What Is the Role for Nuclear Power in Achieving Net Zero?

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The requirement of Net Zero is to simultaneously grow our energy supply dramatically and to decarbonise it. This task represents an immense challenge because fossil fuels account for 80% of global energy. We need to achieve that 'expansive decarbonisation' in a world constrained by environmental protection, the availability of new materials and the volatility of global geopolitics.

All credible predictions suggest that global energy demand will grow through the next millennium. Such demand needs to be balanced against environmental constraints and the availability of raw materials. Meeting the world's energy requirements in this sustainable manner is a huge challenge to humankind.

We live in a rapidly changing world with unprecedented swings in geopolitics meaning we are no longer in control of our energy security, our energy price or the raw materials which affect both.

Climate change and its impact on weather systems at home and overseas loom large in our concerns and in media reports. From the fires in the USA, to the extreme winter weather there recently, to floods closer to home and flood damage routinely occupying the news internationally, the most recent Intergovernmental Panel on Climate Change (IPCC) report indicates we need to do 'everything everywhere all at once' to tackle climate change. This means we have to deploy every available technology and invest in innovation if we are to avoid the worst effects of climate change.

So where does that leave us in terms of our contribution to levels of C02 in our atmosphere and why should we care? After all the UK is only a 1% contributor to the problem which is dominated by China, the USA, India and Russia and surely short term our concerns should be whether we have power at all rather than where it comes from and to have it as cheap as possible to avoid having to make stark choices over such fundamentals as heating our homes or feeding our children. However that is just one side of the argument: the other is that as a responsible first world country we have a duty to do our part in striving to reduce the greenhouse gas emissions known to be so damaging to our ecosystem. Not only that, the net zero challenge presents an enormous opportunity for us to build a green economy.

What does Nuclear Power Provide in a Net Zero system?

Many reviews of world energy demand have been published. Electricity generation makes a significant impact, not just because power generation has a great influence on the environment, but also because increasing industrialisation and quality of life in the developing nations leads to much increased electricity demand. Globally, just under 10% of total demand is produced by nuclear power stations today yet nuclear power provides low carbon, secure and stable energy.

According to the United Nations Economic Commission for Europe (UNECE) 2022 report, nuclear power has the lowest carbon footprint at 5.1g-6.4gCO2eq/kWh with wind energy not much more at 8g-13gCO2eq/kWh and is four times better than solar energy, the two principal sources of low carbon renewable energy. It is a compact efficient energy source with low land use. It is proven over many decades at industrial scale and has the added benefit of being able to provide low carbon heat as well as electricity.

Moreover it is not often mentioned that the uses of nuclear technology extend well beyond the provision of low-carbon energy. Through production of radioisotopes in nuclear reactors, it helps control the spread of disease, assists doctors in their diagnosis and treatment of patients, and powers our most ambitious missions to explore space. These varied uses position nuclear technologies at the heart of the world's efforts to achieve sustainable development.

In view of the reducing reserves and environmental effects of fossil fuels, it is expected that there will be increasing reliance upon nuclear and renewable generation. It is projected that maintaining nuclear at around just 15% of the world electricity generation would require some I000 GWe of capacity by 2050 (compared to 390GWe today) *source world nuclear association info library*. https://world-nuclear.org>information-library

Nuclear Power Today

Thirteen countries in 2020 produced at least one-quarter of their electricity from nuclear power plants. France gets around 70% of its electricity from nuclear energy, while Ukraine, Slovakia, Belgium and Hungary get about half from nuclear power. Japan was used to relying on nuclear power for more than one-quarter of its electricity pre the earthquake and tsunami which impacted the Fukushima power plant and is expected to return to somewhere near that level in the next few years having concluded that in terms of economics and environmental impact that nuclear energy is too important as a source of low carbon reliable energy.

Civil nuclear power can now boast more than 18,000 reactor years of experience, and nuclear power plants are operational in 32 countries worldwide. In fact, through regional transmission grids, many more countries depend in part on nuclear-generated power; Italy and Denmark, for example, get almost 10% of their electricity from imported nuclear power: Italy from France and Denmark from Sweden.

Nuclear Power and the Energy System in the UK

Gas is a key pillar of the UK energy mix and is particularly important for electricity generation and is likely to remain so well into the future. This is particularly so as we consider the impact of decarbonisation of the transport and domestic heating sectors- in effect at least doubling the demand on the electricity grid. We need to realise that especially in the winter there is a wide difference in demand during a 24 hour period with the main peaks met by a high dependency on gas. When the wind doesn’t blow and the sun doesn’t shine it is nuclear energy which forms the steady base of firm secure low carbon power. National Grid has recognized this in its scenario ‘A day in the life of 2035’. With low renewable output and high demand, supply draws heavily on carbon capture at fossil plants (mainly gas) and imports alongside energy storage and demand side flexibility and an amount of nuclear energy comparable to that available today. It is worth noting that in this scenario National Grid envisages relying enormously on around 400 GWh of imports and that as we stand today carbon capture on gas is as yet an unproven technology.

The UK used to be a large producer of oil and gas from the North Sea but production declined significantly since its peak in 2000. In 2004 the country became a net importer of natural gas and in 2005 a net importer of crude oil. During the decade 2007-2017 natural gas and oil net imports more than doubled. Most imports come via pipeline from Norway. In recent years, the proportion of gas imported as LNG has also risen substantially. Given the requirement for substantial quantities of imported gas, it has been recognised that the UK is particularly vulnerable as compared with our European neighbours. We have very little gas storage capacity. Italy has just under 20 times more than the UK, Germany 16 times more. This has left the UK exposed to both availability of gas to keep our power stations running and its cost

So where does the UK sit both in terms of existing nuclear power plants and in future plans? Nuclear energy has provided steady firm low carbon energy for over 6 decades. From a peak of nearly 30% in the mid to late 1990s, nuclear energy currently supplies 12-15% of the grid’s demand but for how long? The UK has been beset by policy flip flops on nuclear energy since the mid 1990’s. The UK’s system of choice back in the 1960, 70’s and 80’s of advanced gas cooled reactors (AGRs) meant that the country was at a disadvantage when it came to longevity of the reactors built compared with international norms in countries, led initially by the United States, which adopted water cooled nuclear power plants, the current international global standard. This means that the UK’s existing fleet of AGRs which has been the bedrock of low carbon energy for decades will retire by the end of this decade. Of the current UK nuclear power stations, only the Sizewell B reactor in Suffolk, a light water reactor which commenced operation in 1995 will be operating.

The UK Government supported additional nuclear investment in November 2020 in The Ten Point Plan for a Green Industrial Revolution, and in its December 2020 white paper, Powering our Net Zero Future, which set out the changes needed to make the transition to clean energy by 2050.

In 2022, following Russia's military offensive in Ukraine, the Government announced a "major acceleration of homegrown power" to "boost long-term energy independence, security and prosperity." The energy security strategy centred on a significant expansion of nuclear energy, with an ambition of up to 24 GWe of capacity by 2050 to provide about 25% of electricity. A new government body, Great British Nuclear, would be set up to "bring forward new projects" and a £120 million Future Nuclear Enabling Fund was launched to "support development of nuclear projects, stimulate competition in the industry and unlock investment."

The Government's 2020 and 2022 strategies as well as indicating a desire for increased nuclear capacity, also set out new ambitions for offshore wind and a new licensing round for North Sea oil and gas projects. However, the engineering and commercial challenges associated with delivering the policy makers aspirations should not be underestimated. Back in 2010 the Royal Academy of Engineering produced a report *Generating the future: UK energy systems fit for 2050*[1], estimating what would be needed to deliver an 80% reduction in carbon emissions by 2050 which was of course the original target rather than net zero. Neither the renewable targets nor those for nuclear energy are anywhere close to being in met. In fact to date NO new nuclear capacity has been added to the grid.

Delivering Nuclear Power

So why is it taking so long to deliver new nuclear power plants in the UK when other countries are moving ahead at pace especially since the development of the situation in Ukraine. Probably THE most important factor affecting the success or otherwise of new nuclear plant is cost, the overnight capital cost and its financing and hence the duration of the build. Looking at it in the traditional way though doesn't tell us where the real problems lie.

Breaking down the capital element starts to reveal the issues which in fact are associated with the non nuclear elements of the plant. On-site construction issues are what have damaged the western world's confidence that nuclear power plants can be delivered to their original budgets and timescales. The main nuclear components comprise only 15% of the overall capital cost. The concrete and steel associated with the construction and the time taken to deliver these elements, form the major contribution to cost. The UK's system of choice, the French ERP (European Pressurised Water Reactor), selected by EdF for the new reactors at Hinkley Point in Somerset and at Sizewell in Suffolk happens to probably be the most challenging in terms of construction and hence build schedule and cost. Other countries including the Unites States have adopted the more modular US Westinghouse designed AP1000 or the Korean APR1400 when looking to replace or initiate nuclear power plant deployment with large 1000+MW systems. China and Russia have both proceeded at pace to continue to invest heavily in their own new nuclear systems.

Since nuclear projects involve capital-intensive construction for years before they start operation, their financing costs comprise the largest share of the ultimate cost of the electricity produced. For Hinkley Point C, for instance, about two-thirds of the guaranteed price of electricity of £92.50/MWh comes from the cost of financing and the risk premiums attached by the private sector to nuclear projects. It is relatively easy to see why this is the case: if a reactor is financed at a 9% interest rate (the level often expected by the private sector) compounding annually over 10 years' of construction, it will more than double the overall cost. A 2% interest rate (more common for government-issued debt) will only raise the cost by around a quarter over the same amount of time.

In a net zero world, investors as well as energy markets are slowly shifting toward supporting only low-carbon, or "green" energy projects. Those projects which are not deemed green would be considered a financial or a reputational risk. They would therefore be able to access a narrower pool of capital at more expensive rates. It is therefore imperative that nuclear is recognized in financial as well as energy frameworks, for its outstanding green credentials, and made eligible for public and private sector green finance initiatives. A wider pool of capital and cheaper financing rates beckons, which offers the prospect of cheaper, as well as cleaner electricity. In the EU, nuclear has been classified as a "transitional" technology essential to the move away from fossil fuels. This reflects a political compromise forced on anti-nuclear Germany by France, rather than the true science, but it will allow pro-nuclear states like France and Poland to issue green bonds to back nuclear projects if they choose, and to signal to the private sector that they can back nuclear projects without fear as well. In the UK, the Government has recently announced its

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[1] Royal Academy of Engineering, London. ISBN 1 903496 54 3

intention to classify nuclear as “environmentally sustainable”, so it has access to the same investment incentives as renewable technologies. That is a major step forward to enable competitive financing of what is an indispensable and irreplaceable clean energy technology.

Small Modular Reactors

With the UK aspiring to return to the top table in terms of being at the leading edge of scientific research and innovation in Small and Advanced Modular Reactor technologies (SMRs and AMRs), how realistic are the ambitions to deliver 24GWe and possibly more on the grid?

Small reactors offer the potential to boost skills and create jobs here in the UK, as well as reducing the cost of nuclear energy through much greater modularisation. The UK Government has been working closely with industry to explore this potential and in particular engaging in cost sharing of the progression of a design of SMR by Rolls Royce. This particular SMR is unique in terms of the extent to which modularisation of the whole power station has been part of the fundamental design basis to transform what would otherwise have been a large complex infrastructure programme, into a factory built commoditised product.

For the Rolls Royce design, approximately 90% of manufacturing and assembly activities are to be carried out in factory conditions, helping to maintain an extremely high-quality product, to reduce onsite disruption and to support international roll out. Other countries like the US have also given their industry significant assistance with $4.5 billion committed to three different First of a Kind units of advanced nuclear designs. This support helps to give confidence to the private sector in investing in more modern concepts. GE-Hitachi have already received an order for their latest design the BWRX-300 from one of the major Canadian utilities.

If the UK is to reach its target of 24GWe of nuclear energy by 2035, it will almost certainly need to deploy a combination of fleets of both large scale GW plants and SMRs. In the case of GW plants utilising well proven international designs with high degrees of modularity and in the case of SMRs either the Rolls Royce system or one of the other international systems already being successfully deployed elsewhere. However progress is needed urgently. Following the Russian invasion of Ukraine, other countries have moved rapidly to enhance or initiate nuclear reactor deployments at pace. The UK is in danger of being at the back of the queue for the global supply chain of new nuclear power plants. For perspective, across Europe, countries are planning about 90GW of new nuclear capacity, and similarly planning to extend the lives of approximately 90GW of nuclear capacity. The UK, by contrast, has only committed to 6.4GW of new build projects. As project developers and technology vendors consider which countries to prioritise, and as supply chain companies weigh investments in new capacity, they will look at where they get the healthiest order book. Eastern European Countries currently moving to make nuclear power station investments are already striking contracts or Memoranda of Understanding with the United States or France.

Advanced Fission Reactor Designs and Fusion

Looking further into the future, the advanced nuclear market, utilising concepts other than Light Water Reactors on which the Global Industry is mainly based, is diverse and includes a range of technologies, which vary widely in their design maturity, in their target markets, and their size. These are often referred to as Small or Advanced Modular Reactors.

- Generation III water-cooled Small Modular Reactors, which are similar to existing nuclear power station reactors but on a smaller scale.
- Generation IV Advanced Modular Reactors, which use novel cooling systems or fuels to offer new functionality (such as industrial process heat) and potentially a step change reduction in costs.

The unifying themes across both groups are that these emerging technologies:

- are smaller than conventional nuclear power station reactors – ranging from 1/3rd to 1/400th of the size of the reactors at Hinkley Point C;
- aim to use manufacturing facility construction techniques rather than bespoke site-based civil engineering; and
- claim to be more easily financed because single unit capital costs are lower – e.g. project costs are estimated at £1-2bn compared to £25bn for Hinkley Point C.

Some concepts such as High Temperature Reactors (HTRs) have been tried and tested decades ago, indeed the UK was a pioneer with the Dragon HTR built at Winfrith in Dorset in the 1960s. It is now widely acknowledged that HTRs are likely to see a significant revival due to their potential to facilitate lower cost hydrogen production – potentially essential for the future clean energy transition and to supply high grade heat more generally as well as electricity. Other systems such as those using molten salts for coolants are also seeing a revival due to their potential to store heat are also being considered but are at an earlier stage of development. Also there is significant interest in micro systems. These are very small reactors supplying just a few MWe or MWth targeted at 'off-grid' applications e.g. at remote mining sites or adjacent to high energy demand industry.

X-energy is a US nuclear reactor & fuel design engineering company developing Generation IV high-temperature gas cooled nuclear reactors & the fuel to power them. Linked with the UK company Cavendish they have aspirations for a first UK project utilizing the Xe-100 at the existing Hartlepool reactor site. The Xe-100 evolved from both the UK's Dragon reactor at Winfrith in Dorset and the Pebble Bed Modular Reactor project in South Africa in which the UK had significant interests back in the late 1990s/early2000s and can build on gas reactor technologies that have been pioneered in the UK, leveraging the experience in the Hartlepool area and across the UK.

Molten salt reactors are at the early assessment stage in a number of counties.

What of fusion technology? Although much progress has been made in the last 3-4 decades there are still fundamental steps necessary in engineering development before a commercial plant can plausibly begin development. Technologies range from the multi billion pounds funded by international agreements between many countries such as ITER the international large scale fusion research and engineering project in France and the national major investments such as the National Ignition Facility in the US to novel technology approaches by well funded start up companies such as First Light Fusion in the UK. There remain significant scale up and engineering and materials challenges not least of which is how to cope with the radiation damage to key components as the fusion machine operates and how to harness and transfer the energy created by nuclear fusion into the existing grids. Like the advanced fission systems, fusion needs time and funding to reach its full potential.

Practical Application of Nuclear Power in a Net Zero World

For both fission and fusion advanced systems where there are many innovative ideas being proposed offering 'much simpler cheaper routes to commercialization, I am reminded of the very wise words of Hymen C Rickover Admiral US Navy and the pioneer behind nuclear technology in the late 1940s and 50s

"An academic reactor or reactor plant almost always has the following basic characteristics: (1) It is simple. (2) It is small. (3) It is cheap (4) It is light. (5) It can be built very quickly. (6) It is very flexible in purpose ('omnibus reactor'). (7) Very little development is required. It will use mostly off-the-shelf components. (8) The reactor is in the study phase. It is not being built now.

"On the other hand, a practical reactor plant can be distinguished by the following characteristics: (1) It is being built now. (2) It is behind schedule. (3) It is requiring an immense amount of development on apparently trivial items. Corrosion, in particular, is a problem. (4) It is very expensive. (5) It takes a long time to build because of the engineering development problems. (6) It is large. (7) It is heavy. (8) It is complicated.

Those making proposals for innovative concepts need to recognise the massive amount of validation and verification which has to underpin a design before it can progress to deployment in a highly regulated sector but we can be confident that the designs available and being deployed internationally today have been underwritten by decades of development and overseen by regulators internationally.

So in concluding, nuclear power has an essential role to play in achieving Net Zero. The goal will be impossible to achieve without it. It is the only source of large scale firm reliable energy capable of powering a 21st century industrialised nation. The modern designs utilising construction techniques with high modularity mean that costs are comparable with the main renewable sources of energy and life spans that are three to four times longer. They are an essential green investment, are fundamental to energy security in an increasingly uncertain world and to keeping the lights on.