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Nuclear energy in the UK

Overview

Nuclear electricity is a predictable and low-carbon part of the UK energy mix, currently providing 15% of the UK's electricity. However, most existing nuclear power stations are set to close by 2030. The Government has an ambition to increase production of nuclear energy. One new nuclear power station is under construction (Hinkley Point C) and another (Sizewell C) has received planning consent. This POSTnote reviews the evidence surrounding the construction of new nuclear power stations and the ways in which nuclear might contribute to emission reduction targets, noting that:

- Globally, nuclear projects have tended to overrun in cost and time.
- New designs, which developers suggest could address historical issues, will require further development and not be available until at least the 2030s.
- Changes to the mix of electricity generation technologies will affect how nuclear can be integrated into the grid.
- Encouraging private investment requires mechanisms to reduce or share financial risk with consumers to minimise costs.
- Nuclear stakeholders suggest a Government supported programme of reactors could reduce investment risk for developers.
- There are concerns that over-emphasis on nuclear could divert investment and resources from other low-carbon technologies.

Background

The world's first commercial nuclear reactor (civil nuclear power generation will be referred to as 'nuclear' throughout) was opened in the UK in 1956.[1] This led to a fleet of first generation (Gen I) Magnox reactors using similar technology, but with many different designs (PN 457). The UK's partly retired nuclear fleet of second generation (Gen II) Advanced Gas-cooled Reactors (AGRs) were constructed between 1965 and 1988.[2] Plans for a fleet of Pressurised Water Reactors (PWRs) were cancelled, with only one built at Sizewell B, Suffolk in 1995.[3] This was the last nuclear power station built in the UK and the peak of the UK's nuclear generation capacity, which has since declined.

International nuclear capacity has plateaued since the 1990s. More recently, three-quarters of reactors started since 2011 have been in Russia or China.[4]

In the UK, between 2000 and 2021, the annual share of electricity provided by nuclear fell from 23.0% to 14.9%. In the same period, renewable generation increased from 3.0% to 39.6%.[5] The dominant reactor type in the UK, the AGRs,[4] cannot have their lifetimes extended by more than a few years for technical reasons,[2] so all will be closed by 2030.[6] Only the Sizewell B power station could have its lifetime further extended.[7]

The Government, as part of its energy security and decarbonisation strategies, has announced an ambition of up to 24 gigawatts (GW)[*] of new nuclear by 2050, about 3.5 times the current capacity[8] and half of 2021 peak electricity demand.[5]

Fusion, an alternative and unproven form of nuclear energy, is briefly discussed, but is unlikely to contribute to emission reduction targets before 2050 at the earliest.[9,10]

Current and future nuclear technologies

Nuclear stakeholders anticipate four potential phases of new nuclear, described below with indicative timeframes for commercial deployment.

Third generation (Gen III) reactor - current

Gen III reactors are similar to earlier reactors (e.g. Sizewell B) but with enhanced thermal efficiency and a more standardised design.[11] Additional layers of safety features address older, single point-of-failure systems, improving robustness and overall safety.[12] They are typically 1,000-1,4000 MW. Most Gen III reactors use water as a coolant and moderator, of which PWR designs are the most common.[13] Gen III+ have incremental design improvements from previous versions.

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[*] A gigawatt (GW) is a unit of energy equivalent to one billion watts. A megawatt (MW) is one million watts - one thousand megawatts equal a gigawatt.

Advanced nuclear technologies (ANT)

Advanced nuclear technologies (ANT) are the next generation of proposed nuclear designs. They are typically smaller than older designs and are constructed in factory-built, modular sections that can be assembled onsite (PN 580).[14] They range from a few megawatts for off-grid applications, up to hundreds of megawatts.[15] Although a few designs have been demonstrated, commercialisation will require significant further development and investment.[15] They can be categorised into two groups.

Small modular reactors (SMRs) – 2030s

Gen III water-cooled designs are the most technologically mature ANTs. In 2020, the first, highly specialised floating design came online in Russia.[15] The modularity in some cases refers to reactors designed to be connected in clusters, such as the 77 MW NuScale reactor.[16]

Advanced modular reactors (AMRs) – 2040s

AMRs use novel coolants or fuels (making them Gen IV) and might provide potential heat and/or hydrogen applications (see Benefits of cogeneration).[3,6,15,17,18] Coolants include helium (referred to as high temperature gas-cooled reactors - HTGR), lead, molten salt and sodium.[15,17] Some technologies were demonstrated in the 1960s and 70s in the UK,[3] with active demonstration plants in China[19] and Japan[20], but have yet to be commercialised.

Fusion – 2050s

Fusion may hold promise for the future, with the potential benefits of low-carbon energy, and fewer of the long-lived radioactivity risks of fuel and waste from fission.[10] Only partial demonstration of the fusion process has been achieved. Extraction of useful energy, if possible, will entail tackling significant engineering challenges and further investment.[9,21] The UK Government-funded Spherical Tokamak for Energy Production (STEP) aims to have a net energy producing demonstration ready by 2040.[22] If research and development is successful, fusion could be technically feasible by 2050, but economic competitiveness will take longer still.[9,10]

Historical issues and current construction

Globally, but particularly in Europe and North America, construction of new nuclear has faced considerable overruns of time and budget.[4,23–27] Although underestimation of cost is a common characteristic of large electricity infrastructure projects, nuclear has had some of the largest percentage cost escalations, with projects between 1969 and 2005 being overbudget by 117% on average.[28] This is despite nuclear specific elements of building a reactor being a minority of construction costs, which for the European Pressurised Reactor (EPR – see Building Gen III reactors) makes up 18%.[26]

The international factors contributing to cost reductions in isolated cases are related to repeatability and project management (see Benefits of repetition and modularity),[29–31] but also cheaper labour[26] and reduced reliance on construction-intensive safety features.[32–34] Having a nuclear programme to build multiple, identical reactors may reduce costs.[29–31] However, analysis has shown that design changes and poor project management can cause costs to increase through a nuclear programme.[25,27,35]

Although new nuclear has nearly always exceeded cost estimates, new plants are designed to operate for 60 years and could generate energy after capital repayment over 25-30 years.[4,36] If expected revenue exceeds maintenance costs, extending a nuclear licence can provide electricity at lower cost than a new build,[37,38] but power stations have also been decommissioned early for economic and safety reasons.[13]

Building Gen III reactors

The two EPRs at Hinkley Point C, designed by the French state-owned Électricité de France (EDF), are the only commercial reactors currently under construction in the UK. They will be the first new British nuclear reactors in three decades, upon expected completion in 2027.[39]

The two 1,600 MW reactors are 66.5% owned by EDF and 33.5% owned by the Chinese state-owned China General Nuclear (CGN).[40] The same design, adapted for site-specific conditions and potential cogeneration of heat and/or hydrogen, is proposed for Sizewell C.[41] It received development consent in July 2022[41] and the Government committed £700 million to the project in the 2022 Autumn Statement.[42]

Globally, EPRs built in China[43] and Finland[44] (with another near completion in Flamanville, France)[45] have incurred significant cost overruns and time delays[45–48] of up to 12 years,[48] and also experienced problems after coming online.[49,50] Although EDF say lessons have been learned from their international experience building EPRs, they say design changes to meet UK regulatory requirements make Hinkley Point C a first-of-a-kind.[51] Learning from building the first reactor has improved some aspects of build times for the second reactor at Hinkley.[51,52]

Box 1: Regulatory design assessment in the UK - generic design assessment (GDA)

The GDA is a non-mandatory regulatory process used by the UK's Office for Nuclear Regulation and Environment Agency to assess the safety, security, and environmental implications of standardised nuclear reactor designs. Site specific licensing is separate.[53] It was introduced to expedite the regulatory process, reduce project risk and encourage deployment of multiple reactors.[54] Entry is controlled by BEIS.[55] The process is technology neutral so can be used for new reactor types.[53] GDAs have been completed for four designs, with another underway:

- EDF's UK EPR (undertaken from 2007-2012; construction underway for Hinkley Point C and proposed for Sizewell C).[56]
- Westinghouse's AP1000 (2007-2017).[57]
- Hitachi-GE's UK ABWR (2013-2017).[58]
- CGN's UK HPR1000 (2017-2022).[59]
- Rolls-Royce's SMR (2022-ongoing; see SMR deployment).[60]

Other approved reactor types (see Box 1) have been proposed for the UK. The Westinghouse AP1000 is a PWR design operational in China[61] and due to come online in 2023 at Vogtle in the US.[62] The bankruptcy of Westinghouse cancelled talks in 2019 to build an AP1000 at Moorside, Cumbria,[63] but they have since resumed for Wylfa, Angelsey.[64] Hitachi-GE's proposals for the Advanced Boiling Water Reactor (ABWR) at Wylfa were abandoned in 2019 after spending £2 billion on the project, but they still own the site.[65]

Benefits of repetition and modularity

Nuclear industry stakeholders have argued the benefits of building multiple nuclear power stations of the same design, as opposed to one-off builds. A well-managed programme could transfer skills, supply chains, and scheduling between projects, reducing costs.[24,26,66] They suggest Government commitment to a nuclear programme can help facilitate this,[35,66,67] as in South Korea and Japan.[26] Multiple units on the same site may also reduce costs.[24,35] The relatively smaller sizes and factory-built modules of ANTs may offer more cost reduction opportunities through repeatability and 'economies of mass manufacture'.[68,69]

However, smaller designs reduce the benefits from economies of scale.[70–72] The economics of this trade-off against 'economies of mass manufacture' have yet to be demonstrated,[26] with cost reduction estimates approximated from other industries.[31,68,73,74] The desire to deploy multiple units quickly, reducing the time for analysis, testing, and demonstration, has been highlighted as contributing to problems in the US deploying Gen II reactors.[75]

As ANT designs will require significant development, it should be noted that nuclear costs almost always increase during the design development process.[26]

Small Modular Reactor (SMR) deployment

The Government has committed to taking at least one SMR project to final investment decision in the next Parliament.[8] The Rolls-Royce 470 MW SMR[76] has received the most UK Government support so far, receiving £210 million last year that was matched by £280 million of private investment.[77]

To justify the economics of SMR manufacturing, SMR developers are reliant on having a full 'order book'.[29,67,68,72] Rolls-Royce expect this to require more than the expected maximum UK demand (estimated as 15 reactors or 7 GW),[30] necessitating export.[78] Other SMR designs have received international attention, such as the US-designed GE-Hitachi's BWRX-300, with a reactor in Canada anticipated to come online in 2028.[79]

The NuScale SMR has received up to $1.4 billion from the US Government for the first reactor due to come online by 2030.[80] However, even with this subsidy, initial cost estimates will be exceeded significantly as it was expected to be ready by 2016.[81]

Advanced Modular Reactor (AMR) deployment

AMR reactors will require more investment in research and development before commercialisation.[31] An ongoing BEIS competition is set to invest up to £170 million into an HTGR R&D programme,[14] identified as the most promising nuclear technology to decarbonise industrial process heat and hydrogen production.[82]

Ultimately, the aim is that this could contribute to the potential deployment of a demonstration reactor in the UK by the early 2030s.[14] As commercial deployment of less mature technologies generally takes at least 10 years from the demonstration stage,[26] AMRs are unlikely to be commercially available until the 2040s. Other international designs may be deployed sooner.[83]

Future energy systems and the importance of flexibility

The UK's future electricity system will include large amounts of variable wind and solar, with a less certain capacity of nuclear. A mix of generation technologies provides greater security: low-carbon energy systems with no new nuclear are feasible but more dependent on other low-carbon technologies.[84–87]

National Grid ESO's Future Energy Scenarios includes a range of 8-16 GW of nuclear power by 2050,[84] and the Climate Change Committee's Net Zero report anticipates no new nuclear beyond Hinkley Point C and Sizewell C.[88]

Economically, because of high capital and low operational costs, but also technically, nuclear is most effective when run continuously at full capacity, whenever possible.[89] Historically, this has been possible as other generation sources (largely gas and coal) can more easily vary output to meet the remaining demand.[29]

Going forward this will be more challenging. As renewable generation is largely weather dependent and output cannot be controlled, the remaining demand will become more variable.[90]

Nuclear stakeholders claim existing reactor types can, to a limited extent, moderate generation to match demand depending on the reactor type. However, this has not substantially been observed in practice.[91,92] Future reactor types may be better designed to do this, but running at less than full capacity still represents sub-optimal operation and reduced revenue. Financial support mechanisms (see Financing new nuclear) further incentivise maximum generation,[26,93,94] which can force renewables off the network.[84,91,93,95]

This challenge will increase the value of both supply and demand side flexibility[84,93,96] in helping to reduce system balancing costs that are recovered by National Grid ESO from consumers (PN 587).[84,91,93,95,97]

Benefits of cogeneration

Currently, 65% of the energy produced by nuclear power stations is wasted as heat.[6] Making better use of this and/or directly using heat generated may help to decarbonise heating and hydrogen production (PN 645).[18,94,98] Potentially useful waste heat comes in two forms.

- High temperature heat (>200°C- see Advanced modular reactors) is extracted before reaching the generation turbine and could be used for direct industrial applications like steel manufacturing.[6,99]
- Low temperature heat (<200°C) from turbine exhausts could be used for district heating, provided proximity of suitable demand, but has significant capital costs and would not improve plant flexibility.[6]

EDF is examining the potential for hydrogen generation using waste heat at Sizewell C.[100] Several hydrogen conversion methods exist, with differing maturities, inputs (electricity, heat, or both) and technical characteristics. Wider suitability will depend on market demand, competition with other energy conversion technologies, and relative technology development rates.[6,98,101,102]

Financing new nuclear

Nuclear power has high up-front capital costs and long construction periods,[103] necessitating significant borrowing that makes the overall cost highly sensitive to borrowing rates and construction uncertainties.[74,98,104–106]

Despite expectations that private finance would replace historical state ownership, investors have been unwilling to fully take on the long-term risks. Government support is therefore still necessary to reduce the cost of borrowing,[26,107–110] particularly for new technologies that are subject to higher risks and construction costs.[35]

This is compounded by the cost of capital during construction (subject to the risk of overruns), which for PWRs in Europe and North America makes up at least 25% of construction costs.[35] Climate change has also been highlighted as increasing the investment risk profile of nuclear (see Siting nuclear power stations).[111]

In 2006, the company designing the EPR (since bought by EDF) claimed the price of electricity for the yet-to-be-built EPR would be £24/MWh.[112] In 2012, to incentivise investment in Hinkley Point C, a guaranteed, index-linked Contracts for Difference (CfD) strike price[†] of £92.5/MWh was awarded by the Government for the electricity generated over the 35 year contract.[113] At the time, the rate of return was estimated at 9%,[114] but in 2021 it had fallen to 7%,[115] with further delays likely causing further reductions.[116] A CfD mechanism is unlikely to be used again due to exposing the developer to all the construction risk (see Historical issues and current construction).[117]

A new financial support mechanism has been introduced via the Nuclear Energy (Financing) Act (2022),[118] the Regulated Asset Base (RAB - see Box 2). It is intended to be used for Sizewell C and possibly any further Gen III or ANT projects.[119] After initial ANT deployment, nuclear finance stakeholders anticipate a "self-sustaining"

[†] Under the CfD financial support mechanism, a generator is guaranteed a pre-determined strike price. When the wholesale price of electricity is below the strike price, the Government will pay the generator the difference; when the wholesale price is higher, the generator pays back the difference.

market with limited government intervention.[120] However, wider electricity markets will likely undergo significant reform before this.[121]

Box 2: Sharing financial risk – the Regulated Asset Base (RAB)

The RAB model is a financial support mechanism legislated for nuclear in 2022, that covers capital interest payments during construction to reduce the risk taken on by developers. Commencing at the start of construction, it allows licensees to collect revenues from consumers via energy suppliers, at a rate regulated by Ofgem, to recover the costs of interest on capital. As with the CfD model, a strike price provides certainty of the price received but will be reassessed every few years so nuclear operators can recover costs.[119]

Although this should result in costs lower than achievable with a CfD, consumers will be exposed to the risk of cost overruns during delivery.[122,123] Whilst this will be capped,[119] it is unclear how high this will be given historical overruns.[123] The model has been used in the UK for projects such as the Thames Tideway Tunnel and Heathrow Terminal 5.[117] In the US, it has been used for the over-budget Vogtle plant, but also resulted in consumers paying billions of dollars for abandoned nuclear projects.[123]

Siting nuclear power stations

National Policy Statements (NPS) set out Government objectives for nationally important infrastructure projects.

The 2011 NPS for nuclear identified eight potential sites adjacent to previous nuclear power stations up to 2025.[124] Nuclear was excluded from a 2021 NPS consultation, but commitment was made to a new plan beyond 2025 without a timeframe.[125]

SMR designers argue that compacted designs should allow greater generation capacity on existing sites than traditional large scale nuclear[126] and colocation with industrial demand.[6] The coastal location of UK nuclear power stations makes rising sea levels and storm surge flooding a future risk[111,124,127–129] that will need to be considered.[130]

Public support and community impacts

Public support for nuclear power generation increased from 30% to 38% between 2012 and 2021. In the same period, support for renewables went from 79% to 86%.[131,132] Higher degrees of local public and political support in areas with existing nuclear influenced the selection of sites in the NPS.[124,133,134]

Locally, construction of nuclear may provide benefits to local communities, such as jobs and direct community investment.[135,136] However, local accommodation, transportation, environment and healthcare can be strained by the scale of construction. For Hinkley Point C, 8,500 people will be onsite at peak construction, but an adaptive management process should mitigate these impacts.[137–139] Competition for employment can, however, damage local businesses and tourism income can be reduced by nuclear power stations.[139]

Nuclear fuel

Australia, Kazakhstan, and Canada have the largest reserves of uranium, the raw material used in nuclear fuel.[140] The UK has imported uranium since 1948 to process into fuel for domestic and international markets, but processing has declined with UK nuclear capacity.[141] Investment in domestic processing capacity could reduce international dependence on Russian produced nuclear fuel, which provides 20% of international demand for enriched uranium.[142] Fuel for Hinkley Point C will be provided by companies majority owned by EDF.[40]

Currently, Russia is the only country capable of commercially providing the more enriched fuel needed for AMRs.[142] The Government plans to award £75 million of funding[141] on top of other specific funding for developing domestic advanced nuclear fuel processing capabilities.[14,143,144]

Nuclear waste

Radioactive nuclear waste is stored medium-term (i.e. decades) at licensed nuclear sites, including power stations and Sellafield, Cumbria, where some is also reprocessed into a more stable form for storage (PN 531).[145]

Nuclear operators are required to set aside funds for end-of-life decommissioning and waste.[146] The internationally recognised long-term form of management for this waste is a geological disposal facility (GDF), which is a deep (200-1,000m) storage facility, engineered to keep radioactive waste separated from all ecosystems.[147–153]

Identification of a suitable site to host a GDF in the UK is ongoing, due to the long-term site-characterisation required and need to achieve community acceptance. Four communities (three in Cumbria[154–156] and one in Lincolnshire)[157] are being considered.

The role of Government

Stakeholders have argued that both over- and under-investment in nuclear could result in a more expensive, sub-optimal energy system.

Under investment could mean missing out on a low-carbon and affordable source of electricity (provided cost reductions claimed by nuclear developers are realised).[26,36,102,158] Nuclear stakeholders repeatedly stress the role of government commitment and subsidy: reducing borrowing costs; encouraging investment in skills; and providing long-term certainty for supply chains and technology development.[67] They say, given the considerable timescales and investment involved, commitment and decisions, not ambitions, are needed to avoid the recent stagnation of nuclear development.[159,160]

For comparison, Government aspirations in 2013 for 16 GW by 2030 have not materialised.[161] Great British Nuclear, a recently announced Government arm’s length body, will be tasked with addressing this through delivering a "resilient pipeline of new builds".[162]

Alternatively, over-investment could divert resources from other low-carbon measures that would be faster and more economical to deploy at scale if promised nuclear cost reductions are not realised.[75,91,163,164]

Optimism bias[‡] has historically contributed to consistent underestimations of nuclear costs and construction times.[24,26,122,165] Stakeholders who questioned the role of nuclear highlighted that, in 2020, BEIS had nearly twice as many people working on nuclear than renewable energy,[166] arguing that committing even more resources to new nuclear capacity could divert valuable resources away from technologies that should play a more prominent role in future energy systems.

[‡] Optimism bias is the overestimation of positive outcomes and underestimation of negative ones.

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