisation of components and systems • Parallel systems, meaning one on line and one on standby (under maintenance) • Wider use of robotics for in service inspection. Reduces reactor down time, allows component removal to optimise waste stream (i.e. remove while still LLW rather than intermediate-level waste (ILW)), allows 'in service' component inspection which may underpin any life extension decisions.	5	4	Gen III, SMR, AMR	2040-50
	Choice of coolant that in AMRs: • Operate at higher temperatures giving higher efficiency and a wider range of applications. • That have improved safety characteristics in loss of coolant accidents or large void reactivity coefficients. • Have lower environmental impact if released into the atmosphere or on final disposal.	4	3	AMR	2030-40
	Improved use of reactor energy generation with more flexibility and wider contribution to decarbonisation: • advanced power conversion cycles • district heating • hydrogen production • heat storage. Where appropriate Combined Circuit Gas Turbines (CCGT) to reduce power losses.	4	3	SMR, AMR	2040-50

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Timeframe
CAPEX – Construction and materials	Construction optimisation: • Waste minimisation • Reduction of cement content in construction • Maximise use of materials such as ground granulated blast-furnace slag • Maximise offsite construction • Onsite verification • Virtual design and advanced simulation. • Radio-scanning	2	3	SMR, AMR	2030-50
CAPEX – Construction installation and commissioning	Modular construction techniques to minimise work on site.	5	4	SMR, AMR	2025-2030
	Digital construction techniques, design simplification, efficient building.	5	4	SMR, AMR	2025-2030
	Supply chain-ready and able to support and deliver this phase – repeatable across other plants (e.g. they just roll from one to the next).	3	3	Gen III, SMR, AMR	2020
	Optimised Commercial Off the Shelf (COTS) engineering to reduce bespoke construction, installation and commissioning thus bringing a unit into service promptly. Requires a supply chain that is engaged and understands what COTS means to nuclear (through life availability, ability to maintain etc.).	4	3	Gen III, SMR, AMR	2020
Operations and Maintenance	Equipment that is optimised for reduced maintenance (routine and breakdown). Requires development of improved material, lubrication, electronics etc.	4	3	Gen III, SMR, AMR	2025
	Digitisation, upgrades in instrumentation and control systems.	5	3	Gen III, SMR, AMR	2020

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Timeframe
Decommissioning	Autonomous robotics and autonomous processes.	3	3	Gen III, SMR, AMR	2040
	Thermal technologies to speed up waste decomposition and reduce overall waste volume.	3	3	Gen III, SMR, AMR	2025
	Better classification to allow improved consignment to either decay storage or correct disposal option, and characterisation of waste such as depth of contamination in structures.	3	3	Gen III, SMR,	2025
	Waste packaging and storage.	3	3	AMR	2025
Waste Management	Advanced Qualification of waste forms.	3	4	Gen III, SMR, AMR	2020
	Packing Density.	3	4	Gen III, SMR, AMR	2020
	Storage Fluids.	3	4	Gen III, SMR, AMR	2020
	Fuel recycling (aqueous recycling, pyro processing).	3	4	Gen III, SMR, AMR	2020
	Fuel Cycle assessment.	3	4	Gen III, SMR, AMR	2020
Regulatory	Streamlined assessment of technology – time to deployment reduced.	3	3	AMR	2030-40
	Aligned regulation in moving from “first of a kind” to ”nth of a kind”	2	3	AMR	2040-50

Source: Frazer-Nash for BEIS, Appraisal

Innovation opportunity deep dive: Digitisation (Gen III, SMRs, AMRs)

Poor or unreliable plant performance data has been highlighted as a substantial problem by industry experts. Complex nuclear systems benefit from advanced analytics that provide detailed data insights. Digitisation entails using the most appropriate digital technology at each of the nuclear power plant life cycle stages to maximise the design, improve operability, and improve performance monitoring of operation.

Rapid data collection and analysis through digital deployment can lead to improved diagnostics, which enhances the understanding of operations and safety. It can also inform design optimisations early, thus reducing the embedment of issues throughout the nuclear power plant fleet. However, digital security needs to develop at the same speed as the technology.

Digitisation software influences many areas of nuclear technology, including the activities of asset managers, designers, builders, suppliers, customers, and regulators. This innovation is applicable to Gen III, SMRs and AMRs, and some digitisation solutions are already available for the nuclear sector.

Innovation opportunity deep dive: Modularisation (SMRs, AMRs)

This innovation reduces risk and costs in manufacturing and construction, improving the route to build and diminishing the overall cost. Modularisation can be paired with single-site building, providing more effective construction that benefits from efficient resource use, such as shared infrastructure and materials, labour specialisation, and time planning. It permits a more rapid transition from “first of a kind” to “n^{th} of a kind”.

Modularisation can inform the activities of owners, designers, builders, and operators. It also has the capability of improving production efficiency and costs reduction in the decommissioning stage, by building standardised waste collecting products. This innovation is already available in some Gen IIIs and is applicable to SMRs and AMRs.

Innovation opportunity deep dive: Design Simplification (SMRs, AMRs)

Plant design completion prior to starting construction provides significant opportunities for certainty and reduction of capital cost. Design simplification innovations allow for the incorporation of considerations such as design replicability and project approval, capital needs, scalability and construction, modularity, time management, operation and maintenance needs, waste management, and decommissioning. Risks can also be designed out at an early stage, by incorporating inherent safety features, such as eliminating a core meltdown scenario in simplified plant designs.

Design simplification can be enriched by innovations in digitisation and modularisation, and can inform the activities of owners, builders, and operators. This innovation is applicable to SMRs and AMRs, but not to Gen III given that the design has already been locked in. Some nuclear companies are already applying simplification of design on their lab-scale technology developments in the UK.

Innovation opportunity deep dive: Reduced downtime – fuels & components (Gen III, SMRs, AMRs)

There is complementarity between innovations at early stages of nuclear planning, such as design simplification, digitisation, and the prevention of downtime. Other innovations that help reduce downtime in nuclear plants are available for fuels. The utilisation of fuels that remain in the reactor for longer periods of time increases operational periods and requires fewer nuclear power plants to deliver energy needs. More power output per reactor implies fewer reactors needed on an assumed baseload. However, they also require changing of traditional maintenance regimes.

Components and systems designed to maximise productivity also affect the reduction of downtime. They include the development of parallel systems so that there is one active while the other is on standby under maintenance, and the use of robotics for in service inspection which can support life extension decisions. Reduced downtime innovations can inform the activities of operators and bring benefits to the energy system. These innovations are applicable to SMRs and AMRs, with some innovations on fuel also applicable to Gen III.

Innovation opportunity deep dive: Flexible output (AMRs)

Nuclear energy has traditionally been used as baseload source of energy. Innovations in AMRs reactors may allow for:

- Low-low cost electricity generation
- Increased flexibility
- Increased functionality (heat output for district heating or production of hydrogen)

AMR reactors are being designed with the ability to store their heat output for many hours at potentially very low cost. This allows for the reactors to release energy to the grid when it is needed. Some plants using different fuels, such as fully coated particle fuel may be capable of the same flexibility as a gas boiler or gas turbine. Other developments may achieve increased flexibility by adopting a thermal storage system that stores thermal power when demand is low and releases it when demand is high. Innovations in flexible output make nuclear plants a good complement to intermittent renewable energy sources, bringing benefits to the energy system.

Business opportunities within nuclear fission

Introduction

Box 6. **Objective of the business opportunities analysis**

The primary objective is to provide a sense of the relative business opportunities against other energy technologies. To do so, the analysis uses a consistent methodology across technologies to quantify the ‘opportunity’; in other words, what *could* be achieved by the UK. The analysis assumes high levels of innovation but remains agnostic about whether this is private or public. This distinction is made in the final section of the report. The two key outputs provided are:

- A quantitative estimate of the gross value added, and jobs supported associated with nuclear technology, based on a consistent methodology across technologies analysed in the EINA. Note, the GVA and jobs supported are *not* necessarily additional, and may displace economic activity in other sectors depending on wider macroeconomic conditions.
- A qualitative assessment of the importance of innovation in ensuring UK competitiveness and realising the identified business opportunities. Note, the quantitative estimates for GVA and jobs supported cannot be fully attributed to innovation.

The following discussion details business opportunities arising both from exports and the domestic market. An overview of the business opportunities, and a comparison of the relative size of export and domestic opportunities, across all EINA sub-themes is provided in the overview report.

More detail on the business opportunities methodology is provided in the Appendix.

The UK has an established nuclear energy industry which has provided low-carbon power generation for over 60 years but has faced challenges exporting. The domestic industry was a pioneer of nuclear energy with the connection of Calder Hall power station to the grid in 1956. Since then, the UK’s nuclear supply chain has developed niches, such as fuel fabrication and decommissioning, but unlike other countries has not developed the capability to export the delivery of nuclear power stations. This is partly due to the lack of standardisation of UK plants and small number of domestic new builds, reducing the UK's ability to compete with countries with large domestic programmes and economies of scale.

UK firms face strong competition both domestically and internationally, with many foreign firms operating in the UK market. Given significant foreign competition and expertise, the UK nuclear supply chain is unlikely to be able to capture more than half of the total value of a new nuclear reactor without government intervention. The UK has specialised areas of expertise, but limited capability across the whole supply chain; partly as a result, all new nuclear development in the UK is led by foreign-owned companies such as EDF Energy.

Demonstrated domestic delivery would be a strong enabler for UK exports across the nuclear supply chain. Domestic deployment of UK reactor technology would strengthen the UK's export position, by demonstrating that the UK's supply chain can deliver. As of 2017, the UK has an installed nuclear capacity of 9.3GW, with plans to replace existing stock in the 2020s.[18] This phase of replacement could provide opportunities for the UK supply chain to domestically deploy innovative technology, such as SMRs and AMRs.[19] Furthermore, the whole system modelling described earlier in this report suggests that domestic nuclear capacity could expand to 58 GW providing significant opportunity for deployment of domestic designs.[20] For example, Rolls-Royce could domestically deploy its SMR plant designs.[21] There are a range of smaller UK and foreign-owned firms that operate in the UK and supply reactor components, such as Heatric, or process fuel, such as Urenco. Rolls-Royce believe domestic firms like these would be able to supply nearly all parts for a smaller reactor like an SMR.[22]

UK export opportunities exist without domestic deployment of its own reactor design, but these are likely to be more niche. Although the delivery of a UK reactor design would serve as a strong platform for wider UK supply chain development, business opportunities remain without it. The UK can innovate in niche areas, such as fuel fabrication, by leveraging existing expertise and facilities. It will also be competitive in supplying decommissioning and waste management support following the long history of domestic decommissioning. The UK supply chain may

[18] BEIS (2018) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770773/Energy_Trends_December_2018.pdf
[19] Nuclear Energy Insider (2018) https://analysis.nuclearenergyinsider.com/rolls-royce-smr-use-site-factories-hit-60-poundsmwh
[20] This 35GW figure does not consider public acceptance or licensing issues.
[21] Rolls-Royce (2018) Press Release https://www.rolls-royce.com/media/press-releases/2018/01-02-2018-rr-and-nuclear-amrc-build-uk-small-modular-reactor-module.aspx
[22] Rolls-Royce (2016) Small Modular Reactors – once in a lifetime opportunity for the UK https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/nuclear/smr-booklet-28-sep.pdf

also find greater opportunities in component manufacturing if it becomes part of a cross-border consortium that designs and deploys reactors. For example, US-based NuScale seeks to manufacture SMRs in the UK for both domestic use and export to the European market.[23]

The business opportunities analysis is set out as follows

- An overview of the global market, with a focus on markets for exports
- A discussion of the UK's competitive position, with a focus on exports
- A discussion of the business opportunities from exports
- A discussion of the UK business opportunities in the UK's domestic market, including a comparison of the relative importance of export and domestic opportunities

[23] NuScale website https://www.nuscalepower.com/about-us/nuscale-in-uk

Box 7. **The UK's current nuclear industry**

UK strengths are pumps and valves; plant instrumentation and control for the reactor, generating plant and ancillary equipment; high-integrity piping systems; and waste management and decommissioning.

Notable UK companies are:

- Rolls-Royce which produces instrumentation and control systems and is the builder of the UK's submarine nuclear plants.24
- Sellafield Ltd, who oversee the safe and secure operation and clean-up of the Sellafield's site.25
- Westinghouse Electric Company employs over 1,000 people at its fuel fabrication plant, Springfields.26
- Urenco, who employ more than 300 people at its Capenhurst enrichment facility.
- Heatric, a specialist manufacturer of advanced heat exchangers employs over 200 people.
- Magnox decommissioning, which is responsible for decommissioning 12 nuclear sites in the UK.

Key competitors for the UK include France, Sweden and Spain in Europe and the US, Russia and China are particularly competitive in the construction and commissioning of nuclear power stations.[27]

Market overview

The global nuclear industry is a large mature market, characterised by high barriers to entry. The global nuclear power industry is worth over £77 billion and is expected to grow to around £189 billion by 2026.[28] The US, China, France, and Russia are the four largest nuclear markets, while China has the most nuclear capacity, 13 GW, under construction.[29] There are high barriers to entry to the nuclear market, with supply chains generally nationally-based, partly due to security. Political and security-based barriers will likely prohibit or severely limit UK access to large

[24] Note, business opportunities arising from the defence sector are not assessed in this report, but given the skills overlap Rolls-Royce's expertise is relevant to the UK's international competitiveness in the sector.
[25] https://www.gov.uk/government/organisations/sellafield-ltd/about#how-we-do-it
[26] Oxford Economics (2016) https://www.niauk.org/nuclear-activity-report/; this report also has data on Urenco, Heatric, and Magnox decommissioning.
[27] The UK competes with Sweden and Spain in the fuel fabrication market.
[28] Statistics MRC (2018) https://www.reuters.com/brandfeatures/venture-capital/article?id=48517; Exchange rate used: 1.3 $/£.$/£
[29] World Nuclear Association (2019) http://www.world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-and-uranium-requireme.aspx

global markets. For example, it is unlikely that the UK supply chain will be able to access the Russian market, and similarly, the UK is unlikely to lead construction of nuclear plants in China (although it may supply specialist parts). More broadly, economic and barriers, such as the capital and expertise required, mean the nuclear market is dominated by large established players and is difficult to break into for new firms. An overview of the market is given in Figure 1.

Most trade in the nuclear market flows from countries with large established supply chains to countries with relatively small nuclear industries. Large markets like Russia, China and France tend to favour their domestic industries when commissioning new stations. Consequently, only 35% of nuclear plants under construction use foreign designs, such as Hinkley Point C in the UK and four plants under construction in the United Arab Emirates.[30] In these cases, international vendors of reactor designs typically rely on their own national supply chain rather than seek substantial cross-border linkages.[31] Hence, a high percentage of the value of the new reactor is imported. Accordingly, our analysis assumes 25% of the capital expenditure CAPEX value of new nuclear deployment is potentially traded.[32] This reflects the size of the market potentially accessible to the UK and would likely focus on exporting nuclear expertise and technology to (smaller) countries that currently have no, or a limited, nuclear industry.

Compared to the market for nuclear components and construction, the international front end of the fuel cycle market is more highly traded. For example, countries such as Sweden export high quantities of fuel despite not having a strong presence in the export of reactor components.[33] All fuel could be tradeable; however, a more realistic figure of 50% is assumed, based on the ratio of the observed trade flows (£7 billion annually) of fuel over an estimate of total fuel required by the nuclear fleet.[34]

In addition to nuclear goods, there is a large and growing market in nuclear services. In the UK alone, the UK's decommissioning authority is currently spending

[30] World Nuclear Association (2019) http://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx
[31] Nuclear Engineering International (2012) https://www.neimagazine.com/opinion/opinionlocalisation-of-supply-how-can-it-work/
[32] Trade data was used to indicate the deviation of these percentages from where they theoretically should be, while opinion from interviewed experts was used to estimate a more realistic percentage.
[33] Front end of the fuel cycle data comes from COMTRADE, using HS codes 840120, 840130, 284420, 284510, and 284590.
[34] The numerator in this ratio, observed trade flows, comes from aggregation of fuel fabrication HS codes: 840120, 840130, 284420, 284510, and 284590. The denominator, total fuel required by the nuclear fleet, is derived from current global installed nuclear capacity (World Nuclear Association) and nuclear cost data based on Carbon Trust analysis (updated from TINAs).

£3 billion per year.[35] Our estimates suggest the global value of the decommissioning market is approximately £20 billion.[36] Most of this turnover is unlikely to be traded. Nonetheless, estimates of the value of decommissioning in markets accessible to the UK (US, Europe and Japan) suggest a market of approximately £2 billion. Strong growth is expected over the coming years, as aging plants are taken out of service.[37] By the 2030s, the tradeable decommissioning market accessible to the UK could be as large as £21 billion.[38] Further explanation of the methodology used to estimate market sizes is provided in Appendix 3..

Although mature, growth is expected in the nuclear industry, particularly during the 2020s and 2030s. Our estimate of global tradeable turnover in nuclear energy grows from around £50 billion annually in 2020 to £100 billion in 2030 (200% growth). This is mostly driven by increases in energy demand as well as a substitution away from high emissions electricity generation, spurring new nuclear capacity installation and fuel demand. This estimate assumes a 2-degree scenario; however, global nuclear generating capacity increases under all International Energy Agency (IEA) scenarios considered.[39] In addition, the decommissioning market is expected to grow rapidly as aging fleets of nuclear capacity must be decommissioned. After a peak in the 2030s, the nuclear market is expected to shrink as both decommissioning and build rates decrease.

[35] UKTI (2015). UK nuclear powering the future.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/397784/UKTI_Nuclear_capability_brochure_AW_REV_1_TAGGED.pdf

[36] Based on estimates of nuclear retirements and assuming the cost of decommissioning globally is comparable to that in the UK.

[37] Grand View Research (2018). 'Nuclear decommissioning services market'.
https://www.grandviewresearch.com/press-release/global-nuclear-decommissioning-services-market

[38] The global market in 2030 is estimated at around £200 billion. It is assumed that approximately 10% is accessible to the UK, limiting trade to the EU, US and Japan, and assuming most of the value of decommissioning is captured domestically.

[39] Scenarios are based on the IEA Energy Transitions Perspectives. The forecasted global nuclear deployment by 2050 is 544GW, 953GW and 973GW under scenarios 1, 2, and 3, respectively. Scenario 1, or RTS, is the Reference Technology Scenario and provides a baseline that includes existing energy and climate-related commitments by countries. Scenario 2, or 2DS, is a CO_2 emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C by 2100. Scenario 3, or B2Ds, is beyond the 2 degrees scenario where currently feasible technology improvements and deployment are pushed to their maximum practicable limits.

Figure 1 **The current and future nuclear energy market**

Current market for nuclear

- *Production:* Global nuclear deployment was over 400GW of installed capacity at the end of 2018, representing turnover of £100 billion
- *Trade:* Most UK production is currently for internal markets, with global trade around £10 billion
- *Markets:* The UK is the fourth largest market for nuclear in terms of installed capacity, with markets outside of the EU, such as Russia and China, likely to be the key markets moving forward

Tradability of market

- *Goods:* Nuclear components are tradeable if a domestic design has been deployed, or if the domestic supply chain has a role within a wider cross-border consortium to supply reactors
- *Services:* Specialist knowledge from nuclear feasibility studies to decommissioning services can be traded; aided by having a reactor design
- *Trends:* Current trade patterns expected to persist, with continued reliance on national supply chains

Trends in deployment

- *Global:* Nuclear deployment is expected to grow by 150% by 2050
- *Growth pattern:* Markets outside of the EU are expected to drive nuclear growth, with deployment expected to fall in the EU by 2050
- *Uncertainty:* Global deployment could increase by 70% under the reference to technology scenario by 2050 and by over 150% under the beyond 2 degrees scenario

Tradeable market size to 2050

- *Growth trend:* Substantial growth out to 2050 to meet SDS targets. Sales growth will slightly exceed deployment growth given replacement needs, particularly given the programme of nuclear replacement commencing in the mid 2020s
- *Key markets:* EU market is expected to total £8 billion, with the rest of the world expected to be £29 billion by 2050

Source: Vivid Economics

UK competitive position

The UK has a moderately-sized nuclear industry relative to other countries, but is strongly reliant on overseas firms for the design and manufacture of new nuclear capacity. The UK's modest nuclear industry size is reflected in nuclear trade flows: The top 10 countries by nuclear exports in 2017 sold an average of £452 million overseas, with the UK exporting only £5.4 million of goods.[40] This relative strength of other nations has led to the strong presence of foreign-owned firms in the UK supply chain. Research indicates domestic firms are unable to deliver more than 50% of the supply chain requirement of large-scale reactor designs and must rely on overseas firms to supply the designs themselves.[41] An overview of the UK's competitive position is in Figure 2.

Nuclear energy exports are not a competitive strength for the UK. The UK's revealed comparative advantage (RCA) of 0.01 for nuclear exports suggests nuclear

[40] The top 10 countries by nuclear exports, using COMTRADE data, were: Russia, Germany, France, the US, Sweden, Netherlands, China, South Korea, Spain, and Kazakhstan.
[41] Oxford Economics (2013) The economic benefit of improving the UK's nuclear supply chain capabilities http://namrc.co.uk/wp-content/uploads/2013/04/economic-benefits.pdf

exports are not a strength (above 1 suggests strength) .[42]

However, the UK does have areas of expertise in which it currently successfully exports, particularly in the front end of the fuel cycle. The UK currently has a modest 1% share of the European fuel fabrication market, but has significant production capacity with activity at two main sites: Urenco's Capenhurst facility and Westinghouse's Springfields facility.[43] These facilities export to countries such as Spain; the Springfields facility has an agreement with EDF France for the provision of uranium cylinder maintenance services. Sweden, France and Russia are key competitors for the UK in the fuel fabrication industry. These 3 countries have captured nearly 50% of the EU's nuclear fuel market, with Sweden leading with a 17% market share. Given the internationally competitive nature of this market, innovation will be vital for the UK's fuel fabrication industry to maintain its share.

The UK also has leading expertise in decommissioning and waste management. The UK has previously won decommissioning contracts in Europe, and the US and has an established decommissioning supply chain capable of dealing with all aspects of the safe and efficient clean-up of nuclear facilities.[44] As the global nuclear fleet ages, there is a significant opportunity for the UK to win further decommissioning contracts, particularly in the European Union (EU), US and Japan. Key firms in this industry are:

- Magnox Decommissioning, which has employed innovative 'lead and learn' techniques to the 12 nuclear decommissioning sites it manages.
- Low Level Waste Repository Ltd, which has recently deployed new high-precision containers to deliver radioactive waste.
- Dounreay Site Restoration Ltd, which is involved in demolition and waste management.

Russia and China are the leading exporters of nuclear reactors in the world and would be key competitors should the UK choose to export its own reactor design. Russia is by far the world's largest exporter of nuclear reactors. The Russian state-owned company Rosatom has over 30 orders to supply nuclear reactors worldwide. China and France are the second and third largest nuclear reactor exporters, respectively. Learning-by-doing is expected to increase the productivity for every additional nuclear reactor deployed. International competition is generally either partially of fully state backed, with Russia in recent years seeking to supply reactors to countries which are neither major allies of itself nor the United

[42] Using COMTRADE data https://wits.worldbank.org/ HS codes used were: 840110, 840120, 840130, 840140, 284420, 284510 and 284590.
[43] Trade data from COMTRADE, using 840110, 840120, 840130, 840140, 284420, 284510, and 284590 HS codes. Fuel fabrication facilities from Oxford Economics (2016) https://www.niauk.org/nuclear-activity-report/
[44] UKTI (2015) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/397784/UKTI_Nuclear_capability_brochure_AW_REV_1_TAGGED.pdf

States. A key route for the UK to access the major Capex value of the international reactor market is through demonstrated domestic deployment of its own reactor (or joint European) design, such as an SMR or AMR. There are other wider opportunities, but these are likely to revolve around specific parts, such as British instrumentation in Chinese reactors, and hence represent smaller opportunities.

Figure 2 **The UK's competitive position in trade in nuclear goods**

Current UK competitiveness

- *Market shares (of relevant goods trade):*
  EU *(excl. UK) ~ <1%*
  Rest of World ~ <1%
- *Strengths:* Fuel cycle, decommissioning, manufacture of pumps and valves
- *Weaknesses: No UK reactor design so limited business opportunities to access high-value Capex trade*

Key competitor - Sweden

- *Market shares (for relevant goods trade) :*
  EU *~ 16%*
  Rest of World ~ 5%
- *Strengths*: Key player in the fuel cycle sector, with Westinghouse's fuel fabrication plant at Västerås supplying European countries and Ukraine
- *Weaknesses: Limited exports of nuclear reactor parts*

Key competitor - France

- *Market shares (for relevant goods trade) :*
  EU *~ 15%*
  Rest of World ~ 13%
- *Strengths*: Established reactor design that can be exported, with strength in nuclear reactor parts
- *Weaknesses: Reliant on the European Pressurised Reactor (EPR) for long-term growth*

Key competitor – Russia

- *Market shares (for relevant goods trade):*
  EU *~ 15%*
  RoW ~ 19%
- *Strengths: Has its own reactor design with orders to supply over 30 reactors overseas; key strength in the fuel cycle sector*

**of content by value*

Note: *Market shares are based on UN COMTRADE data using 840110, 840120, 840130, 840140, 284420, 284510 and 284590 HS codes.*

Source: *Vivid Economics*

Box 8. **Industry workshop feedback regarding business opportunities**

- Innovative reactor designs, SMRs in the 2030s, and AMRs in the 2040s/2050s, could provide a good business opportunity for the UK.
- Innovation to create a UK reactor design is crucial to unlock export opportunities throughout the supply chain; without this the UK is likely to export only in niche areas.
- Innovation in fuel would help the UK's competitiveness in this international market, presenting a good opportunity for the UK.
- There is an opportunity for UK firms to supply nuclear advisory services– these activities are not observed in trade data, and hard to quantify, but can be substantial.
- Scale is crucial to international competitiveness in this sector, therefore unless the UK can deploy at scale, it is unlikely to partner or gain opportunities with countries such as China.

Table 7. **Export market shares and innovation impact – nuclear fission**

Technology	**Tradeable market 2050 (£bn)**	**Current share of related UK market**	**2050 outlook with strong learning by research** **Market share (%) ***	Captured turnover (£m)	Captured GVA from exports (£m)	Rationale for the impact of innovation on exports of related equipment and services
Front end of the fuel cycle	**EU: 1** RoW: 13	**EU: <1%** RoW: <1%	**EU: 7%** RoW: 7%	**EU: <100** RoW: 870	**World: 420**	Innovation can enable UK producers to supply fuels for a domestic SMR design deployed overseas. There are further opportunities for the UK to supply new fuel types to newly built reactors in an expanding global market.[45] The potential increase in UK market share is benchmarked so that UK turnover in the front end of the fuel cycle in 2050 equals current French turnover.
Capex– Components	**EU: 2** RoW: 6	**EU: <1%** RoW: <1%	**EU: 5%** RoW: 5%	**EU: <100** RoW: 290	**World: 110**	The UK market share grows to 5% of the EU and the RoW markets by 2050. This was considered plausible at the workshop. This is driven by the UK gaining a partial or full stake in a reactor design, enabling UK firms to supply components overseas.
Capex – Materials [46]	Not traded	Not traded	Not traded	Not traded	Not traded	Unlikely to be significant trade in this category as materials can be sourced locally.
Capex – Construction	**EU: 2** RoW: 5	N/A	**EU: 5%** RoW: 5%	**EU: <100** RoW: 260	**World: 100**	If UK firms are contracted to deliver a UK reactor design, they are more likely to be able to capture service fees, such as financial and legal, associated with construction. To capture this, the UK market share grows to 5% of the EU and the RoW markets by 2050. This was considered plausible at the workshop.

[45] The possible market share % the UK is set so that UK fuel export levels would equal those of France currently.
[46] Capex materials are not assumed to be tradeable.

Technology	Tradeable market 2050 (£bn)	Current share of related UK market	2050 outlook with strong learning by research			
			Market share (%) *	Captured turnover (£m)	Captured GVA from exports (£m)	Rationale for the impact of innovation on exports of related equipment and services
O&M	Not traded	Not traded	Not traded	Not traded	Not traded	Unlikely to be significant trade in this category as O&M can be sourced locally.
Decommission-ing	**EU: 2** RoW: 3	N/A	**EU: 5%** RoW: 5%	**EU: <100** RoW: 140	**World: <100**	Firms in the UK supply chain can export innovative decommissioning techniques that reduce the cost and human involvement. To capture this, the UK market share grows to 5% of the EU and the RoW markets by 2050. This was considered plausible at the workshop as the UK is competitive in this area.
Waste Management	**EU: 1** RoW: 1	N/A	**EU: 5%** RoW: 5%	**EU: <100** RoW: <100	**World: <100**	Innovation can enable the UK to capture greater market share by leveraging existing facilities and the advanced capabilities that its supply chain has in this sector. To capture this, the UK market share grows to 5% of the EU and the RoW markets by 2050. This was considered plausible at the workshop.

Note: *Future market shares are not a forecast but what UK business opportunities could be potentially. The possible market share of the UK, and rationale for the impact of innovation are based on stakeholder input gathered in 2 workshops. Table is based on IEA scenario from the 2017 Energy Technology Perspective. The scenario used in this table is the 2 degree scenario, which is the standard reference throughout the business opportunities section. N/A indicate trade data is not available.*

Source: *Vivid Economics*

UK business opportunities from export markets

Box 9. **Interpretation of business opportunity estimates**
The GVA and jobs estimates presented below are *not* forecasts, but instead represent estimates of the potential benefits of the UK capturing available business opportunities. The presented estimates represent an unbiased attempt to quantify opportunities and are based on credible deployment forecasts, data on current trade flows, and expert opinion, but are necessarily partly assumption-driven. The quantified estimates are intended as plausible, but optimistic. They assume global climate action towards a 2 degree world and reflect a UK market share in a scenario with significant UK innovation activity.[47] More information on the methodology, including a worked example, is provided in Appendix 2, and a high level uncertainty assessment across the EINA subthemes is provided in Appendix 3.

Growth of UK nuclear exports could add over £0.7 billion of GVA per annum and support around 8,300 jobs by 2050.[48] This export growth is driven by the key assumption that the UK can capture a greater share of the tradeable market in nuclear CAPEX, which would likely require the UK to demonstrate domestic deployment of a UK design, such as an SMR. This could subsequently create strong export opportunities for the entire UK supply chain. The expected growth of the overall nuclear market could also lead to natural export growth for the UK, assuming current market shares in specialist niches are maintained. Notably, the estimate of possible UK nuclear exports is relatively insensitive to different assumptions on the trajectory of the global energy transition, as nuclear market share is relatively consistent across scenarios.[49] Further explanation of the methodology used to estimate UK business opportunities from export is provided in Appendix 2.

UK exports and business opportunities are likely greatest in the 2030s, with the nuclear industry supporting £1.3 billion in GVA each year and support nearly 20,000 jobs, as shown in Figure 3 and Figure 4. This is driven by the replacement of existing nuclear stock from the mid-2020s globally, and significant

[47] Note, other IEA climate scenarios were also used as a sensitivity. Where the level of global climate action has a meaningful impact on market size, this is highlighted in the market overview section. Full results are available in the supplied Excel calculator.
[48] The jobs figures are those supported by exports for a particular year. The jobs figures reported are not the number of new jobs created per annum. This is assuming the IEA 2 degrees scenario, which is assumed to be the standard scenario in our analysis.
[49] IEA's 2 degrees scenario was used predominantly throughout this analysis and adds around £1.2 billion annually to GVA and supports 15,000 jobs. The reference to technology scenario adds around £0.9 billion to GVA and 11,000 jobs; while the below 2 degrees scenario adds around £1.3 billion to GVA and 17,000 jobs.

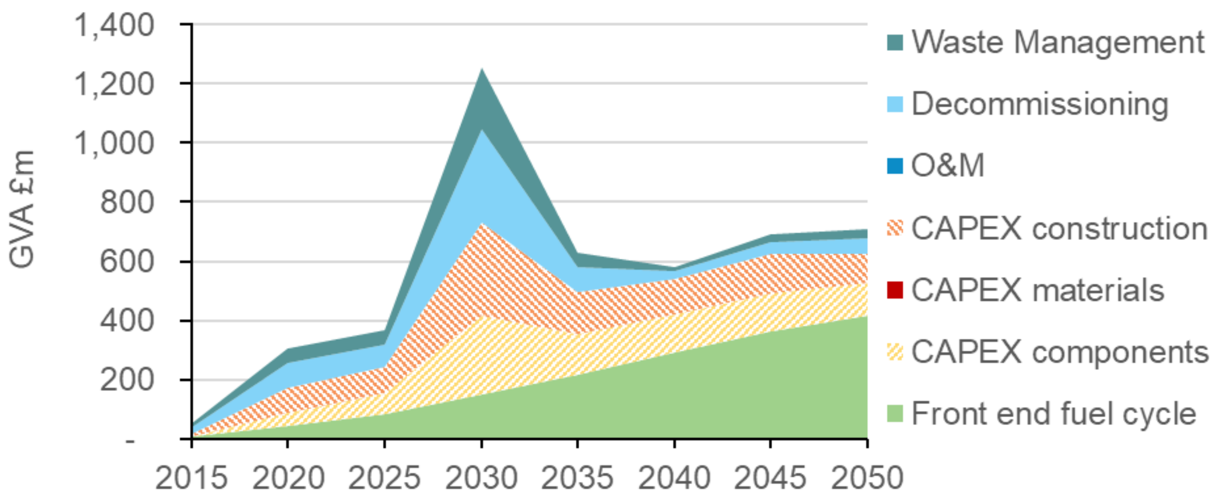
expansion of nuclear capacity. The UK's strength in decommissioning is relatively well-established, but the potential GVA and jobs from exports for a UK designed reactor hinge on the UK developing a competitive advantage it has not yet demonstrated. Rapid innovation and (likely domestic) demonstration are crucial to deliver this outcome.

Business opportunities from nuclear exports are dominated by three areas. The role of innovation in unlocking these business opportunities is summarised in Table 7.

- Front end of the fuel cycle exports can lead to £420 million in GVA per annum and support 4,400 jobs by 2050.
- Capex components and construction are expected to provide a combined £200 million in GVA per annum and support over 2,500 jobs by 2050. This is driven by the UK deploying a domestic reactor design overseas and supplying components throughout the supply chain.
- Although relatively small by 2050, export of decommissioning services in the 2030s could lead to £320 million in GVA per annum and support 4,100 jobs.

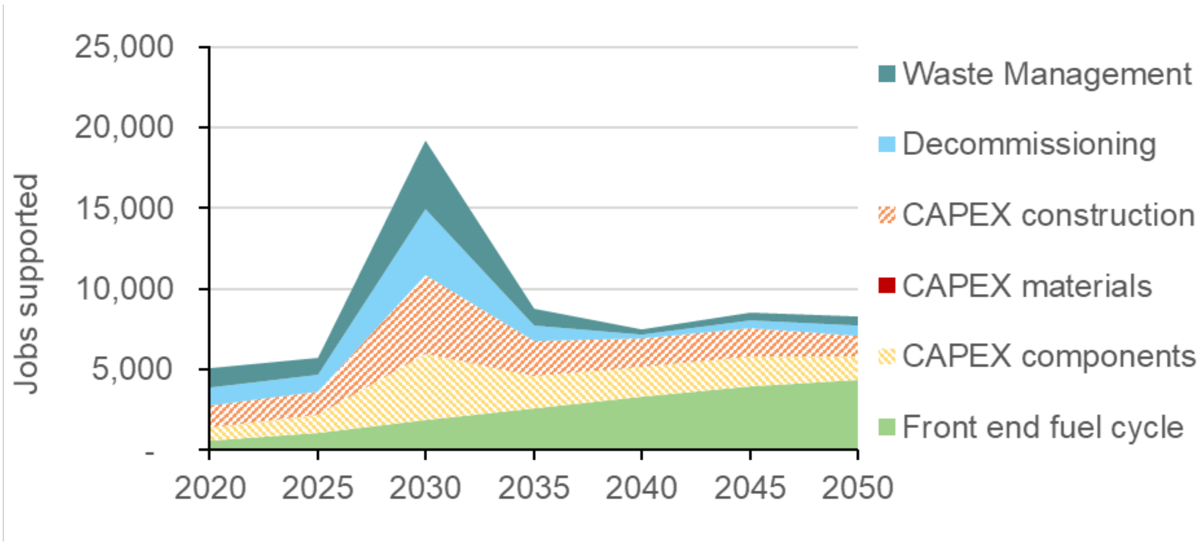
Other categories are expected to contribute minimally to GVA and jobs figures because they are assumed to be less tradable and reflect a relatively small percentage of costs of a nuclear plant.

Figure 3 **GVA per annum from export markets by component – nuclear fission**



Note: *See appendix for assumptions on nuclear, cost and GVA data.*
Source: *Vivid Economics*

Figure 4 **Jobs supported per annum from export markets by component – nuclear fission**



Note: *See appendix for assumptions on nuclear, cost and GVA data.*
Source: *Vivid Economics*

UK business opportunities from domestic markets

Discussion

The expansion of UK generating capacity would create substantial domestic business opportunities. In 2017, the UK had nuclear deployment of 9.3GW, accounting for 11.5% of total generating capacity.[50] ESME estimates indicate 58GW of nuclear capacity by 2050 (including 21 GW of SMR capacity) under a high UK nuclear innovation scenario. Although this expansion of nuclear power would represent a sizeable increase in domestic capacity, it is comparable to estimates by others. For example, the WeSIM model estimates 38 GW of nuclear deployment, without assuming particular innovation in nuclear.[51]

Despite foreign companies having a vital role in delivering planned large Gen III reactors, UK firms can still capture a high share of the plant construction value. For example, 64% of the construction value of Hinkley Point C is expected to go to domestic firms.[52] Given that signed contracts already cover over 80% of the project's value, this relatively high local content share of 64% should be realised.[53] UK firms will capture all the construction value that is not tradeable (15%[54]) and a reasonable share of the remaining high-value components, with contracts already awarded for UK firms to supply the electrical cabling and equipment installation, mechanical pipework, pumps, power transmission, and project management services.[55]

As in the export analysis, domestic business opportunities are uncertain. Although the absence of new deployment does not preclude domestic business opportunities because of lengthy decommissioning and waste management timeframes, new deployment and the maintenance of operating stock are an important driver of business opportunities. Given some of the UK's new fleet of large Gen III reactors is now in doubt, with Hitachi and Toshiba both suspending or

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[50] BEIS (2018) Energy Trends https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770773/Energy_Trends_December_2018.pdf

[51] Carbon Trust and Imperial College London (2016). An analysis of electricity system flexibility for Great Britain. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

[52] EDF Energy website https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/about

[53] BEIS (2018) Hinkley Point C wider benefits realisation plan https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/725960/HPC_Benefits_Realisation_Plan.pdf

[54] These are the materials costs associated with a Gen III nuclear power stations e.g. concrete and are not traded Source: Carbon Trust

[55] Nuclear AMRC (2015) Preferred suppliers named for Hinkley Point C https://namrc.co.uk/industry/hpc-suppliers-july15/

cancelling projects in recent months, it is unclear whether nuclear capacity will grow by as much as anticipated.[56] If the new fleet of reactors does not materialise, domestic business opportunities would be far lower, likely concentrated in O&M, the front end and back end of the fuel cycle rather than component supply and reactor construction.

In addition to the components considered in the export analysis, we also consider components with low tradability in the domestic analysis. We include Capex materials and O&M in the domestic analysis; and allow UK firms to realistically capture a greater share of the front and back ends of the fuel cycle, as some value associated with these components, for example nuclear waste, has low tradability and therefore was not considered in the export analysis.

UK business opportunities can build on existing strengths in some areas of the nuclear supply to develop reactor IP, whilst continuing to capture high shares in the front and back ends of the fuel cycle and untraded components. UK domestic market shares are averages across reactor technologies, with uncertainty around the final split between Gen III, SMR and AMR. Across the components considered, the shares of the UK market captured by domestic businesses are outlined in Table 8, and detailed below:

- **Front end of the fuel cycle**: the UK domestic market share grows from 49% in 2018 to 57% by 2050. In 2018 the UK captures most of the uranium enrichment and fuel fabrication for domestic plants, which is 49% of the value associated with the front end of the fuel cycle; by 2050, the UK can leverage existing mothballed facilities to re-capture most of the conversion process value and grow domestic market share to 57%.[57] Given the lack of uranium mines in the UK, all uranium value (43%) is assumed to be imported, placing an upper bound of 57% on the UK's domestic market share in the front end of the fuel cycle.[58]
- **Capex components**: the UK domestic market share grows from 58% in 2018 to 88% by 2050, in line with Japan's current domestic market share in nuclear reactor components.[59] For the UK to grow its domestic market share, its supply chain must develop reactor IP, for example in SMRs. Without this intellectual property, stakeholder evidence indicates UK domestic market

[56] Reuters (2019) Hitachi halts UK nuclear project as energy supply crunch looms https://uk.reuters.com/article/uk-hitachi-nuclear-idUKKCN1PB0RO
[57] HM Government (2015) UK nuclear: Powering the future https://www.gov.uk/government/publications/uk-nuclear-powering-the-future/uk-nuclear-powering-the-future#a-world-class-partner-across-the-fuel-cycle
[58] World Nuclear Association (2019) Economics of Nuclear Power http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx
[59] HM Government (2012) The Nuclear Supply Chain Action Plan https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/65658/7176-nuclear-supply-chain-action-plan.pdf

share is likely to remain broadly constant, with continued reliance on high value imported reactor components.

- **Capex materials**: these materials have low tradability; the analysis assumes a 90% domestic market share to allow for minor imports.
- **Capex construction**: the UK domestic market share grows from 58% in 2018 to 88% by 2050, in line with Capex components. If the UK develops its own IP, and supplies substantially more components for domestic nuclear construction, UK firms can capture greater ownership and contingency fees associated with reactor construction to drive increases in Capex construction domestic share.
- **O&M:** these services have low tradability; the analysis assumes a 95% domestic market share to allow for minor imports.
- **Decommissioning**: the UK domestic market share is assumed to be 80% up to 2050.[60] Although the UK does import some high-value components utilised in the decommissioning process, the uniqueness of UK reactors and its experienced workforce and supporting supply chain enable UK firms to capture most of the market.
- **Waste management**: the UK market share is assumed to be 80% up to 2050, in line with decommissioning. Waste management is a strength of the UK, with most UK waste handled at the Sellafield site; domestic waste management is expected to continue, driving a broadly constant domestic market share.

Domestic business opportunities in nuclear fission could contribute £9.6 billion per annum in GVA and support 130,000 jobs by 2050, as shown in Figure 7 and Figure 8. These opportunities rely on a high nuclear innovation scenario and are dependent on the uncertain future growth of nuclear capacity. As a point of comparison, a PwC study in 2011 found that 125,000 people were directly employed by the nuclear industry in France, which then had nuclear capacity of 63.1 GW.[61,62] Given ESME estimates UK nuclear capacity of 58GW in 2050, once stronger decommissioning and new build opportunities in the future are accounted

[60] The decommissioning value to the UK is around £1.7 billion annually (Source Nuclear Industry Association) and nuclear power imports are around £300 million annually (Source House of Commons (2017) https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/378/378.pdf). Therefore, by taking the ratio of decommissioning value to the sum of decommissioning value to the UK + imports you get a lower bound for the market share of UK firms in the decommissioning industry (~80%). However, nuclear trade data is of poor quality with some decommissioning equipment imports likely not captured by nuclear power imports data. In the absence of an alternative, we continue to use 80% as the market share, but recognise it could be higher.
[61] World Nuclear Association (2018) Nuclear Power in France http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx
[62] OECD (2018) Measuring Employment Generated by the Nuclear Power Sector https://www.oecd-nea.org/ndd/pubs/2018/7204-employment-nps.pdf

for, the relative ratio of nuclear capacity to jobs supported in this analysis is comparable to the existing French industry.

Domestic business opportunities far exceed those of the export analysis, as shown in Figure 5 and Figure 6. UK firms capture £9.6 billion of domestic GVA per annum in 2050 compared to under £1 billion of export GVA. The expansion of nuclear capacity to 2050 more than doubles the current GVA estimates for the nuclear energy industry of £3.5 billion.[63] The domestic economy supports around 130,000 jobs in 2050, compared to only 8,300 in the case of exports. This sharp difference illustrates the low tradability inherent in the nuclear industry and a reliance on national supply chains.

The construction of new nuclear plants is the primary driver of these opportunities,[64] with new deployment supporting around £6.5 billion per annum and 88,000 jobs by 2050. Opportunities associated with capital expenditure (£4.3 billion in GVA and 59,000 jobs) will be new because of the necessity to expand the UK's electricity supply and the absence of nuclear construction since the 1990s. O&M and front end of the fuel cycle opportunities will partially replace existing opportunities. But the expansion of nuclear capacity also offers avenues for growth in O&M and front end of the fuel cycle opportunities compared to those currently observed.

The back end of the fuel cycle can contribute £3.1 billion in GVA per annum and support 43,000 jobs by 2050. As the Nuclear Decommissioning Authority (NDA) continues the decommissioning process for previously shutdown facilities and EDF oversees the decommissioning of the Advanced Gas-cooled reactor fleet, back end of the fuel cycle opportunities increase substantially. Decommissioning can contribute around £1.8 billion GVA annually by 2050 and support 20,000 jobs; whilst waste management can contribute around £1.3 billion annually by 2050 and support 23,000 jobs. Unlike other opportunities, back end of the fuel cycle opportunities are not reliant on the growth of nuclear stock with most decommissioning and waste management costs up to 2050 tied to plants that have already shutdown or soon will.

[63] UK Parliament (2017) Nuclear Sector Report https://www.parliament.uk/documents/commons-committees/Exiting-the-European-Union/17-19/Sectoral%20Analyses/24-Nuclear-Report.pdf

[64] This contains capital expenditure opportunities, front end of the fuel cycle and the O&M to run these new plants. All front end of the fuel cycle and O&M opportunities by 2050 will be associated with plants built after 2015 because the existing nuclear fleet will be decommissioned before then.

Quantitative results

Table 8. **Domestic market shares and innovation impact – nuclear fission**

Technology	Domestic market 2050 (£bn)	Current share of related UK market	2050 outlook with strong learning by research			
			Market share (%) *	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
Front end of the fuel cycle	1.8	49%	57%	1,000	450	The UK market share rises to 57% by 2050, as UK suppliers re-capture the conversion value of the front end of the fuel cycle using existing mothballed facilities. UK supply chain innovation drives continued high market shares for uranium enrichment and fuel fabrication in the domestic market, but all uranium continues to be imported in the absence of commercial mining.
Capex components	5.1	58%**	88%	4,500	1,700	The UK market share rises substantially to 88% by 2050, comparable to Japan's current component share in its domestic market. UK reactor IP, or a stake in a cross-border reactor design consortium, drives a rise in the market share of domestic reactor construction value. Without domestic IP, market share is unlikely to increase, and can be expected to remain broadly constant up to 2050.
Capex materials	2	90%	90%	1,800	630	The UK market share remains at 90% by 2050 as this component, including materials such as cement, has low tradability.
Capex construction	6.1	58%**	88%	5,400	2,000	The UK market share rises substantially to 88% by 2050, comparable to Japan's current construction share in its domestic market. Innovation that

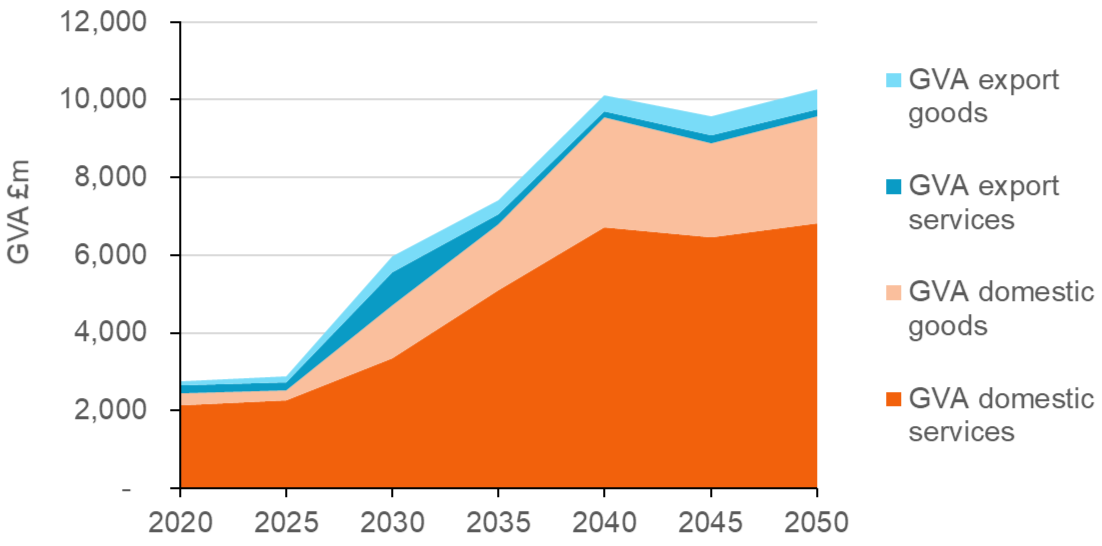
Technology	Domestic market 2050 (£bn)	Current share of related UK market	Market share (%) *	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
	2050 outlook with strong learning by research					
						develops UK IP in a reactor design enables UK firms to access a greater share of the value of this component, for example ownership fees.
O&M	3.7	95%	95%	3,500	1,700	The UK market share remains at 95% by 2050 as this component has low tradability.
Decommiss-ioning	5.8	80%	80%	4,600	1,800	The UK market share remains at 80% by 2050. Leading UK expertise in decommissioning of the domestic supply chain and the uniqueness of the UK's advanced gas-cooled reactors allow for limited penetration of foreign suppliers.
Waste management	2.9	80%	80%	2,300	1,300	The UK market share remains at 80% by 2050. The UK can leverage its leading capabilities developed at the Sellafield plant to continue to domestically manage nuclear waste and its long-term storage.

Note: ** Future market shares are not a forecast, but what UK business opportunities could be potentially in the context of the EINAs. The possible market share of the UK, and rationale for the impact of innovation, are based on PRODCOM analysis and additional market research. N/A indicates data is not available.*

*** Although the UK will capture 64% of the construction value of Hinkley Point C, these market shares are revised downwards to account for UK firms capturing most of the value associated with Capex materials, which has low tradability.*

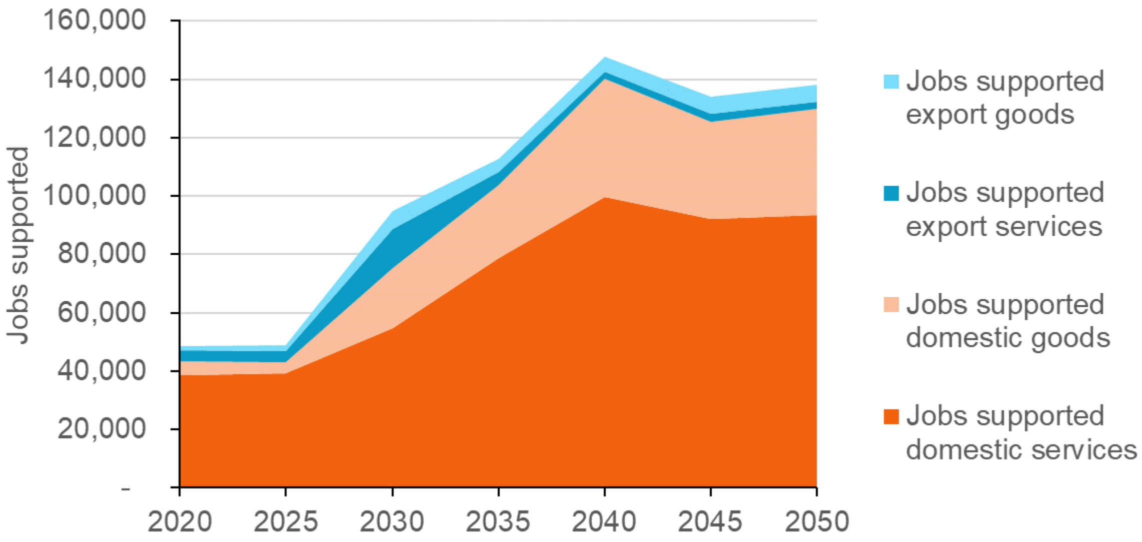
Source: *Vivid Economics*

Figure 5 **GVA per annum from export and domestic markets – nuclear fission**



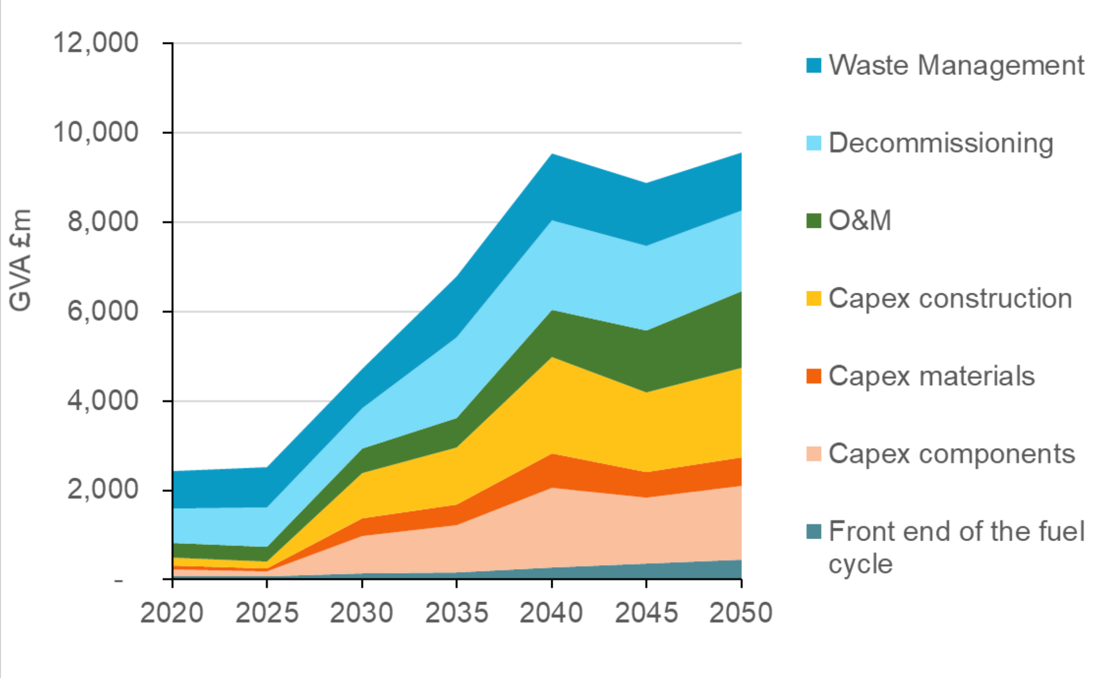
Source: Vivid Economics

Figure 6 **Jobs supported per annum from export and domestic markets – nuclear fission**



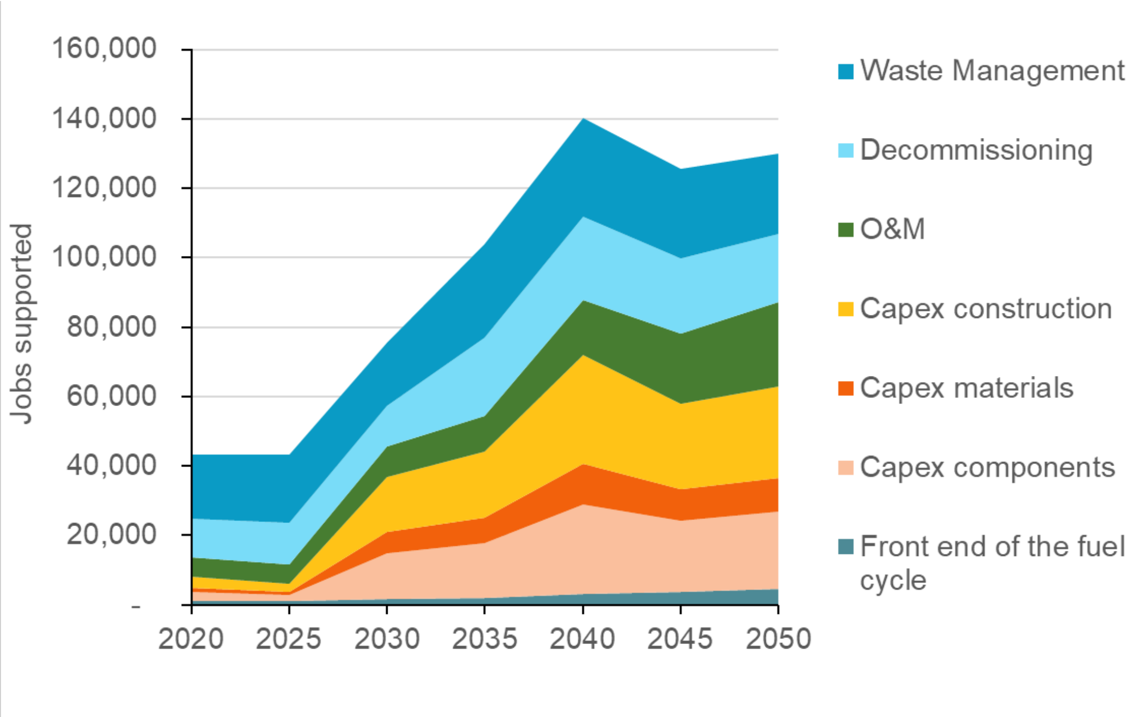
Source: Vivid Economics

Figure 7 **GVA per annum from domestic markets by component – nuclear fission**



Source: *Vivid Economics*

Figure 8 **Jobs supported per annum from domestic markets by component – nuclear fission**



Source: *Vivid Economics*

Business opportunity deep dive: SMRs

SMRs represent a sizeable business opportunity for the UK supply chain. SMRs are expected to have a lower capital cost per unit than conventional reactors, which may increase the financial feasibility of the UK supply chain's investment financing for nuclear technology.[65] Furthermore, UK firms can access economies of scale if output for the domestic market is intensified at a centralised production facility. This can unlock export markets with a cost-competitive product. However, competition from China and others is likely to be strong in the market for the delivery of all types of nuclear plants. Therefore, innovation will be crucial for the UK to produce a design which it can deploy domestically and export. To realise this ambition, a programme of coordinated support is likely required.

An SMR design can unlock markets for UK firms throughout the supply chain. The international vendors of reactor designs usually have nationally-based supply chains which support their deployment overseas. In the case of Hinkley Point C, the French supply chain will be heavily involved in supplying components for the construction of the plant. If the UK supply chain successfully innovates to develop its own reactor design, UK firms can utilise their knowledge of the design, as well as existing relationships with the design owners, to export materials and components for its deployment overseas.

The UK supply chain could gain a first-mover advantage to increase their global market share. According to a recent Rolls-Royce report, a UK SMR could create 40,000 skilled jobs.[66] This includes the domestic market and is hence significantly larger than our estimates of around 10,000 jobs, but nonetheless gives a sense of scale. The SMR market opportunities for the UK supply chain may be found in new markets which previously considered large-scale designs prohibitively expensive, and in existing markets, which expect SMRs to lead to cost, safety, and performance advantages.

Business opportunity deep dive: Front end of the fuel-cycle

Front end of the fuel cycle innovations will be crucial to increase market share. Growth in UK front end of the fuel cycle exports could add £400 million to GVA per annum, which is the highest of any cost component, and 4,500 jobs by 2050. Innovation that allows UK facilities to supply fuel for SMRs and the next generation of nuclear reactors, Gen IV, is key if UK producers are to capture market share. The supply of fuel to these new generations of reactors is likely to be an immature market

[65] SMR Start (2017) http://smrstart.org/wp-content/uploads/2017/09/SMR-Start-Economic-Analysis-APPROVED-2017-09-14.pdf
[66] Rolls-Royce (2016) https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/nuclear/smr-booklet-28-sep.pdf

with fewer entrenched competitors, which will enable the UK supply chain to more readily capture a greater share of the market, particularly if it gains a first-mover advantage. If the UK supply chain does not innovate in the front end of the fuel cycle, then strong international competition to supply existing reactor technologies may occur. Candidate countries are Sweden, Russia and the United States. This could limit the extent to which the UK market share can grow.

The strength of the UK's front end of the fuel cycle sector could be leveraged to drive export growth. The UK has facilities with the ability to supply fuel for all light water- and gas-cooled reactor types, such as Westinghouse's Springfields site, despite not domestically deploying all reactor types. This suggests that even if the UK does not deploy its own reactor design, it still has the capability to grow its market share in the fuel fabrication sector, as, unlike other areas of the supply chain, the front end of the fuel cycle sector is more internationally competitive. This is shown in the case of Sweden, which has a 17% share of the world fuel fabrication market in the absence of a strong export base for reactor designs and components.

Market barriers to innovation within nuclear fission

Introduction

Box 10. **Objective of the market barrier analysis**

Market barriers prevent firms from innovating in areas that could have significant UK system benefits or unlock large business opportunities. Market barriers can either increase the private cost of innovation to levels that prevent innovation or limit the ability of private sector players to capture the benefits of their innovation, reducing the incentive to innovate.

Government support is needed when market barriers are significant, and they cannot be overcome by the private sector or international partners. The main market barriers identified by industry are listed in Table 9, along with an assessment of whether HMG needs to intervene.

Market barriers for nuclear fission

HMG plays an important role in providing an environment for innovation in nuclear energy production in the UK. Energy levels produced by nuclear energy globally are currently lower than they were in the 1990s and early 2000s, as plant closures are more frequent than new openings. The most recent plant built in the UK is Sizewell B, which opened in 1995, and most recent constructions have taken place in Asia.[67] Due to the large upfront costs, regulatory and safety requirements in the sector, and political sensitivity, government tends to play an important role in supporting private sector innovation in nuclear energy production.

The important role of government is demonstrated in the UK. For example, by the research centres; Nuclear Innovation Programme; the Industrial Strategy Nuclear Sector Deal; the framework for SMRs and AMRs set out in the Sector Deal; and the ambitions for 2030 set out in the Sector Deal, including a 30% reduction in the cost of new build projects, 20% savings in the cost of decommissioning and up to £2

[67] IEA, Statistics: nuclear energy production 1990-2016, n.d., accessed on 18/01/2019
HMG, Nuclear capacity in the UK, n.d.

billion contract wins.[68] Efforts focus predominantly on reducing barriers to deployment by lowering investment risks, expanding potential applications to smaller grids, and increasing safety.[69]

Market barriers are significant, and they cannot be overcome by the private sector or international partners. Table 9 lists the main market barriers in the nuclear sector, along with an assessment of whether HMG needs to intervene.

For each identified market barrier, an assessment of the need for government intervention is provided. The assessment categories are low, moderate, severe and critical.

- **Low** implies that without government intervention, innovation, investment and deployment will continue at the same levels, driven by a well-functioning industry and international partners.
- **Moderate** implies that without government intervention, innovation, investment and deployment will occur due to well-functioning industry and international partners, but at a lower scale and at lower speed.
- **Severe** implies that without government intervention, innovation, investment and deployment are significantly constrained and will only occur in certain market segments or must be adjusted for UK market.
- **Critical** implies that without government intervention, innovation, investment and deployment will not occur in the UK.

Table 9. **Market barriers**

Market barriers for nuclear innovation	Need for HMG support	Component	Gen III, SMR, AMR
Policy uncertainty and regulatory barriers to SMR build in the UK	Critical	All	SMR
Uncertainty over future fuel cycles	Severe	All	All
Decommissioning for new build takes place in the far future and is heavily discounted, resulting in little incentive to innovate to reduce costs in the design stage	Severe	All	All
Site-specific certification requirements drive up costs and slow down the process of innovation adoption	Severe	All	All
High capital costs and long timescales discourage private sector innovation; high market perception of risk in the sector	Severe	Capex	All

[68] BEIS, Nuclear Sector Deal, 2018
NIA, Innovation and future technology, n.d.
HMG, Funding for nuclear innovation, 2017
HMG, Building our Industrial Strategy, Green Paper, 2017
HMG, Industry experts assemble in bid to make cutting-edge nuclear technology a reality, 2018.
[69] IEA, Nuclear power Tracking Clean Energy Progress, 2018.

Market barriers for nuclear innovation	Need for HMG support	Component	Gen III, SMR, AMR
increases cost of finance and de-risking is difficult to demonstrate			
Limited opportunity to use new materials due to stringent safety requirements, costly demonstration of safety compliance disincentivises innovation	Moderate	Capex	All
Development of industry best practice and sharing of O&M learning is achieved under the responsibility of the World Association of Nuclear Operators	Moderate	Mining, Processing, Enriching, Fabricating	All
Necessary skilled workforce requires a long time to reach maturity and is vulnerable to high turnover rates and obsolescence	Moderate	Decommissioning	All
Limited number of nuclear vendors with advanced manufacturing capabilities, low competition, and high barriers to entry	Low	O&M	All

Source: Vivid Economics based on stakeholder input

Box 11. **Industry workshop feedback**

Industry experts raised several areas that require HMG support:

- The UK National Policy Statement only provides cover to seek development consent for Gen III reactors deployable by 2025 and needs more clarity for non-Gen III reactors. It currently reduces incentives for UK firms to develop SMRs, as securing development consent for a project in the UK is riskier. SMR design is a costly and inherently risky process. Insecurity over whether nuclear will still be politically feasible in the future further compounds the implications.

- Uncertainty over future fuel cycles and any lack of clarity on the policy position on reprocessing may reduce incentives for innovation in waste management, reprocessing, and storage.

- For newly designed plants, decommissioning activities occur far in the future, beyond 45 years, and therefore are heavily discounted. This discourages innovation for cost reduction in the design stage. Decommissioning is a UK strength, and innovation in legacy Gen III plant decommissioning occurs, including in robotics.

- HMG can support project implementation by streamlining certain approval and licensing processes. Site-specific certification is an important cost driver and streamlining or standardising processes where possible would contribute to the timely development of nuclear reactors in the future.

- The high capital cost nature of nuclear technology and long timescales involved discourage private sector investment and innovation. A high market perception of risk in the sector further increases the cost of finance and de-risking is difficult to demonstrate.

- Globally, government policy positions on nuclear energy are unclear and subject to change. In Europe, policy positions can fluctuate between a commitment to phase out all nuclear to constructing more reactors. In general, policies are sensitive to public opinion, as demonstrated by phasing out all nuclear energy in Germany and Denmark after the Fukushima nuclear disaster. Particularly long planning, licensing and deployment timelines in the sector prevent players from responding quickly to policy changes.

International opportunities for collaboration

There are potential international opportunities to collaboratively innovate, but also threats from international innovation and competition:

- SMR reactors from modified existing reactor designs will potentially begin to be deployed in the next ten years. Revolutionary AMR designs will take longer to deploy and will incorporate a mix of technologies. The long timeframe has implications for competitiveness, as other countries may develop and deploy these designs sooner.
- International collaboration would allow for better sharing of learnings to design more cost-effective and safer reactors. Sites for testing safety features of new designs could be shared between many countries. The potential value of designs, their proprietary nature, and the inherent difficulty in changing them results in an industry that has a lower willingness or ability to collaborate between countries and businesses.

Appendix 1: Organisations at expert workshop

- Cavendish Nuclear
- Dalton Institute
- Energy Systems Catapult
- Frazer Nash
- HM Treasury
- National Nuclear Laboratory
- Nuclear Decommissioning Authority
- Nuclear Innovation and Research Office
- Rolls Royce
- Westinghouse

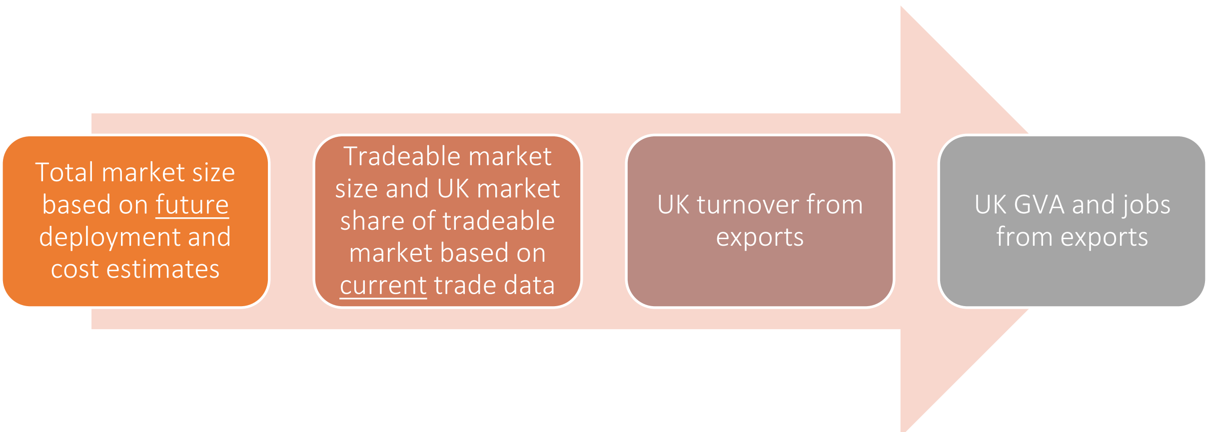
Appendix 2: Business opportunities methodology

Methodology for export business opportunity analysis

In identifying export opportunities for the UK, the EINA process uses a common methodology to ensure comparability of results:

- The **global and regional markets** to 2050 are sized based on deployment forecasts, which come from the IEA when available. For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market.
- The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs created**.

Figure 9 **Methodology for assessing export opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Export business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade data, where available. If the technology is immature or export levels are low, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to reach a market share in the EU and RoW by 2050. The potential future market share is intended as an ambitious, but realistic, scenario. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.
- Market share assumptions are validated at a workshop with expert stakeholders and adjusted based on stakeholder input.

Export business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The EINA methodology does not quantify opportunities associated with installation and operation and maintenance as these are typically performed locally. Exceptions are made if these types of services are specialised, such as in offshore wind.
- The key services to consider are based on desk research and verified through an expert workshop.
- The services considered in the CCUS EINA export analysis are EPCm services, transport and storage services.

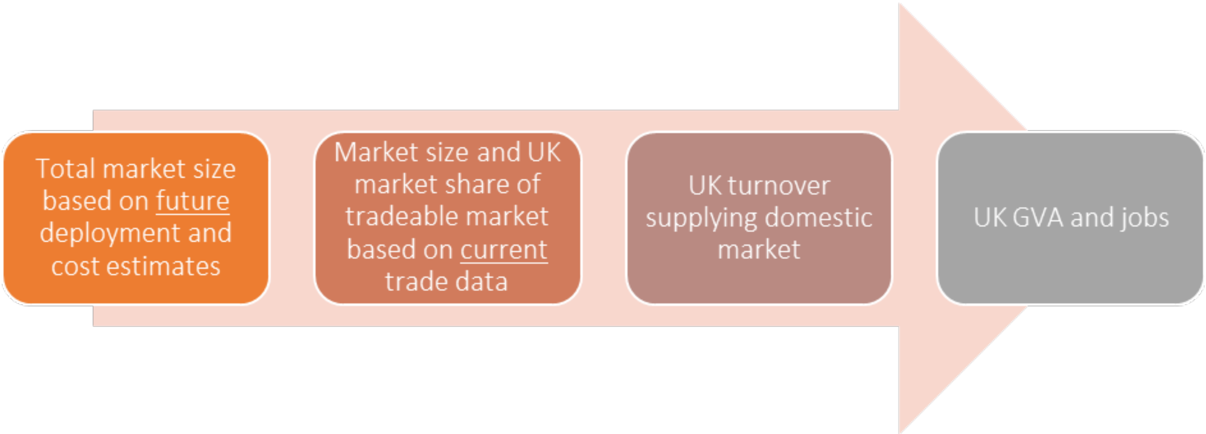
Methodology for domestic business opportunity analysis

To estimate the size of domestic business opportunities for the UK, the EINA methodology, as developed to size export opportunities, is adapted. The domestic analysis leans heavily on insight gleaned from the export analysis, particularly in estimating UK competitiveness and ability to capture market share in its domestic market. To estimate the domestic opportunity, the following methodology is used:

- The **domestic market** to 2050 is sized based on deployment and cost estimates. Deployment estimates are based on ESME modelling used for the EINAs and cost estimates are equal to those from the export work, and based on analysis for each of the EINA sub-themes.[70] For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the UK's market is likely accessible for foreign firms (e.g. electric vehicles), and how much is likely to be exclusively provided by UK companies (e.g. heat pump installation).
- For the traded share of the UK market, the UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- To estimate **UK captured turnover** the traded and non-traded markets are summed.
  - The UK's captured turnover of the UK traded market is estimated by multiplying the tradeable market by the UK's market share.
  - The UK's turnover from the non-traded market is equal to the size of the non-traded market.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs supported**.

[70] For detail on cost estimates used, please refer to the Excel calculators provided for each sub-theme, and the individual sub-theme reports.

Figure 10 **Methodology for assessing domestic business opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Domestic business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade (import) and domestic production data, where available. If the technology is immature, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to potentially increase its market share in its domestic market. This estimate is informed by the previously performed export analysis. It is triangulated using:
  - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
  - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
  - The importance of innovation in the technology.

Domestic business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The domestic assessment explicitly quantifies services such as O&M and installation, which are typically not traded but can support a large number of

jobs associated with e.g. heat pumps. For these services, the estimate of potential service jobs supported is based on:
  - An estimate of the total turnover and GVA associated with the service
  - A ratio of GVA/jobs (adjusted for productivity increases) in analogous existing service sectors based on ONS data.
- The key services to consider are based on desk research, verified through stakeholder workshops.

Worked example

1. The **global and regional markets** to 2050 are sized based on illustrative deployment forecasts, which come from ESME when available.[71] For example, deployment of nuclear power (37 GW by 2050) is multiplied by O&M costs (~12% of total plant costs) to obtain annual turnover for the nuclear O&M market (~£2.5 billion by 2050).
2. The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market. In the case of nuclear O&M, tradability is 0% being as it is not tradeable. For the domestic analysis, tradability does not directly feed into our model, but is vital to provide insight on the share of the domestic market UK firms will capture.
3. The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below. For example, for nuclear O&M the UK domestic market share is 100% because the component is not tradeable and therefore foreign firms do not capture some of the value.
4. The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**. For nuclear O&M, market turnover (~£2.5 billion) is multiplied by the UK market share (95%) of O&M to obtain UK-captured turnover (~£2.5 billion by 2050).
5. The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by labour productivity figures for that sector to obtain **jobs supported**. For example, appropriate Standard Industrial Classification (SIC) codes are chosen for nuclear O&M. This leads to a GVA / turnover multiplier (49%) that is multiplied by market turnover (~£2.5 billion) to isolate GVA (~£1 billion by 2050), which is then divided by labour productivity (~70,000 GVA / worker by 2050) to isolate jobs supported (~16,000 jobs by 2050).

[71] If deployment information is not available from the IEA, alternative projections from, for example, Bloomberg are used. Please see individual sub-theme reports for further detail.

Additional notes

The below lists areas where the analysis under the EINA Nuclear Fission subtheme deviates from the general approach and highlights any major caveats.

Decommissioning and waste management market turnover: Annual new deployment and costs cannot be used to determine the market turnover for decommissioning waste management because these costs are not realised until the end of the fuel cycle. Instead our analysis considers historical nuclear deployment in the UK (every reactor ever deployed) and existing operating reactors. The Nuclear Decommissioning Authority's (NDA) planned total expenditure up to 2050 is used to determine the market turnover associated with nuclear plants that have already shutdown. For the soon-to-be decommissioned existing Advanced Gas-cooled reactor fleet, our analysis assumes no decommissioning and waste management costs are realised for the lifetime of the plant, but that their costs will be realised in equal annual flows for the 50 years after the plant is decommissioned. This method gives the market turnover for decommissioning and waste management associated with currently operating plants and is added to the NDA figure for already shutdown facilities. Although some costs will be realised for waste management during the operation of the plant, we make the simplifying assumption that they are all realised after the plant has closed e.g. long-term waste management. This analysis assumes the UK continues to pursue a SAFSTOR policy.

Appendix 3: Assessment of business opportunities uncertainty

The assessment of business opportunities in the long term, associated with new technologies is uncertain. This assessment does not attempt to forecast what *will* happen. Instead, the business opportunity assessment attempts to provide a realistic and consistent assessment, based on current information, on the business opportunities that *could* be captured by the UK. Whether these opportunities are indeed realised depends on domestic and international developments, political decisions, macro-economic conditions, and numerous other complex variables.

As this assessment is not intended as a full forecast, a formal quantitative sensitivity analysis has not been performed. the below provides a high-level qualitative assessment of the uncertainty associated with the sized opportunity. Note, this is *not* an assessment of how likely the UK is to capture the opportunity, rather it is an assessment of the uncertainty range around the size of the opportunity. The assessment is based on three key factors driving the assessment

1. *The level of future deployment of the technology*. Technologies such as offshore wind are deployed at scale across different energy system modelling scenarios and hence considered relatively certain. In contrast, there is more uncertainty for e.g. hydrogen related technologies. The export analysis is based on 3 IEA scenarios (with numbers provided for the IEA ETP 2 degree scenario). Domestic analysis is based on a single ESME run used across the EINA process.
2. *The potential domestic market share* the UK can capture. This assessment attempts to estimate a plausible market share for the UK across relevant markets. Where this can be based on longstanding trade relationships and industries, this assessment is considered more robust.
3. *Future technology costs and production techniques* are a key driver of the future turnover, gross value added and jobs associated with a technology. For immature technologies for which manufacturing techniques may, for example, become highly automated in future, future costs and jobs supported by the technology may be significantly lower than assessed.

The ratings in the table below are the judgement of Vivid analysts based on the above considerations. The analysts have worked across all sub-themes and the ratings should be considered as a judgement of the uncertainty around the size of the opportunity relative to other sub-themes. As a rough guide, we judge the uncertainty bands around the opportunity estimates as follows:

- **Green**: Size of the opportunity is clear (+/- 20%). Note, this does not imply the UK will indeed capture the opportunity.
- **Amber:** Size of the opportunity is clear, but there are significant uncertainties (+/- 50%).
- **Red:** There are large uncertainties around market structure and whether the technology will be taken up at all in major markets. The opportunity could be a factor 2-3 larger or smaller than presented.

Table 10. **Assessment of uncertainty in business opportunities across sub-themes**

Sub-theme	Uncertainty rating	Comments
Biomass and bioenergy		• **Deployment**: Moderate deployment uncertainty; BECCS can produce negative emissions that have high value to the energy system under a deep decarbonisation pathway; there is moderate uncertainty as to whether BECCS will be used for hydrogen production, as in the ESME modelling, or for power generation. • **UK market share:** Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services and feedstocks. • **Costs and production techniques:** Relatively certain costs with most opportunities associated with labour input rather than immature technologies.
Building fabric		• **Deployment:** Depends on levels of retrofit that greatly exceed those seen to date. • **Market share:** Speculative for traded. However, majority of market untraded, highly likely captured domestically. • **Costs and production techniques:** High share of labour costs (independent of uncertain tech cost).
CCUS		• **Deployment:** Moderate deployment uncertainty; decarbonisation scenarios anticipate rapid uptake of CCUS, though there are few large-scale facilities today. • **Market share:** Moderate market share uncertainty; the UK is likely to be competitive in the storage of CO2 and EPCm services while component market shares are less certain given numerous technology choices and lack of clear competitors. • **Costs and production techniques:** Moderate cost uncertainty; the lack of large-scale facilities today makes estimating future costs difficult.
Heating and cooling		• **Deployment**: Expected to be deployed in most UK buildings by 2050. • **Market share:** some uncertainties, immaturity in markets such as for hydrogen boilers. • **Costs and production techniques:** Relatively certain given relative maturity of boilers and heat pumps. • **Deployment of hydrogen boilers or heat pumps** lead to similar opportunities for UK businesses, while heat networks present a 50 per cent smaller opportunity per household.

Hydrogen and fuel cells		• **Deployment**: Highly uncertain future deployment with a wide-range of 2050 hydrogen demand estimates across scenarios, particularly for export markets. • **UK market share**: Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services. • **Costs and production techniques:** Although deep uncertainty in future hydrogen production costs, for example electrolysis, most domestic costs are associated with labour input rather than equipment.
Industry		• **Deployment**: Relative certainty in deployment as it is based on the 2050 Roadmaps • **UK market share**: Some uncertainty due to poor quality of trade data that may not be representative of technologies within scope. • **Costs and production techniques:** Some uncertainty in costs, particularly for less mature technologies.
Light duty transport		• **Deployment**: Certainty in deployment; low-carbon vehicles will be required in any deep decarbonisation scenario. • **UK market share**: Speculative market share for a relatively immature market; a small number of uncertain future FDI investment decisions generates high uncertainty in overall business opportunities. • **Costs and production techniques:** Highly uncertain future costs, with substantial falls in battery costs a key enabler of BEV uptake.
Nuclear fission		• **Deployment**: Moderate uncertainty in future deployment with some proposed nuclear plants recently cancelled • **UK market share**: Relatively certain market shares based on robust estimates of current nuclear activity; market share growth is dependent on uncertain development of UK reactor IP; however, most business opportunities are associated with untraded activity or areas where the UK has existing strength • **Costs and production techniques:** Uncertain costs for nuclear new build, with dangers of construction overrun; deep uncertainty in costs for immature nuclear technologies, for example SMRs and AMRs.
Offshore wind		• **Deployment**: Offshore wind will be required in any deep decarbonisation scenario, with clear government commitments. • **UK market share**: Expected growth in current market shares given commitments and progress to date. • **Costs and production techniques:** Costs are relatively certain, with clear pathways to 2050.
Tidal stream		• **Deployment**: Global sites for tidal stream are relatively limited, and hence the potential market size well established. • **UK market share**: Although the market is immature, the UK has a an established (and competitive) position. • **Costs and production techniques:** Costs are relatively certain, although the impact of potential scale production is hard to anticipate.
Smart systems		• **Deployment**: High deployment uncertainty given immaturity of smart system market today and evolving business models and regulatory framework. • **UK market share**: Moderate uncertainty given immaturity of the market today and scalable nature of digital smart

		technologies, though there is UK leadership in aggregation services and V2G charging. • **Costs and production techniques**: Moderate uncertainty of cost reductions of batteries and V2G and smart chargers, though costs are expected to continue to fall.

Source: Vivid Economics

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