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Nuclear Free Local Authorities
Councils working for a renewable, safe and peaceful future

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Small & Advanced Modular Nuclear Reactors and the UK – low carbon energy panacea or another nuclear 'white elephant' project?

i. Overview of Policy Briefing

This edition of the NFLA New Nuclear Monitor has been kindly developed by Professor Stephen Thomas, Emeritus Professor of Energy Policy at Greenwich University. It follows on from his recent presentation to the NFLA Welsh Forum webinar on the 9th April. The briefing paper considers an issue that is currently being pushed by the nuclear industry and the UK Government – the proposed development of small modular nuclear reactors (SMRs) and advanced modular reactors (AMRs) over the next decade. This has become a significant issue in local government as one of its main proponents, Rolls Royce, has been giving presentations to several English and Welsh Councils, mainly those who have previously hosted Magnox or AGR nuclear reactors.

SMRs / AMRs are being touted by the nuclear industry as a core alternative to large nuclear reactors with an important role to play in the critical challenge to tackle the climate emergency. The industry is particularly active in Canada and the United States, parts of Eastern Europe and the Middle East, but recent opinion pieces have even advocated for use of the technology in Ireland, Australia and Estonia.

This report follows on from an international analysis that Professor Steve Thomas, Professor M V Ramana, Dr Paul Dorfman and the NFLA Secretary Sean Morris put together as a joint NCG / NFLA report on 'Prospects for Small Modular Reactors in the UK and Worldwide'. This was developed and published in July 2019. This can be found on the NFLA website: https://www.nuclearpolicy.info/wp/wp-content/uploads/2019/07/Prospects-for-SMRs-report-2.pdf

With SMRs heavily trailed in the Prime Minister Boris Johnson's 'Ten Point Plan for a Green Industrial Revolution', this briefing paper seeks to consider progress with the technology, the challenges around its development and what prospects there are for any SMRs / AMRs being developed in any significant number in the UK. Like with the July 2019 report, this policy paper is sceptical the technology will progress in the manner its advocates may wish of it.

The NFLA sincerely thanks Professor Thomas, Professor Ramana and Dr Dorfman for their ongoing analysis in this area of nuclear policy.

1. Introduction

As part of the government's 10-point plan for a 'green industrial revolution', unveiled in November 2020, there appeared to a major commitment to new, small reactor designs. (1)

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It has announced measures that seemed to commit up to around £600m of government money to support development of such designs via its Advanced Nuclear Fund. However, this money was all subject to 'value for money and future spending rounds' and is therefore far from firmly committed.

2. What are the technologies?

The UK Government uses a range of acronyms and other nuclear jargon that makes deciphering the announcements difficult for the non-specialist. The main ones are: Small Modular Reactors (SMRs), Advanced Modular Reactors (AMRs), and Advanced Nuclear Technologies (ANTs). The UK Government's announcement also included funding for fusion reactors despite this being a very different technology.

2.1. Advanced Nuclear Technologies (ANTs)

This UK term covers the range of new technologies with the main common feature that they are smaller than the reactor designs currently on offer.

2.2. Small Modular Reactors (SMRs)

This is an internationally widely used term to cover smaller reactors regardless of technology. The International Atomic Energy Agency defines SMRs as reactors smaller than 300MW of electrical output. (2) The UK government appears to restrict use of this term to Pressurised Water Reactors (PWRs), the type operating at Sizewell B and under construction at Hinkley Point C. However, given that the Rolls Royce PWR SMR is expected to produce 470MW, it is flexible on what constitutes 'small'.

2.3. Advanced Modular Reactors (AMRs)

In 2000, the Generation IV International Forum (GIF) was set up by ten governments, led by the USA, of a larger number of countries with active nuclear power programmes, including the UK, to develop new reactor designs, so-called Gen IV. (3) Gen IV designs were required to be cheaper, safer, and generate minimal waste, be proliferation resistant and use uranium reserves more economically than existing designs. It identified six designs that it saw as the most promising including both the advanced designs that have received UK Government funding. A 2002 roadmap produced by GIF foresaw that these designs would be available for commercial deployment by 2030 or earlier. (4) However, by 2018, GIF's time perspective was a readiness for commercial fleet deployment by around 2045 (for the first systems). (5) All six designs will require significant technological progress for them to be deployable.

AMR covers reactor types that at most have been built as prototypes or demonstration reactors, or in some cases not built at all. Despite this, ***all these designs have been talked about for 50 years or more.*** There are now four main designs currently being discussed:

- The ***sodium-cooled fast reactor*** (SFR) has been built at a number of sites worldwide, including Dounreay (Scotland) but the operating record for it is poor.
- The ***high temperature gas-cooled reactor*** (HTGR) has also been built at some sites worldwide, including the Dragon reactor (England) but also with poor results.
- The ***molten salt reactor*** (MSR) and the **lead-cooled fast reactor** (LFR) have not been built as power reactors despite a long history of research into the concepts.

The UK Government is presently providing funding for an HTGR and an LFR design (see below). The UK Government highlights the high reactor temperature, 800+C, as a likely characteristic of these designs, of importance if they are to be used to manufacture hydrogen.

2.4. Fusion Technology

Fusion has long been seen by some as the ultimate answer to power generation, providing, it is claimed, unlimited power. In a fusion process, two lighter atomic nuclei, expected to be the nucleus of a hydrogen atom, the smallest atom, combine to form a heavier nucleus, while releasing energy. For fission, the basis for all operating rectors, some of the largest elements, usually uranium, split (fission) causing more fissions and the release of energy. However, at best, fusion technology has always been several decades away from commercial availability.

In the 10-Point plan, the government announced continued support for the Spherical Tokamak for Energy Production (STEP). It said: '*We are already providing £222 million for the visionary STEP programme, which aims to build the world's first commercially viable fusion power plant in the UK by 2040, and £184 million for new fusion facilities, infrastructure and apprenticeships to lay the foundations of a global hub for fusion innovation in the UK.'* (6) Given the clear differences between this and the 'fission' technologies noted above, this briefing note will not consider fusion in any specific detail.

NFLA has developed a separate New Nuclear Monitor 62 on fusion technology, which can be found at:
https://www.nuclearpolicy.info/wp/wp-content/uploads/2020/09/NFLA_New_Nuclear_Monitor_No62_Nuclear_fusion_sites.pdf

3. What is the rationale for SMRs?

3.1. Factory manufacture of most of the plant

The fundamental selling point for SMRs is that large reactors are built in small numbers requiring components to be fabricated on a one-off basis with most of the construction work occurring at the site. This is said to make components expensive and because of the difficulties of controlling site work, leads to high costs, delays and cost overruns. SMRs are expected to be built in large numbers allowing production-line manufacture of components with most work occurring in the controlled environment of a factory - leaving only limited assembly at the site. While these savings have an intuitive logic, they need to counteract the scale economies that would be lost – a 1000MW reactor would, all else being equal, be expected to be much cheaper than ten 100MW reactors. The problem for policy is that the only way to test the claim of reduced costs due to factory manufacture is to build a large number of SMRs of a particular design to see (assuming the technology works) if they are not only cheaper than large reactors but are also competitive with other low-carbon generation such as wind.

3.2. Modularity

While the government frequently characterises reactor designs as 'modular', it seldom says which of two very different meanings of 'modular' it is referring to. 'Modular' could refer to the method of assembly with the reactor largely factory assembled and delivered to the site as a 'flat pack' with limited site work needed. Rolls Royce summarises the advantages of this meaning as follows: *"Factory production of modules removes all the cost and schedule risks of on-site manufacture on large-scale projects. Modules can be transported to site on a truck exactly when they're required."* (7)

The other sense in which modularity is used was illustrated by the IAEA, which said: *"Their modular nature also allows for scaling up capacity by adding units according to demand."* (8)

Multiple large reactors can be built on the same site and in France and Japan six or more reactors have been built on the same site. However, unlike large reactors which must be fully independent, at least some of the designs share facilities thereby hoping to reduce cost.

It is relevant to note that one of the current large reactor designs, the Westinghouse AP1000, is claimed to be modular in the sense of being largely factory manufactured with reduced site work compared to other designs, but despite this, the six reactors of this design, completed or under construction, have as poor a record as the other current large reactor designs in terms of delays and cost over-runs. Construction of two reactors of this design was abandoned at Sellafield Moorside by Toshiba because costs and timescales had escalated out of control.

3.3. Purpose

Their proponents claim SMRs are more versatile than large reactors being more flexible and offering more than simply power generation for grid supply. These claims include:

- ***Load-following.*** The designs are claimed to be able to vary their output level at short notice allowing reactors to be used for more than just base load.
- ***Hydrogen production.*** Hydrogen is being increasingly promoted as a fuel that can replace natural gas and oil for applications such as transport or for residential uses such as heating, and water-heating.
- ***District heating.*** District heating using the hot water left after power generation that would otherwise not be used is being suggested as an alternative to use of natural gas.
- ***Desalination***. Power from nuclear reactors can be used to desalinate seawater to produce drinking-quality water.
- ***Power sources for remote (off-grid) communities and industrial facilities***.

The last two options are of little relevance for the UK but the other three require analysis.

3.3.1. Load-following

On load-following, large reactors are seen as inflexible options suitable for only base-load operation because of technical and economic issues. Varying nuclear output imposes physical strains on a reactor, causes reactivity problems (xenon poisoning) while the very high construction of nuclear means that it is a high priority to use the plants as intensively as possible so these fixed costs can be spread as thinly as possible. This means that nuclear is not useful for meeting the large proportion of demand that varies from hour to hour, from day to day and from season to season.

For example, if electricity was used to replace gas as the main source of space-heating energy, the demand profile would become massively uneven with huge demands on cold winter days and low demand in other seasons. Which, if any, of the SMR designs are physically suitable for load-following will depend on their design but the claim of flexibility is untested. The already suspect economics of SMRs would be further damaged if the number of kWh generated was significantly reduced by load-following.

3.3.2. Hydrogen

Hydrogen is often portrayed as an important future energy source for uses as diverse as replacing natural gas as a network energy source to aircraft fuel. Its production is also seen as a way to use potential output from inflexible power generation sources such as nuclear and renewables that would otherwise not be used. One proposal for the UK would involve a so-called Wind-Nuclear Hybrid including NuScale SMRs and off-shore wind in combination. Few details of the proposal are available yet. (9)

Hydrogen can be produced by using electricity to split water into hydrogen and oxygen component parts although the efficiency is of the order 80%. A more efficient process is possible if 800+C heat is available, hence the focus of government policy for Advanced Modular Reactors on designs that operate at this temperature or higher.

While there may be applications for which hydrogen is well suited and for which there are few alternatives, a fundamental problem is cost. It is hard to see why energy to produce hydrogen from a nuclear reactor would be charged at a lower rate than if it was used for power generation. The UK wholesale price of electricity is typically about £50/MWH while the UK wholesale price of natural gas is typically about a third of that. Given that nuclear power is highly unlikely to be able to match the current wholesale prices and given the extra costs from turning the power into hydrogen as well as the additional infrastructure costs, the hydrogen produced would be prohibitively expensive for most applications.

3.3.3. District Heating

One option for replacing gas as the primary source of space-heating in the UK is district heating using nuclear energy. Under this, the low-grade heat (as hot water) left after power generation would be piped to houses and used to heat homes. While the use of heat in this way would lead to a relatively small reduction in electrical output, the problem would be the investment required in infrastructure to install pipes to deliver the hot water to houses. It would also require reactors to be sited close to population centres. Given that the climate of the UK is not that cold (and with climate change getting warmer), it is questionable whether the investment in infrastructure would be cost-effective. A more cost-effective option might be energy efficiency measures to substantially reduce space-heating demand.

4. UK Government policy

The first sign of significant interest in SMRs at a UK Government level followed a 2014 feasibility study (10) funded by seven nuclear organisations, including Rolls Royce. This produced some infeasibly optimistic forecasts including a potential world market of 65-85GW by 2035 with 7-21GW installed in the UK. In the UK Government's November 2015 Budget, the government announced it would spend at least £250m by 2020 on 'innovative nuclear technologies.' This appears to have been almost exclusively for SMRs, including a competition to identify 'the best SMR for the UK'. (11) In March 2016, the government launched the competition with a call for expressions of interest in supplying SMRs. The first phase of this competition was expected to be complete by late 2016 when an 'SMR Delivery Roadmap' would be published. (12) Little came of these initiatives. It is not clear how much, if anything, of the £250m budget was spent while the roadmap was never produced.

In December 2017, the £250m competition was replaced by a £44m 3-year Advanced Modular Reactor Design Competition aimed at reactor designs that were not commercially available , i.e., not a PWR or its close relative, a Boiling Water Reactor. (13) In June 2018, the UK Government published its 'Nuclear Sector Deal' promising £200m to develop new nuclear technologies. (14) However, the largest element, £86m, was for fusion technology, while the next largest element was £56m for AMR design development, including the £44m previously announced in December 2017. In September 2018, the three companies proceeding to the next stage of the AMR design competition were announced, although one of these was the Tokamak fusion option which we do not consider here. The Westinghouse 450MWe lead-cooled fast reactor (LFR) (15) and the U-Battery HTGR were the other two and these remain the options receiving government support. (16)

While Westinghouse is a US-based, Canadian owned company, there appears to be little interest in the LFR design outside the UK and the development work is expected to be carried out entirely by UK and Europe-based companies. (17)

U-Battery is a 4MWe HTGR being developed by a consortium led by the uranium enrichment company, Urenco (co-owned by the UK, German and Dutch governments). Canada is also showing interest in U-Battery. Its small size and its relatively high operating temperature (710C) mean it is seen as an option for remote communities, mining facilities and industrial processes requiring high temperature heat. These applications have little relevance to the UK.

In November 2018, at a "Commercialisation of Small Nuclear in the UK" event held at the Trawsfynydd, then expected to host the first UK SMR, the Energy Minister Richard Harrington announced an intention that ONR's nuclear regulatory GDA process would be open to review SMR designs. (18) There appears to have been no significant mention since then of Trawsfynydd as a site for SMRs, perhaps because technologies like the Rolls Royce SMR and the Westinghouse LFR, which are about the size of the two Magnox reactors that operated there till 1991, are too big for this site.

In July 2019, the UK government announced it would grant £18m to the development of the Rolls Royce SMR. (19) In the government's 10-point plan for energy published in November 2020, point 3 was 'Delivering New and Advanced Nuclear Power. The spending commitments were:

'Alongside this [pursuing large-scale nuclear projects], we are also looking to invest further in the next generation of nuclear technology. Subject to value-for-money and future spending rounds, we are announcing up to £385 million in an Advanced Nuclear Fund. This will enable investment of up to £215 million into Small Modular Reactors to develop a domestic smaller-scale power plant technology design that could potentially be built in factories and then assembled on site. It will unlock up to £300 million private sector match-funding.

We are also committing up to £170 million for a research and development programme on Advanced Modular Reactors. These reactors could operate at over 800°C and the high-grade heat could unlock efficient production of hydrogen and synthetic fuels, complementing our investments in carbon capture, utilisation and storage (CCUS), hydrogen and offshore wind.

Our aim is to build a demonstrator by the early 2030s at the latest to prove the potential of this technology and put the UK at the cutting edge against international competitors.

To help bring these technologies to market, we will invest an additional £40 million in developing the regulatory frameworks and supporting UK supply chains.' (20)

The £215m was widely seen as being committed to the Rolls Royce SMR but the UK Government has not confirmed this. Development studies for the AMRs would be completed in 2022.

5. Technology prospects

The government is notably more optimistic than GIF for the prospects for Advanced Modular Reactors, expecting a demonstration plant to be in operation by the early 2030s. By contrast, GIF, an organisation set up by governments to promote the development of such designs, does not expect the designs to be commercially available until 2045. In the 16-year period 2002 to 2018, GIF's expected date of commercial availability has gone back 15 years, suggesting that 2045 is likely to still be over-optimistic. In that respect, given that the UK government has a zero-carbon pledge for 2050, AMRs are an irrelevance and are not considered further. We focus on the two PWR designs that appear to be most likely to be deployed in the UK, the Rolls Royce SMR and the NuScale SMR.

5.1. The Rolls Royce SMR

In March 2016, Rolls Royce submitted a bid to the UK Government for the SMR contest although details of the design were vague, with the reactor size specified as 220-440MW. (21) The few details of the design published suggest it is essentially a scaled down version of the PWRs already in operation round the world. The design is said to be modular in the sense of it being largely factory built. Rolls Royce claims: *"About 90% of the value of the nuclear power station is delivered in a factory environment. That means, the nuclear island, the main concrete assembly and the other "major elements" are pre-fabricated and put together on-site."* (22)

There is no suggestion it is modular in the sense of being built in clusters on the same site with major reactor facilities shared. Clearly more than one reactor could be built on the same site but the cost saving from the sharing of facilities would be small. Rolls Royce have set up a consortium to progress the design including the likes of Amec Foster Wheeler, Nuvia and Arup as well as the UK government's Nuclear Advanced Manufacturing Research Centre.

Rolls Royce opted for a larger version of 440MW, upgraded to 470MW in February 2021. (23) It claims the cost of the reactors would fall to £1.8bn each after four had been built, that the reactors could be built in four years and that the cost of power would be £40/MWh compared to £112/MWh (at 2020 costs) that Hinkley Point C is contracted to receive. All previous history suggests that further power upgrades will be announced to try to improve the economics of the plant.

It is clear though that the consortium is unwilling to risk its own money developing the design unless there are cast iron guarantees of a large volume of orders, 16 reactors, for the UK.

The steps that must be taken to get to commercial deployment are:

1. Taking the design from its current conceptual stage to a fully filled out design that can be reviewed by the UK safety authorities, the Office of Nuclear Regulation (ONR), for review under its Generic Design Assessment (GDA) process, Rolls Royce has estimated it would require about £400m to carry out this phase and it might take till 2024.

2. Carrying out the GDA. There has been no estimate of the cost of this phase, but this process has taken at least four years for the three designs that have completed it. These designs had all been reviewed by regulators in other countries whereas the ONR would be the first to review the Rolls Royce SMR, putting an extra burden on it.
3. Setting up the factory production lines. Again, there is no cost or time estimate for this, but even the first reactor is expected to be built using components manufactured on production lines. Rolls Royce expects that these production lines would be able to produce equipment for two reactors per year.
4. Construction of the 16 reactors Rolls Royce is demanding be ordered. The economics will only be proven by reactors built on production lines and when five reactors have been built. It would make no sense to set up production lines, then mothball them until the first reactor is operating and can prove the technology and give some indication of the economics. So, assuming the first reactor can be built in four years, work on a further seven reactors will be underway before the first plant is operating. There will be no demonstration plant.

5.2. NuScale/Shearwater

The NuScale/Shearwater proposal was only publicised in January 2021 and few details are available. (24) Given the long history of development of the NuScale design, its backing by the large US corporation, Fluor, review by the US Nuclear Regulatory Commission (NRC) and the fact that, of the SMR designs, it is closest to receiving a commercial order (in the USA), it deserves some examination.

Shearwater's project would be: *'to build a wind-SMR (Small Modular Reactor) and hydrogen production hybrid energy project in North Wales'* specifically at Wylfa and would produce a: *'3 GWe of zero-carbon energy and is also expected to produce over 3 million kilograms of green hydrogen per year for use by the UK's transport sector.'* (25) The breakdown of the capacity into nuclear and offshore wind is not given, whether it would one cluster or two clusters of 12 reactors. As is usual some highly optimistic and implausible projections are made by its promoters of times and costs. The power would come at 'a fraction of the cost of a conventional nuclear power station' and first power would be in 2027.

Nevertheless, if the Rolls Royce option is not pursued (Rolls Royce has partnership deals with NuScale), NuScale might be seen as an easy option to replace it. The NuScale SMR has a development history going back about two decades. (26) It is a pressurized water reactor (PWR), currently designed to produce 77MW with design features not yet incorporated into an operating reactor. The output figure was increased by nearly 30 per cent in 2020 from 60MW, by 20 per cent in 2018 from 50MW, which was itself increased from 45 MW in 2014, an indirect testimony to its need to achieve economies of scale to improve its economics.

The other scale advantage that NuScale seeks to obtain is building its reactors in clusters of up to 12 units. It has had backing from the large US engineering company, Fluor (previously involved in the UK in the decommissioning programme at Magnox sites) for more than a decade albeit Fluor shareholders are increasingly opposing further large-scale investment in NuScale by Fluor. The 50MW version completed an in-depth review by the NRC in 2020 after nearly four years, albeit a number of significant issues remained unresolved. (27) The 50MW version will not be offered for sale and the 50 per cent larger 77MW version will need to go through the whole review process again. (28)

NuScale is claiming construction costs would be $4200/kW, about half the level of large reactor projects in the USA, the UK, France and Finland. (29) However, the NuScale design is still far from finalised, so current estimates must be seen as promotional only. The NuScale design is much smaller than its main competitors, so the lost scale economies compared to large reactors will be correspondingly harder to make up through savings that might accrue from using assembly line manufacture.

The lead project is for a cluster of 12 reactors to be owned by Utah Associated Municipal Power Systems (UAMPS), a collection of very small utilities. It would be constructed in Idaho, within the national laboratory in that state. However, less than half of the output of the plant has been sold with a number of investors pulling out and construction will not start until all the capacity is sold. The claims of completion in 2027 seem infeasible given the need to redo the NRC safety review and find investors. Unlike the Rolls Royce SMR, NuScale plans not to use production lines to build the UAMPS project so this project, if it goes ahead and is technically successful, will not prove the economics of NuScale.

6. Sites

One of the claims for SMRs is their size means siting would be easier because they can be sited nearer population centres and placing fewer demands, for example, on cooling water.

For the two PWR SMRs that are front-runners for the UK, this does not apply. The Rolls Royce SMR is larger than all except one of the Magnox reactors and comparable in size to an AGR. It is bigger than the Fukushima 1 reactor that melted down in 2011. The NuScale design is meant to be built in clusters of 12 77MW reactors, 924MW, so both designs would effectively not be small. The Westinghouse LFR is also about the same size as the Rolls Royce SMR and therefore no easier to site. Only the U-Battery design can be seen as small.

There seems no reason to believe that siting new reactors will become any easier and the current programme of large reactors was sited at existing reactor locations precisely because it was expected to minimise local opposition. The likelihood therefore is that if a publicly acceptable site can be found, the natural tendency will be to place as many reactors as possible on it, making the sites even more comparable to those housing large reactors.

Of the six sites identified as suitable for large reactors, three projects have collapsed (Wylfa, Moorside and Oldbury), two are in serious doubt (Sizewell and Bradwell) and only one is proceeding (Hinkley Point). These existing sites are likely to be a far more attractive proposition to developers than trying to open up a greenfield site. Of the other sites of existing reactors, two are in Scotland (Hunterston and Torness), where the Scottish Government has already taken a policy decision not to build any new nuclear reactors. The Dungeness site was disqualified because it is a Site of Special Scientific Interest. The publicity that Trawsfynydd would be a likely location for a first SMR has gone very quiet and it may be that the site is now seen as not suitable. Heysham and Hartlepool, sites of AGRs, may come into the reckoning at some point in the future.

The planning processes for Wylfa, widely seen as the best site for new reactor development, had not been completed when the project was definitively abandoned in January 2021. However, the Examining Authority (ExA) of the Planning Inspectorate concluded: *"on balance, the matters weighing against the proposed development outweigh the matters weighing in favour of it. The ExA therefore finds the case for development is not made and it recommends accordingly."* (3)

7. Conclusions

The UK Government has been actively pursuing SMRs since 2015. However, there have been a number of changes of direction, programmes announced but not followed through and large sums of money announced but with open-ended timescales and few details of how the money will be spent. The sums of money spent so far have been relatively small and much of it has been on nuclear fusion, a technology that has little in common with nuclear fission technologies. Fusion has always been since as a promising technology but one that is several decades from commercial deployment, if ever. Much of the rest has been spent on technologies, often known as Gen IV, that, despite highly optimistic forecasts by the UK government of deployment in the early 2030s, are unlikely to be commercially available for more than two decades, if ever. Fusion and Gen IV designs are therefore irrelevant to the commitment to decarbonise the UK electricity generation sector by 2050.

The claims made by Rolls Royce are extraordinary but very similar to those made for the current generation of reactor designs such as the EPR being built at Hinkley Point. Around 2000, the so-called 'Nuclear Renaissance' was based on claims that these reactors could be built in four years or less and would cost \$1000/kW (about £800/kW) of capacity. Less than

20 of these designs have been completed or are claimed to be near to completion. All are far over budget and all will take much more than 4 years to construct. The latest cost estimate for Hinkley Point C is about £27bn (2020 money) or about £8400/kW. It still has at least 5-6 years of construction left and inevitably further cost increases. Rolls Royce's claims must therefore be taken with a very large pinch of salt.

Rolls Royce is also making extraordinary demands on the UK government that it must commit to before further significant development work takes place. UK taxpayers would have to provide a large proportion of the cost of design development, navigating the GDA and of setting up component production lines. It would also have to guarantee orders for a minimum of 16 reactors, which, even on Rolls Royce's unrealistic cost estimate, would be a commitment to ***spend nearly £30bn before it has progressed beyond a conceptual design***. Given the lack of interest from utilities, it seems likely the UK Government would also have to commit to own the plants. It is hard to see how any responsible government could take such a massive 'punt' using public money. It is perhaps significant that the amounts of government money committed to the Rolls Royce design is still small, about £18m, and it remains to be seen how long Rolls Royce and its partners will be willing to keep the design programme going without the level of commitment it is asking for. Rolls Royce lost £4bn in 2020 (31), due to serious problems exacerbated by the Covid-19 pandemic and lockdowns, so it has very limited scope to keep investing without a public commitment given by the government.

The NuScale option, whether as a standalone plant or a hybrid with offshore wind, suffers from the fact that while the individual reactors are small, they are designed to be in as cluster of 12, making the site capacity about 1GW, making it effectively a large reactor and, until the UAMPS project is completed and operating efficiently and economically, it will remain unproven and risky.

8. References

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