Fission Impossible? Building better nuclear for the future

ADAM SMITH

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EXECUTIVE SUMMARY

- The UK's long-term energy provision is a key issue, since security of supply concerns are now a major political concern. Very heavy investment in new nuclear-build seems inevitable, given that all currently operating nuclear plants in the UK are due be closed by 2036;
- In the Energy White Paper 2020, it was stated that electricity demand 'could double by 2050', due partly to sharply rising demand from electric vehicles (EVs). Given that every current fossil-fuel and nuclear plant, except the under-construction Hinkley Point C, will have closed by then, investment in both renewable generation and new nuclear-build seems certain to soar;
- Based on these figures and the government's targeted 25% share for nuclear generation, we estimate that ca. 25MW of new capacity will be needed. Of this new-build, it is likely that ca.12GW-20GW of large-scale nuclear plant – similar to Hinkley Point C – will be required, alongside ca.6GW-12GW of Small Modular Reactor (SMR) capacity;
- Financing new nuclear-build will be immensely challenging. For large scale plants, such as the European Pressurised Reactor (EPR), either governments, state-owned entities or plant vendors, such as Westinghouse, should undertake this financing role. For SMRs, private sector financing should be more feasible as proposed by the General Electric - Hitachi Nuclear Energy (GE-Hitachi) consortium for the planned Darlington SMR near Toronto, Canada - an obvious model for SMRs in the UK;
- In assessing nuclear plant financial models, the weighted average cost of capital (WACC) is a key
 figure: to attract investment, every effort needs to be made to lower it. With declining interest
 rates due in coming years, the nuclear new-build WACC should decline from current levels;
- The UK government is holding a procurement competition for SMR providers, with the aim of delivering operational SMRs by the mid-2030s. It is expected that the SMR models from Rolls Royce, from GE-Hitachi and probably from Westinghouse will be short-listed. In EdF's case, retaining its focus on the much larger EPR construction programme would be desirable, although - if the response from the other five SMR bidders were underwhelming - the EdF NUWARD SMR might be short-listed;
- SMR financing methods will vary, depending upon the circumstances of the short-listed companies. GE-Hitachi and Rolls Royce, both of whom are well-capitalised quoted companies, are most likely to be short-listed, although EdF's state ownership confers certain financing advantages and Westinghouse's long nuclear expertise is an undoubted benefit;
- To supplement and eventually to replace the existing competitions in place, the government should move towards an approach which is more technology neutral. This process could mean establishing a contracts for difference (CfD) price rather than just the 'picking winners' approach. It could also allow more developers to enter the UK market without recourse to taxpayer co-funding;
- Innovative new models, which the government could approve, are often held back because of the planning system. Since the older nuclear sites are typically owned by the Nuclear Decommissioning Authority (NDA) or by other players in the national nuclear network, the ability to acquire or to utilise such land, without explicit approval from the government, is often diminished. Swift approval (or the granting of no objection)

therefore needs to take place for the acquisition of first - and then ideally multiple - sites;

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- As construction of new nuclear-build proceeds, there is a strong case as envisaged by the Energy White Paper 2020 for the Regulatory Asset Base (RAB) financial model to be applied: this has already been done with the Thames Tideway Tunnel (TTT) project;
- There are various alternatives to drawing up off-take contracts, which should facilitate funding. Formulae linked to CfDs the Hinkley Point C model or to the retail price cap set by Ofgem or via an electricity equivalent to British Gas' wholesale weighted average cost of gas (WACOG) calculation are front-runners;
- Given the massive over-runs, both in terms of cost and of time, at the ongoing Hinkley
 Point C project and at Sizewell B in the late 1980s and early 1990s, some form of silo
 accounting during construction is necessary. The most expensive elements of a nuclear
 new-build project should be listed and re-costed each year via an official auditing
 process and, unless there are compelling security issues, made publicly available;
- In time, the decommissioning and related nuclear waste issues need to be resolved

 like a discarded can, the latter has been perennially kicked down the road.
 In fact, due to discounted cash flow (DCF) analysis, the present-day costs of decommissioning/waste disposal are very modest the real cost arises at the end of a new nuclear power station's life in the 2070s and beyond. Furthermore, NDA's policy should be shifted to consider how in the near and long term, the nuclear waste stockpile should be used for re-processing for domestic energy generation. This could be a revenue generating measure to offset decommissioning costs;
- Overseas, nuclear new-build is under discussion in various countries. For the UK, the Polish procurement plan, which has resulted in Westinghouse's AP1000 model being chosen by the Polish government for its first nuclear plant design, is one of the most relevant: construction of the plant in Pomerania is due to start in 2026. The Polish nuclear procurement process, including the bridging contract, should be carefully studied as it provides a very workable template that the UK can adopt;
- To ensure quicker delivery, a form of mutual international recognition of standards for SMA and for Advanced Modular Reactors (AMR) projects should be introduced.

HISTORY OF UK NUCLEAR POWER

In the inter-war years and beyond, coal-fired generation prevailed in the UK. However, in the 1950s and 1960s change was afoot. First, cheap oil imports led to the construction of oil-fired plants. Secondly, the world's first nuclear power plant was commissioned at Calder Hall, Cumbria in 1956.

Following the quadrupling of oil prices in the early 1970s and the serious cost and industrial relations issues in the coal industry – there were major miners' strikes in 1972, 1974 and 1984/85 – the UK's nuclear portfolio became increasingly important.

Initially, the first generation, but now closed, Magnox plants lay at the heart of the UK's nuclear power station portfolio. In the early 1970s, the UK-designed advanced gascooled reactor (AGR) was selected. Seven such plants, with capacities of between 1.1GW and 1.3GW each, were built. In 1995, the portfolio was strengthened with the addition of the UK's only pressurised water reactor (PWR) that was built at Sizewell B.

Unquestionably, the dreadful – and unprecedented – accident in 1986 at the Chernobyl plant in the former USSR (now Ukraine) created massive challenges for the global nuclear industry. A combination of serious design faults of the (then) USSR RMBK nuclear reactor and poor working practices were the prime causes of this disaster.

And, in 2011, the Fukushima Daiichi nuclear plant in Japan experienced massive problems following an earthquake and a tsunami, which took out most of the energy back-up systems. Subsequently, several leading countries, most notably Germany, decided to phase out their nuclear plants due to the perceived danger – rightly or wrongly – that they posed.

Since the Sizewell B plant was commissioned almost 30 years ago, no new nuclear plants have opened in the UK. However, the controversial and highly expensive – the latest cost is over £25 billion – 3.2GW EPR plant at Hinkley Point C is under construction. The most recent completion date forecast is 2029.

All the original Magnox plants have now been decommissioned and three AGRs -Dungeness B, Hinkley Point B and Hunterston – have also closed. Given the lack of investment in nuclear power in recent years, it is no surprise that the sector's contribution to the UK's generated output has fallen appreciably and is now around 16%.

Whilst the massive and far-reaching impact on gas prices of the war in Ukraine has dominated recent media coverage of energy issues – and made most of the UK's fleet of combined cycle gas turbine (CCGT) plants uncompetitive for base-load operation – the longer-term issue of climate change is increasingly coming to the fore.

Aside from the horrendous environmental damage caused by the Chernobyl disaster in 1986, especially in modern-day Ukraine and in neighbouring Belarus, and the very serious impact of the earthquake and tsunami on part of the eastern coast of Honshu island in Japan, nuclear power generation does offer very distinct environmental benefits. Crucially, there are no carbon dioxide emissions, an issue that dominates the debate about coal-fired generation, especially in the US, China and India. It is against this background that new nuclear-build has become far more of a reality in recent years, despite all the cost over-runs and time delays of the past. Many new nuclear power designs, principally of smaller-sized reactors, are being actively marketed, such as Generation IV lead-cooled fast reactors.

Whether they can meet the UK's technical requirements is still not clear - virtually all putative designs have still to secure major regulatory approvals. Crucially, too, there is the issue of financing, where the WACC is pivotal to determining the expected returns from investment in nuclear power plants.

The issue of how to finance new nuclear-build in the UK – and how best to do it – lies at the heart of this paper.

CURRENT UK NUCLEAR PORTFOLIO

Aside from the now decommissioned Magnox plants and the under-construction Hinkley Point C, the UK had an AGR capacity of almost 8.4GW. With the subsequent closure of three AGR plants and adding in the Sizewell B PWR capacity, total UK nuclear capacity is around 7GW. This figure represents under 10% of the UK's total generation capacity – a comparatively modest percentage, especially compared with France where it exceeded 60% in 2022.

However, the nature of nuclear power generation is that it operates on a base-load schedule, so that it generates around-the-clock, apart from planned – or, in some cases, unplanned – outages. Hence, its output contribution far exceeds its proportionate nameplate capacity figure.

The table below shows the UK's existing AGR and PWR nuclear portfolio. Various adjustments have been made to the original British Energy table to reflect updated decommissioning dates.

Plant	Capacity (GW)	Commissioning Date	Current Status
Heysham 2	1.25	1989	Due to close in 2028
Torness	1.25	1988	Due to close in 2028
Hinkley Point B	1.22	1976	Closed from 8/2022
Hartlepool	1.21	1989	Due to close in 2024
Hunterston B	1.19	1976	Closed from 1/2022
Sizewell B (PWR)	1.19	1995	Due to close in 2036
Heysham 1	1.15	1989	Due to close in 2026
Dungeness B	1.11	1985	Closed in 2021

Source: British Energy, Nigel Hawkins Associates

Given the age of the existing portfolio, very heavy investment is clearly needed to replace all the AGR plants that are due to close within the next few years. To be sure,

Hinkley Point C, once it is commissioned, will boost the UK's nuclear capacity. Other EPR plants, such as Sizewell C, are planned; but the time-scale of large nuclear plants is very extended – well over a decade. And even for many of the various smaller SMR designs, there will be very lengthy regulatory assessments to determine whether they should be approved for operation in the UK.

SECURITY OF ENERGY SUPPLY

In recent years, security of energy supply, as is periodically the case, has moved up the political energy agenda. Aside from the quadrupling of oil prices in the early 1970s, which effectively put an end to oil-fired plant as base-load generators, it has been three miners' strikes – in 1972, 1974 and 1984/85 – that highlighted the importance of security of supply. In fact, during the 1972 strike, a nationwide three-day week was introduced to save electricity. However, during the 1984/85 strike, which lasted for almost a year, no power cuts took place despite the depletion of coal stocks, whose levels had been built up previously.

More recently, security of supply concerns have been revived by the outbreak of war in Ukraine and, more specifically, by the widespread application of sanctions against gas from Russia. During the spring of 2022, gas prices surged. At the extreme, forward delivery contracts - on a weekly basis - priced gas at 12p per therm in May 2020 and at almost 600p per therm in August 2022 – an unprecedented fiftyfold increase. Given the very high percentage of gas input costs within the profit and loss of a CCGT, it was inevitable that the latter would become uncompetitive as a base-load generator, unless gas prices fell markedly.

TRENDS IN GENERATION SOURCES

In recent years, there have been pronounced switches in generation sources, with the production of fossil fuel-generated output having fallen by 54% since 2010, as the Graph below - published in the Digest of UK Energy Statistics (DUKES) - highlights.



Source: DUKES 2023

Most specifically, between 2000 and 2020, coal-fired generation – once the driver of the UK's industrial base – has virtually disappeared. In 1998, its contribution was around a third; by 2020, it was almost nil. Instead, CCGT plants became increasingly important until the Ukraine-driven gas supply crisis. As such, over the twenty-year period, there has been a pronounced decline in fossil fuel-generated output.

Similar conclusions apply on the nuclear front – although for very different reasons. The ageing of the UK AGR fleet has meant a declining contribution – a scenario that may begin to reverse over the next two decades.

Much of the shortfall has been made up by output from the heavily-subsidised renewables sector, and especially from wind turbines – both on-shore and off-shore – which are now making a valuable contribution to the UK's generated output.

The chart below, published by DUKES, shows the dramatic increase in recent years of renewable generation, with wind turbines, both on-shore and off-shore, dominating the sector. Future sharp increases in the contribution from the renewables sector are expected in coming decades.



MOVING TOWARDS A CONSENSUS

On the generation front, there seems to be a broad - if somewhat unstable - consensus that the key sources of future electricity should be nuclear power and renewables output, especially wind. For varying reasons, primarily environmental but also due to high gas prices, fossil fuels are being superseded, at least in the UK. Furthermore, with a tiny coal-mining sector - certainly compared with the years immediately after world war one, with over one million coal-miners at work – and high, unpredictable gas prices, **9** fossil fuel generation would struggle, even without its environmental drawbacks.

While fuel sources have been major drivers of change in the UK electricity supply industry, the demand side of the equation will become increasingly prominent as the quest for Net Zero becomes more of a priority – unless it is pulled back – and, more specifically, as EVs replace petrol/diesel-fuelled vehicles.

Projecting long-term electricity demand levels is very challenging, especially the rate and timing of switching from predominately petrol/diesel-fuelled vehicles to EVs. In the latter case, a massive increase in new generation capacity will be needed if the Net Zero EV targets are to be achieved.

The government's 2020 Energy White Paper is based upon an assumption that total electricity demand may double between now and 2050. How that generation gap could be closed is a key issue – new nuclear-build seems set to be a major part of the answer, as shown below.



A further solution lies with the renewables sector, where wind generation is the dominant force. In the longer term, major UK investment is expected in off-shore wind plants. Solar generation, too, will have a role to play, especially in the south of England.

The 2020 Energy White Paper shows the surge in renewable generation that is widely expected in the next 30 years, as shown at the botton of this section.



NEW NUCLEAR-BUILD IN THE UK

A key assumption in the 2020 Energy White Paper is that electricity demand 'could double by 2050'. If this projection were correct, there would be major implications on the UK power sector, with massive new-build required.

Subsequent events may prevent such a scenario becoming a reality. The Net Zero target in 2050, though widely supported politically, is immensely costly and may be pulled back, either by rolling back the date to 2060 and beyond or by converting a legislatively-backed commitment to an aspiration.

However, in seeking to be prepared to meet the doubling of electricity demand by 2050, it has to be recognised that every existing coal-fired, gas-fired and nuclear power station, including Sizewell B which is due to close in 2036, would have been decommissioned. But Hinkley Point C should still be generating output in 2050.

Indeed, by 2050, the government has assumed a vast expansion of renewable power generation, with up to 75% of UK capacity being met through renewable resources. Off-shore wind will be the key driver, with the government's seemingly optimistic plans to quadruple its capacity by 2030. In aspiring to the 75% figure, it is assumed that real advances are made in the ability of a wind plant to store its generated power, not only for days but also for weeks. Only the two very capital-intensive pumped storage plants at Dinorwig and Ffestiniog in Wales, with capacities of 1.7GW and 360MW respectively, currently offer that option.

The doubling of overall capacity – as assumed in the higher case scenario in the Energy White Paper 2020 – and the aim for nuclear power to account for a quarter of generated output in Great Britain (GB) by 2050 give rise – after certain adjustments including the commissioning of Hinkley Point C – to a need for some 24GW of new nuclear capacity 11 to come on stream by 2050.

As things stand, this additional 24GW of new nuclear capacity would probably be split between EPRs and new SMRs. In reality, this split will be very dependent upon how the SMR initiatives – both in terms of securing regulatory approvals and being cost competitive – develop in coming years.

EPRs

On the EPR front, there is no doubt that EdF remains a preferred supplier, even though its Hinkley Point C project has seriously over-run – and at roughly £25 billion remains significantly over budget. Unless the SMR procurement competition throws up unexpected cost savings, when compared with EPRs, it seems probable that further EPRs or their equivalent will need to be built.

The Hinkley Point C plant has a capacity of 3.2GW and the proposed Sizewell C plant is expected to have a similar capacity. If two further plants were ordered before the end of 2040, there should be four EPR plants, with a capacity of almost 13GW in operation – thereby meeting around half of the government's higher case 2050 projections.

There are other large-scale nuclear power plant alternatives, such as the Westinghouse AP1000 which was recently selected by the Polish government as the design for its first nuclear power plant; this model may well come into the reckoning for the UK, perhaps to be developed alongside further EPRs.

SMALL MODULAR REACTORS

If between 12GW and 20GW of new capacity were met by EPRs or their equivalent, then between 6GW and 12GW of capacity would need to be provided by new small modular reactors (SMRs). Assuming an average capacity of 400MW per plant, this would suggest at least 20 new nuclear plants – an unprecedented number for the UK. Most would be built on existing sites and many units would be built alongside one another.

Nonetheless, it would be a formidable challenge, although major efforts have been undertaken over many years to design and build SMRs, driven in part by the various challenges that have been faced in building new nuclear plants with capacities of 1GW+.

Reputedly, there are around 80 SMRs designs in circulation. But none has yet been built to a commercial scale and very few have secured any meaningful – in terms of commercial operation – regulatory approvals in the UK and abroad.

Against this background, the government has launched a procurement competition for new SMRs to be built in the UK.

Among the key criteria specified for this procurement initiative is the requirement to be 'most able to deliver operational SMRs by the mid-2030s'. Given the regulatory process

is at a very early stage and the fact that many SMRs still have many technical issues to overcome, this base requirement looks optimistic. Moreover, given the construction time for SMRs – admittedly far shorter than that for larger EPRs – key decisions will need to be taken within the next three years or so.

The table below provides brief details of the six SMR contenders. The published data on SMRs, especially on the financial front, is scant and any comparisons are potentially misleading.

Company	Owner	Model	Capacity	Other Issues
EDF	French state	NUWARD	340MW (2x170MW)	PWR, based on EPR design
GE-Hitachi	Market quoted (indirectly)	BWRX-300	300MW	Scaled down BWR design
Holtec	Private	SMR-160+0	320MW (2x160MW)	PWR, with 80-year design life
NuScale	Market quoted £0.5bn cap	VOYGR	462MW (6x77MW)	Some design approvals but projected 75% cost increase since 2020
Rolls Royce	Market quoted £20.3bn cap	SMR Unit	470MW	Approval mid 2024? 90% manufacturing and assembly in house
Westinghouse	Brookfield	AP300	300MW	PWR, scaled down from the AP1000 model

Source: Nigel Hawkins Associates, Company websites

Ideally, the outcome of the SMR procurement plan will give rise to the emergence of either two or three high-quality contenders, with Rolls Royce's SMR, the GE-Hitachi BWRX-300 and probably the Westinghouse AP300 being the most likely to be selected. With regard to EdF, the government may prefer to concentrate the former's efforts on the roll-out of new nuclear-build, where the capacity exceeds 1GW. While the USbased – and privately-owned Holtec – has had its successes, it looks to be the outsider of the sextet, along with NuScale which has suffered major setbacks of late with the cancellation of its Utah project and the soaring cost increases that it has announced.

Given HM Treasury's well-known obsession with 'price tension', it is unlikely that a single design will be chosen. More detailed information will be required on capital expenditure costs, not just for the first-of-a-kind (FOAK) plant but also for subsequent units.

NEW NUCLEAR PLANT CONSTRUCTION COSTS AND OTHER PLANT MODELS

Recently, considerable concern has been expressed about the likely costs of SMRs. The original intention was that their price, because of major design advances and substantial off-site building, would mean that – on a per MW basis – they would be very much cheaper than EPRs. However, recent increases in various plant-related costs indicate that this viewpoint may be mistaken.

In reality, it is premature to assess – and indeed to compare – the relative costs of the six SMRs being considered by the government. Insufficient information is publicly available, while the few reported SMR selling prices are hardly comparable, given the differences in their calculation, especially with respect to interest costs. By way of example, Rolls Royce has quoted a figure of £1.8 billion for a fifth SMR plant, equivalent to £3.8 million per MW.

Importantly, the US-based NuScale confirmed a very sharp price rise for its first SMR, which it had planned to build in Utah. Since January 2021, its capital expenditure price for this FOAK plant had increased from \$5.3 billion (£4.3 billion) to \$9.3 billion (£7.6 billion): this very pronounced price rise has had serious repercussions.

In particular, the putative client, Utah Associated Municipal Power Systems (UAMPS), a coalition of energy members numbering some 50 entities, and NuScale mutually agreed in November 2023 to terminate this agreement. The lack of 'subscriptions' – presumably driven by the soaring cost increases of late - was cited as the prime reason for this U-turn. This development is not only a major blow to NuScale, whose shares have plunged by 73% so far during 2023, but also to the nascent SMR sector.

Furthermore, before the termination of its Utah project, NuScale had highlighted several of the cost drivers since January 2021, namely:

- Fabricated steel plate, up by 54%;
- Carbon steel piping, up by 106%;
- Electrical equipment, up by 25%;
- Fabricated structural steel, up by 70%;
- Copper wire and cable, up by 32%.

Importantly, since January 2021, interest rates have moved up sharply so that NuScale's WACC on its now abandoned Utah plant would have risen appreciably in the intervening period.

Capital costs are also very dependent upon the number of units built, with materially lower costs being expected for the fifth unit compared with a FOAK unit. Hence, in order to attract more companies who have or are in the process of developing SMR or AMR reactors, the government should encourage developers to create plans to deliver a full fleet of reactors, rather than implementing a piecemeal approval process – the original aim of the Sizewell B PWR project in the 1980s. This proposed reform will aid nuclear innovation, support opportunities for the wider UK supply chain, and support investment in new and enhanced facilities. Such a fleet deployment approach should also generate economics of scale and eventually lower bills for energy consumers.

SMRs are widely regarded as being Generation III technology - in effect, lower capacity models of existing nuclear plant designs. But Generation IV models, based on various new design technologies, are showing significant advances especially with regard to Advanced Modular Reactors (AMRs). Many proposed Generation IV reactors are fuelled with mixed oxide (MOX) - a combination of depleted uranium and plutonium - which can avoid the related mining operations. Instead, some are designed to use fuel waste from across the nuclear industry. Furthermore, some Generation IV models offer innovative coolant systems.

NEW NUCLEAR-BUILD IN THE EU

Nuclear power policies have varied considerably amongst leading EU members over the years; in several cases, there have been pronounced U-turns, most notably from Germany after the Fukushima accident in 2011. Aside from the catastrophic Chernobyl disaster in 1986 in the former USSR (modern-day Ukraine), the most notable developments have been:

- France in the 1970s, following the quadrupling of oil prices, a vast nuclear power building programme was undertaken. As a result, although at considerable cost, France acquired a large portfolio of nuclear plants, almost all of which are now owned by EdF, an integrated power company that is now being renationalised. France's focus on nuclear power has been beneficial during the recent surge in gas prices. However, the legacy is a massive repair bill; furthermore, a new EPR1000 is being constructed at Flamanville on the Cherbourg peninsula. Its costs have soared and its projected delivery time has been greatly extended;
- Germany having embraced nuclear power, notably in Bavaria, Germany decided to
 phase out nuclear power shortly after the nuclear accident at Fukushima in Japan in
 2011. All its nuclear power plants are now closed; politically, it would be very difficult for
 Germany to build any new nuclear plants given the role of the Green Party in government;
- Italy following a referendum, in the wake of the Fukushima accident in 2011, Italy's electorate rejected proposals to build any new nuclear power plants;
- Sweden until recently, a similar nuclear power policy to Germany had been adopted; this stance has now changed as Sweden is seeking to acquire 2.5GW of new nuclear capacity by 2035 and to undertake a massive expansion of nuclear generation plants by 2045;
- Spain various nuclear power plants have operated for many years but there seems no realistic prospect of new nuclear-build, especially since wind and solar power generation have taken off in Spain in recent years;
- Finland the first EPR1000 in the EU was ordered by Finland. It is now operational, after massive cost overruns and delays of over a decade. A second such plant may also be built near the same site at Olkiluoto on Finland's west coast.

THE POLISH NUCLEAR PROCUREMENT TEMPLATE

In October 2022, the Polish government confirmed that the Westinghouse AP1000, a PWR model – with considerable assistance from the US government – had been chosen for Poland's first nuclear power station at Lubiatowo-Kopalino in Pomerania.

Furthermore, the Polish government has confirmed that a total nuclear power capacity of 6GW to 9GW (including the Lubiatowo-Kopalino plant) is being targeted by 2040:

either two or three locations will be used as generation sites.

For Poland, whose economy is thriving, this initiative marks a radical change from the past, where coal-fired generation prevailed. Last year, it provided over 65% of Poland's electricity, led by the vast Belchatow plant, whose capacity of over 5GW dwarfs the near 4GW of capacity that Drax used to offer in the past.

These nuclear-related developments in Poland have considerable relevance for the UK power sector in certain respects.

First, the Westinghouse AP1000, which has an impressive operating record, was chosen for various reasons. The fact that it is partly US-backed, presumably through plant vendor finance, was undoubtedly in its favour.

Secondly, a forward-looking contract system has been established, covering both a bridge contract and an execution contract. The former addresses a wide range of preliminary issues, such as planning; since the bridge contract has already been signed, work can begin. The crucial execution contract, which will inevitably be a long and complex document, will follow in time.

In short, Poland's nuclear power procurement process merits detailed study by both UK ministers and the relevant officials. As part of such a review, the government should also consider how to align mutual recognition of certification standards for SMR and AMR nuclear power projects. This process could quickly highlight best practice from OECD countries with either new or well-developed nuclear industries (especially countries – such as France – which have very large amounts of nuclear power plant construction.) The objective for the UK would be to help expedite the approval process of new projects - and is especially imperative in light of the UK's Net Zero transition commitments and of the mass closures of existing nuclear power sites.

FINANCING IMPLICATIONS OF NEW NUCLEAR-BUILD

As history has shown, building new nuclear power stations is both very expensive, and highly unpredictable. Heavy cost over-runs and quite excessive time delays have been all too common. The EPR at Olkiluoto in Finland, the first such model to be built in Europe, is estimated to have cost roughly $\in 11$ billion (£9.6 billion), compared with a budgeted figure of around $\in 2$ billion (£1.7 billion). In terms of delivery, the original projected completion date of 2010 was missed by no less than 13 years: Olkiluoto was finally commissioned in May 2023.

Hence, in addressing new nuclear-build, financing issues are crucial. Moreover, it is proposed that different financing arrangements should apply to the planned EPR new nuclear-builds, most notably to the Sizewell C project, and to the various SMRs that are expected to be ordered after the results of the competition involving six competing SMR models.

The immense challenges in securing finance for the Hinkley Point C project indicate

that either governments, state-owned nuclear energy companies or plant vendors are best placed to provide the massive amount of financial investment that is required.

Although it is possible that a third party could emerge – such as South Korea's KEPCO, one of whose subsidiaries is involved in designing Poland's second nuclear power plant at Patnow – the reality is that the UK government must be the lead financing party for future large-scale EPR projects. Despite very heavy investment demands to modernise its extensive French nuclear portfolio, the UK government will expect major investment from EdF, whose renationalisation by the French government is expected to be completed shortly.

Given various well-publicised security issues, proposed investment from Chinese organisations has effectively been spurned, despite the original intentions of the Sizewell C backers to embrace it.

US investment for new EPR plants in the UK, apart from plant vendors, and - possibly - some complex, financially-orientated deals involving small shareholdings, looks unlikely.

It should be added that, in terms of capacity, there are few obvious alternatives – apart from Westinghouse's AP1000 and the South Korean-based KEPCO's AP1400 - to the EU-developed EPR. Of course, capacity could be enhanced by developing large numbers of SMRs to meet nuclear capacity requirements.

Whilst SMRs are a relatively new concept, their development has been undertaken over many years. The obvious drawbacks – inter alia planning, construction and financial – of commissioning vast nuclear plants, such as the AGRs and – most notably – of both Sizewell B and Hinkley Point C, have provided powerful incentives to find alternative solutions.

In theory, SMRs, being far smaller and much easier to construct, meet the criteria, especially as the financial arrangements are less challenging. Whether they will be competitive on cost grounds remains uncertain: the NuScale experience with UAMPS is not reassuring.

However, the reality is that no SMR has been approved for a major project the as yet, although NuScale has secured approval from Nuclear Regulatory Commission (NRC) its VOYGR SMR design. for

Unlike with the EPR, there are better prospects - though it will not be easy - to secure private sector investment, probably on a similar basis to conventional independent power projects (IPPs). Nevertheless, some state involvement seems inevitable, both via some direct investment and the provision of financial guarantees to protect investors if serious issues were to arise - a major nuclear power station accident somewhere in the world being an obvious example.

Hence, in addressing the financing issue, the IPP model, which has been used in the power sector for many years, provides the obvious template. Importantly, GE, the US behemoth, has recently concluded a new nuclear-build investment agreement via its joint venture with Japan's Hitachi, along with other institutional investors – including Ontario Power Generation (OPG) – to finance the construction of a SMR at Darlington in Ontario, Canada.

This agreement is expected to be widely replicated as more SMRs move towards financial close – although it will take many years. This nuclear-based IPP template arguably underpins the financing of SMRs. The involvement of GE is particularly important. Although its share price rating has been sorely hit in the last two decades – its market capitalisation is now dwarfed by Amazon and Apple – it remains an American institution.

In the UK, the SMR competition is underway, with six short-listed design models. To adjudicate on the six models submitted will be no straightforward task. After all, none of them, with the notable exception of NuScale's VOYGR's design technology, has acquired regulatory approval. It is likely that at least two winners will emerge from this process, despite the many uncertainties.

It is widely presumed that the Rolls Royce 470MW SMR unit will be one of the designs chosen, especially given Rolls Royce's expertise in providing nuclear power to the UK submarine fleet. Moreover, Rolls Royce currently has a market capitalization of around £20 billion so it is well-placed to undertake private sector investment in the sector.

Of the remaining five candidates, the GE-Hitachi model is in a strong position, especially given its Darlington investment. The combination of GE's immense experience in power engineering, its robust finances – despite the challenges of recent years – and its ability to provide private finance is undoubtedly attractive.

Westinghouse's famous name in power engineering – its AP1000 model is highly regarded – should be beneficial but it has undergone many ownership changes during the last two decades. Having bought the business for \$46 billion in 2017 from Toshiba, Brookfield Asset Management is now its majority shareholder.

While the NuScale design offers some benefits on the regulatory issue, there are underlying concerns on several other fronts, especially on its costings, on its technology and on its relatively small size, which limits its financing options. The cancellation of its Utah project is undoubtedly a major setback.

If EdF were selected for procurement of SMRs, the finance arrangements may be similar to those proposed for its EPR orders, although it may be possible, given the perceived lower risk of SMRs, to secure some private sector investment. In reality, the government may decide that EdF is best focused on delivering its large-scale EPR orders and its formidable investment requirements for new nuclear plants in France.

In assessing the expected financial returns from any long-term power project, the issue of the WACC is crucial. Given the extended length of any nuclear power station construction, higher interest rates drive up the accumulated net debt figure. In the case of large EPR projects, it can be many years – and often decades – after commissioning before the outstanding net debt is actually paid off.

With recent increases in UK interest rates, 10-year gilt yields have not surprisingly risen sharply – up from just over 0.6% in July 2020 to 4.1% currently.

If future EPR investment is to be financed directly by governments or by state-owned undertakings, WACC increases are less of an issue – they can be absorbed by public expenditure budgets, as is the case currently with Network Rail's net debt of almost £60bn.

For any private sector investors in new SMR projects, who face real uncertainty regarding long-term returns, the impact of rising WACCs is an added risk.

To address these concerns, the government has proposed to integrate a regulatory asset base (RAB) model into the financial regime for new nuclear-build. In its 2020 Energy White Paper, the government indicated that, after consultations, there was a role for the RAB model for 'private investment in new nuclear generation'. Further, it concluded that 'a RAB model remains credible for funding large-scale nuclear projects'. In this case, the reference to 'large scale' is taken to cover the financing of SMRs where it will be crucial – and not to 1GW+ EPR projects where securing any major private sector investment, apart from plant vendors, is likely to be very challenging.

In essence, the RAB model provides a return which is calculated from the asset value that has accumulated since the project's start. Hence, investors receive a financial return even before any generated output from the new nuclear plant is delivered.

The RAB model, widely used in the regulation of privatised utilities such as the water sector, has also been deployed in the case of the roughly £4.5bn Thames Tideway Tunnel (TTT) scheme. To date, it has proved successful, with relatively modest over-runs, although some construction delays occurred due to the covid-19 pandemic. Furthermore, Thames Water's retail customers are already paying for this project even though it has not yet been commissioned. Undoubtedly, TTT provides a solid template for the RAB model to be applied, especially for SMR financing and, possibly also for EPR financing, despite lesser relevance in the latter case.

CONTRACTUAL ARRANGEMENTS

At the heart of the nuclear financing issue are the contractual arrangements covering a new plant's output. To lower their risk, investors generally prefer – on the right terms – a long-term contractual agreement that sets a pricing regime and an expected output level from the plant. Generation plants that operate on a merchant base, whereby the output is sold to the market at the prevailing price, are regarded as higher risk: the merchant selling price per MWh may be far lower when output is generated compared with the price at the time the plant achieved financial close.

To ensure that there is viable market for a new plant's generated output, there is a case for imposing on all major energy suppliers – small suppliers would be exempt - an obligation, as part of their supply licences, to take a certain percentage of their electricity requirements from new nuclear power operators. This arrangement would underpin the finances of a new nuclear power station.

In terms of determining a selling price, the government specified a figure of £92.50 per MWh, based on 2012 prices, for the contracts for difference (CfDs) that were applied for output from Hinkley Point C. Inevitably, that figure, a very long-term 'best estimate', has looked wildly inappropriate at times – and especially before the beginning of the war in Ukraine when long-term, North Sea wind-generation CfDs were being signed at prices of below £38 per MWh, based on 2012 prices. To that end, establishing CfD prices has to be done early on in the development cycle. This principle is especially important if multiple reactors are constructed by the same company or consortium of companies: the

first may be loss-making, but the average generation cost may be lower than the CfD price after several more are constructed.

With a retail price cap currently in operation – based on the latest market prices – there is a case for using this figure as a yardstick: it would need to be averaged out to avoid short-term distortions. Hence, the strike price could be calculated as a percentage of recent price cap figures, although the impact of the war in Ukraine on price cap data might need to be eliminated in its entirety. This link would avoid the very long-term 'best estimate' process - which was inevitably speculative - that was inherent in the original Hinkley Point C strike price formula.

Alternatively, an electricity equivalent of British Gas' weighted average cost of gas (WACOG) figure – though no longer published – could be developed, both for the electricity sector and, in time, for nuclear power output. In essence, it would be comparable with the wholesale equivalent of the retail price cap.

More generally, the profound security of supply concerns of recent years should make it far easier to drive new nuclear-build through to fruition – and especially if Net Zero is to become a reality, as is widely – though not unanimously – supported.

In the long term, the government should consider adopting a new approach which is more technology neutral when providing regulatory support for new nuclear build. Such a reform could, for example, entail establishing a CfD price, rather than the current 'picking winners' approach.

OTHER FINANCIAL ISSUES

While the 2020 Energy White Paper prescribed a deadline of 2025 for a new nuclear plant to have reached financial close, it is intended that many others, whether EPRs or SMRs, will be built subsequently.

More specifically, the FOAK principle should enable major cost savings to be achieved, if a fleet of similar new nuclear reactors were commissioned. This thesis was emphasised in the prolonged debate about the PWR that was eventually built at Sizewell B. In the event, this plant remains the UK's only PWR, so that the projected FOAK savings never materialised. It explains, too, why the Rolls Royce SMR is costed at £1.8 billion, on the basis that the first four plants in the proposed fleet will cost significantly more.

In common with other major UK infrastructure projects, including the now scaled-back HS2 and numerous ill-fated defence projects, new nuclear-build has suffered from serious cost and time over-runs. The ongoing Hinkley Point C project and the Sizewell B nuclear power plant in the early 1990s are obvious examples.

To address these issues, it is proposed that a silo accounting system should be introduced, which would track the cost movements of the key construction elements each year. Hence, the quoted price of, for example, the most expensive 50 pieces of equipment, along with labour costs, could be specified at the outset and updated, in cost terms, through an annual external audit. While not ideal, it would provide some guide as to how the project was progressing in financial terms: movements in interest costs would

need to be tracked separately. Furthermore, aside from sensitive security-related items, these figure could be published and regularly updated. Any objections on commercial sensitivity grounds should only be accepted if the case is compelling.

While the National Audit Office (NAO) does undertake some analysis, their conclusions are often highlighted once a particular project is widely known to have seriously overrun in cost terms: such shortcomings are normally accompanied by time delays.

PLANNING AND THE APPROVAL PROCESS

Many serious shortcomings to UK infrastructure projects, especially in terms of UK new house-build, are due to planning issues which often cause excessive and unacceptable delays. The notorious 340-day Sizewell B public enquiry in the early 1980s, which considered the case for building the UK's first PWR, is the obvious example.

For new nuclear-build, a national approach, based primarily on enhancing the UK's security of supply, should be paramount. Nimby-led arguments should be set aside unless there is a compelling case. Furthermore, the widely-publicised and – in some instances totally unacceptable – compulsory purchase policy pursued by HS2 planning executives should not be replicated. Fortunately, for new nuclear-build SMRs and AMRs, the land element involved, unlike for a new railway line, is comparatively minor.

Furthermore, it seems very probable that many new nuclear-build projects will be undertaken on sites where nuclear power stations are currently sited, such as Sizewell, or where historically there have been nuclear power plants, such as Trawsfyndd in Wales where a Magnox plant was commissioned in 1965 and closed in 1991. In such localities, there has been an element of acceptance locally – built up over a long period - of a nuclear plant operating nearby.

Aside from facilitating the planning issue, operational or former nuclear sites also offer the benefits of either existing power links into the National Grid or of installing replacement connections at a much lower cost. By way of example, there are obvious pylon-related savings.

Additionally, existing potential sites for new nuclear-build should be freed from Office for Nuclear Regulation (ONR) and Nuclear Decommissioning Authority ownership and control. This change has the potential to allow construction of SMR and AMR projects without direct taxpayer subsidy (subject to companies having sufficient capital to meet construction and operational needs) and would complement - but not replace - the existing Great British Nuclear (GBN) competition.

Subsequently, a new rules-based system should be put in place for potential sites for AMR projects. This reform could allow a presumption for approval and could function in a similar way to permitted development rights for residential construction in the UK. Potential developers would be able to identify suitable sites and these could be acquired on a 'use it or lose it' basis. The 'use it or lose it' principle would be especially appropriate for existing nuclear sites where competition is strongest. This proviso would allow developers with the requisite finance to proceed more quickly and at their own risk.

NUCLEAR WASTE

Inherent in the debate about new nuclear-build is the contentious issue of nuclear waste disposal, which has been the subject of various enquiries for decades. Indeed, the highest grade of nuclear waste is currently stored at Sellafield, whilst much of the lowest grade of waste is held at nearby Drigg. Despite many proposals to construct a long-term, underground nuclear repository, siting discussions remain ongoing.

In purely financial terms, the waste disposal issue is not a high priority because of the impact of discounted cash flow analysis. If new nuclear-build were operational by the early 2030s, the long-term disposal of waste arising from its plant decommissioning would probably not take place until the 2070s. By discounting the projected cost of nuclear waste decommissioning to the current value of money, the discounted cost is quite modest – and certainly when compared with the construction cost of new nuclear-build.

However, the fact remains that nuclear waste management remains an expensive longterm consideration. As such, the government should consider alternative ways to handle the costs of nuclear waste. In the longer term, a substantial amount of nuclear waste could be converted into nuclear fuel, thereby enabling innovative technologies to develop. Hence, the NDA should place less emphasis on seeking to store nuclear waste - potentially for thousands of years - in an underground repository and more in reprocessing it into nuclear fuel which could be used in domestic energy production: current government policy does allow for this practice. By way of example, the NDA states that its aim is for all plutonium to be re-used or disposed of by 2120. With recent technological advances, especially in AMR technology, nuclear fuel re-use should be pursued as a priority.

CONCLUSION

This paper has addressed the UK's generation capacity options at a time when Net Zero is widely seen as a political priority - and at a time when a major switch away from petrol and diesel to EVs is planned. In terms of the latter, ensuring that there is sufficient generation capacity is a major challenge. The 2020 Energy White Paper assumed an annual higher case GB demand of almost 700TWh, compared with the 2022 demand figure of 320TWh.

With coal-fired generation now virtually non-existent and base-load gas-fired generation mostly uneconomic, due to soaring gas prices, the responsibility for baseload generation is increasingly falling onto the nuclear sector, whose current fleet – Sizewell C excepted – is due to have closed by the end of the decade, during which Hinkley Point C may have been commissioned. As such, a massive nuclear new-build programme is needed, both for the larger EPR plants and for the smaller SMRs.

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