Rolls-Royce

UK SMR:
A National Endeavour

Low cost, low carbon, local electricity

Securing homegrown energy

UK Small Modular Reactor (SMR)

Creating jobs and Brexports

Technically the right choice

UK SMR: Supporting all aspects of HMG's Industrial Strategy

Investing in science, research and innovation

Investment of >£100m in research & technology to develop the UK SMR power station design. Sustained investment of ~£40m per annum through life of fleet.

Developing skills

Creation of **40,000** jobs through peak construction period and sustained level of >15,000 jobs. Requirement for additional skilled individuals to design, construct and operate expanded nuclear fleet.

Upgrading infrastructure

Construction of 16 new nuclear power stations nationwide to support safe, secure and cost-effective provision of low-carbon electricity.

Supporting businesses to start and grow

Overall benefit to the UK economy of more than £100Bn in Gross Value Added (GVA). Majority of benefit spread across UK regional areas.

Improving procurement

Opportunity for strategic Government involvement to reinforce regional profile of the proposed programmes and to act as a catalyst for broader inward investment into the UK SMR programme.

Encouraging trade and inward investment

Opportunity to support International export sales via UK Export Finance. UK Government involvement in UK SMR programme will enable and encourage inward investment from a diverse variety of international players.

Delivering affordable energy and clean growth

Targeting levelised cost of electricity of £60 per MWh, providing affordable low carbon electricity to homeowners and businesses.

Driving growth across the whole country

Up to 16 separate project sites for SMR plant construction, distributed across the UK. Multiple supply chain facilities in support of manufacture and construction. Associated development of through-life servicing capability in regional centres. Engagement, funding and support of multiple university and research centres across the UK.

Cultivating world-leading sectors

Returns UK to a true 'Top Table' position in nuclear with an established 'Reactor Vendor' offering and associated full-lifecycle capability (as complemented by existing capability in fuel-cycle and decommissioning).

Creating the right institutions to bring together sectors and places

Opportunity to engage across the existing UK nuclear landscape with involvement from skills bodies, industry associations, academic communities and international organisations.

Foreword

by Lord Hutton, Chairman, Nuclear Industry Association

Rt Hon Lord Hutton of Furness - Chairman, Nuclear Industry Association, Co-chair, Nuclear Industry Council

In early 2016, the UK Government launched a Small Modular Reactor (SMR) competition and took the important first step in acknowledging the role SMRs could play in the UK's future energy mix. Since then, the UK SMR Consortium, led by Rolls-Royce, has made significant progress in developing the design of the power station and providing the technical, cost and economic analysis to give confidence in the programme's delivery certainty.

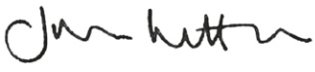
I truly believe that a UK SMR programme will be an important element in delivering the UK Government's Industrial Strategy, fostering development of all 10 pillars. And it will undoubtedly provide a once in a lifetime opportunity for UK companies to be at the forefront of world-leading nuclear technology.

It is vitally important to make the decision to move forward on this opportunity now. That is why the Government should make clear its intentions so that the UK can deliver a solution that will supply secure, reliable and affordable electricity for more than 60 years, and capitalise on new overseas markets that are emerging for SMRs.

A UK SMR programme is a national endeavour that by 2030 could represent a significant element in the reinvigoration of the nuclear sector and help the UK become a vibrant, world-leading nuclear nation. The programme will bring together the essential players including research bodies, academia, regulators, skills network, industry and Government to tackle the challenges and exploit the opportunities that lie ahead.

The UK has an enviable reputation for high quality, safe and reliable nuclear operations and this programme will bring huge benefits for nuclear skills recruitment, retention and development for both the UK's existing and future civil and defence programmes.

I welcome the commitment of the UK SMR Consortium to this programme and firmly believe it is fundamental for the UK to meet its 2050 decarbonisation targets and will deliver secure, reliable and affordable electricity for generations to come.



Rt Hon Lord Hutton of Furness

Rolls-Royce

ARUP

NUVIA

LAING O'ROURKE

amec foster wheeler

NUCLEAR AMRC

Executive summary

Warren East, CEO, Rolls-Royce

The UK has never had a greater need for low cost, low carbon, safe, secure and reliable energy production. Our energy infrastructure continues to age and we are overly reliant on fossil fuels to generate our electricity. Demand for energy will rise as the UK embraces the opportunity of a new and exciting electrical economy, with innovative technologies such as electric cars and enhanced digital connectivity transforming the way we live our lives and run our businesses. In a changing political environment, such as our withdrawal from the EU, it's becoming increasingly important that the UK is able to produce and sustain its own energy supplies.

Since 2007, the UK has recognised the important role that nuclear has to play within its energy policy. This ongoing commitment to nuclear by the UK Government has led to multi-billion pound investments in the UK's planned nuclear plants from overseas Governments and companies. But it's a huge task, and in order to successfully deliver large new build reactors, there are three significant hurdles to overcome. First, financing new large plants is expensive; second, few organisations are willing to take on such construction risks; and third, there is low confidence that these projects can be delivered on time. As a result, our reliance on overseas technology and costly foreign investment has resulted in the UK nuclear industry becoming fragmented. It has limited the available opportunities for the UK to create its own intellectual property and invest in 21st century capability. Yet this will be vital to reduce the cost of generating future electricity and to create value through the development of new products, services and technologies for both our home and international export markets.

> An independent review team led by Richard Maudslay and comprising members of the Royal Academy of Engineering agreed that a successful, Rolls-Royce-led UK SMR programme would have many positive benefits for both the UK's civil and defence programmes and could lead to significant UK export

There is another way. Nuclear power plants based on SMR technology offer a convincing alternative to the uncertainties of the large nuclear new build programme. For a relatively small investment outlay, SMRs avoid the complex challenges associated with nuclear mega-projects that require tens of billions of pounds of Government-backed investment to progress. As such, they can produce large savings and offer an attractive and commercially investible proposition. A UK SMR programme would support all 10 'pillars' of the Government's Industrial Strategy and assist in sustaining the skills required for the Royal Navy's submarine programme. Design, development and production of a UK SMR fleet would create up to 40,000 skilled UK nuclear supply chain jobs. It would also add over £100 billion to the value of the UK economy, locally and nationally , through both domestic and export sales.

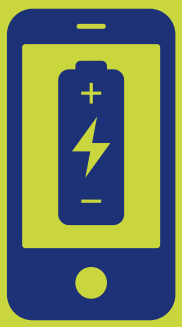
A UK SMR programme represents a once in a lifetime opportunity for UK nuclear companies to design, manufacture, build and operate next generation reactors to meet our energy challenge. A powerful partnership between UK Government and industry will enable the rapid development and deployment of a fleet of SMR Power Plants across the UK. This will deliver growth across the whole country and return the UK to the top-table of the global nuclear industry with world-leading technology, intellectual property and capability to deliver nuclear projects on time and on budget. Rolls-Royce is prepared to invest in this programme, if matched by Government support.

Warren East

One UK SMR power station will produce 440MWe of electricity.

Enough power to:

Supply a city the size of Leeds

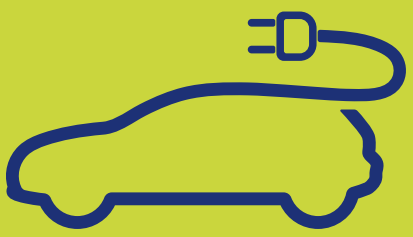


Charge **88,000,000** smartphones

Light **40,000,000 bulbs**

Run **8,000,000** large TVs

Charge **62,857** electric cars



Rolls-Royce: Trusted to deliver excellence

> Rolls-Royce is the UK's only nuclear island systems designer, supply chain integrator, and manager

> For more than 60 years Rolls-Royce has designed, engineered, manufactured and supplied custom equipment for reactor projects around the world

Rolls-Royce has been the technical authority for the UK Nuclear Steam Raising Plant for the UK's submarine fleet for 60 years

Rolls-Royce is the UK's only nuclear island systems designer, supply chain integrator, and manager, and has a long history of supplying specialised components, systems and services to the civil nuclear industry. For more than 40 years we have designed, engineered, manufactured and supplied custom equipment for both new build projects and operational reactors around the world.

For the past 60 years, we have been the Technical Authority and sole supplier for the UK Nuclear Steam Raising Plant, responsible for powering the whole of the UK Royal Navy submarine fleet. This has involved the design, manufacture and through life support of a range of reactor technologies operating in challenging circumstances.

We have invested approximately £5 billion in our global supply chain, and our well-established position in the nuclear sector has helped maintain a network of more than 300 certified suppliers. By continually developing our supply chain we enable new skills which further strengthen supply chain integration capabilities for future projects that can last 60 years or more. This ensures both sustainable quality and cost benefits for our customers.

Rolls-Royce is renowned for being a world leader in high value manufacturing. The company invests hundreds of millions of pounds every year to maintain its position at the forefront of manufacturing techniques and processes. Striving for continuous advancement in capability, Rolls-Royce plays a leading role in a number of advanced manufacturing research centers, within the UK and worldwide.

Rolls-Royce is strongly placed to deliver the design and, together with a Consortium of UK companies, the construction and delivery of almost all aspects of a fleet of new nuclear SMR plants.

Calder Hall, the world's first commercial nuclear power station

Pioneers of nuclear technology

In 1956 the UK opened the first commercial nuclear power reactor at Calder Hall, and for a generation British nuclear energy technology led the world. Policy changes in the 1970s and 1980s gradually led to the erosion of this position, with nuclear energy removed from future policy during the 1990s. This trend was reversed in the first decade of the 21st century and since the 2007 White Paper, 'Meeting the Energy Challenge' (DTI, 2007)[1] nuclear energy has been a cornerstone of the UK's energy policy. This ongoing policy commitment to nuclear has encouraged foreign Governments and companies to make multi-billion pound investments in new nuclear plants, such as the two European Power Reactor (EPR) power plants that Areva and EdF Energy will construct at Hinkley Point. Yet in spite of this, so far there has been limited UK Government support for any redevelopment of UK capability to design, develop and export nuclear products, technology and services.

Decarbonising the energy mix

To date, the UK has relied heavily on fossil fuels to generate electricity but today there has never been a greater need for safe, reliable, low cost energy production that is also low carbon. In October 2016 the Paris Agreement on the Framework Convention on Climate Change was ratified (UNFCC, 2016)[2]. Global leaders now recognise the challenges being caused by unabated carbon emissions and the need for action on climate change. Within the UK, the Committee on Climate Change (CoCC) has identified multiple areas where action is required, with risks posed by flooding and high temperatures considered the most pressing (CoCC, 2017)[3]. These pressures reinforce Government legislation to reduce Greenhouse Gas emissions by 80% of 1990 levels by 2050 (HMG, 2008)[4].

> Today there has never been a greater need for safe, reliable, low cost energy production that is also low carbon

How best to decarbonise the UK energy mix has been widely debated and many different future scenarios have been proposed and analysed in recent years (Hughes & Strachan, 2010; National Grid: Future Energy Scenarios, 2017)[5]. In fact, energy production only accounts for around 24% of total carbon emissions in the UK (CoCC, 2013)[6], the remainder being generated by transport, buildings, industry and other sectors. Recent announcements from Government include a ban on selling new petrol and diesel cars by 2040 (Ofgem, 2017)[7] and funding for battery technologies to support electric vehicle development (HMG, 2017)[8]. These policies reinforce the need for growth in clean electricity generation, as batteries for cars won't charge themselves.

Around 40 GWe of nuclear capacity could be installed by 2050 as part of a balanced mix of energy technologies

Historically, a large proportion of UK energy production has been provided by the consumption of fossil fuels, particularly coal and gas (HMG, 2014)[9]. By reducing our reliance on these carbon-based fuels it is hoped that early progress can be made in the overall effort to decarbonise the UK. To this end, all coal plants in the UK are due to close by 2025 to assist in meeting carbon targets but, to avoid a looming energy gap, alternative low cost, low carbon electricity generation must be put in place.

The UK Energy Technologies Institute (ETI) has conducted scenario modelling to show how the UK can achieve the targets set for Greenhouse Gas emissions between now and 2050. The ETI's lowest cost scenario for decarbonisation, taking into account a wide range of economic, technical and social parameters is the 'Clockwork' scenario (ETI, 2015)[10]. In this scenario around 40 GWe of nuclear capacity is installed by 2050 as part of a balanced mix of energy technologies (Figure 1).

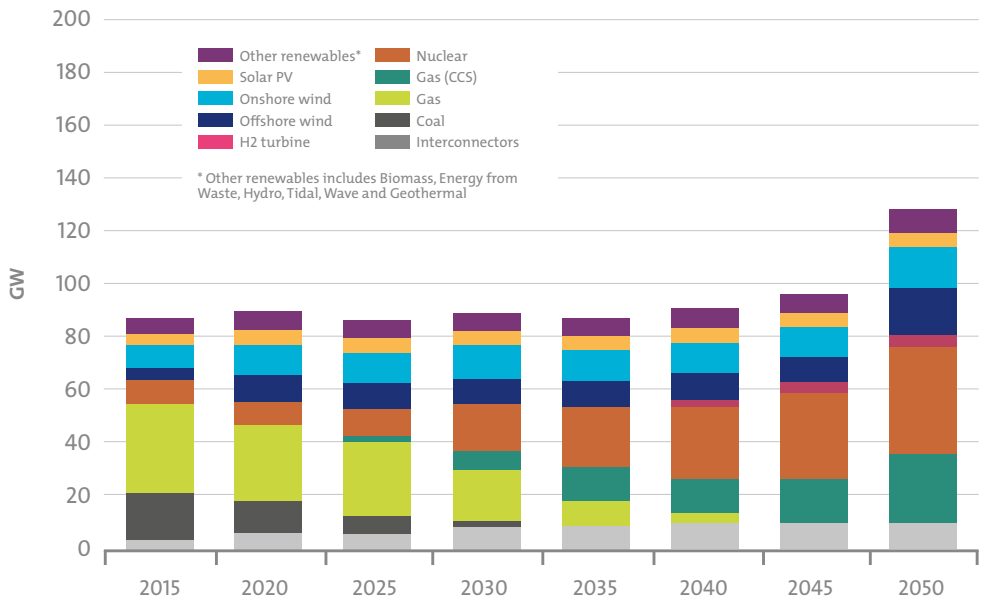


Figure 1. ETI 'Clockwork' scenario; showing rise of nuclear from current levels to around 40 GWe by 2050 (ETI, 2015)[10].

However, the ETI concludes that in order to achieve 40 GWe of nuclear by 2050, confidence in the ability of the nuclear industry to deliver new nuclear plants is key. At present, this confidence relies on the large new nuclear plants provided by international vendors at sites such as Hinkley Point, Wylfa Newydd, Bradwell and Moorside.

The construction of large nuclear plants is a significant undertaking, costing many billions of pounds with substantial and complex financing requirements. In fact, the funding and commercial issues associated with large scale nuclear plants have already severely challenged ongoing and planned new build projects in the UK, France and Finland. Further, even assuming completion of the UK's large new build reactors, only around 16-19GWe of nuclear capacity will have been installed. This is just 40% of the capacity required by 2050 to achieve the lowest cost mix of energy generation technologies described in the ETI 'Clockwork' scenario (ETI, 2015)[10]. If UK nuclear energy is to fulfil its potential, it needs a paradigm shift.

SMRs offer a convincing alternative to the complexities of financing and constructing large scale reactors around the world and represent a very substantial commercial opportunity. In light of the recent problems associated with the delivery of large reactors, and the financing challenges they present, the case for mitigating these potential risks through SMR deployment in the UK has never been stronger. Beyond supporting the UK in meeting its future energy requirements, SMRs also present an enhanced opportunity for UK business to engage in the development and deployment of nuclear technology.

All of the current large new build reactors rely on foreign technology and foreign investment. Whilst this brings advantages in reducing some development risks, it also brings challenges associated with energy security and sustaining UK nuclear capability. Additionally, a reliance on imported technology compromises the UK's ability to export, further fragmenting and reducing the financial sustainability of the UK civil nuclear sector. The development of an SMR in the UK would not only complement existing plans for large new build reactors in supporting the future energy mix, it would allow the UK nuclear industry to embark on a long-term sustainable programme of international export; supporting jobs and growth for decades to come.

> Assuming completion of the large new build reactors, only around 16-19 GWe of nuclear capacity will have been installed, just 40% of the capacity required by 2050 to achieve the ETI 'Clockwork' scenario

Small investment; large savings

Working towards a target of £60 per MWh

'Plug and play' reactors cheaper and more flexible

Part of a balanced, economically stable energy mix

Low cost, low carbon, local electricity

Each power station can supply a city the size of Leeds and would fit inside Wembley stadium

Low cost, more affordable, certainty of delivery

Every home will be better off with SMRs

Why SMRs?

A key role in the UK and global future energy mix

Many different nuclear technology concepts have been proposed to address the challenges associated with the current large nuclear plant build programme. Globally, over 70 new reactor designs have been conceived by a wide range of organisations from universities to start-ups to engineering multinationals (NNL, 2014)[11]. The vast majority of these concepts are based on an SMR approach. Such plants are deliberately designed to provide much less power per reactor unit than large plants though each could still power a city the size of Leeds.

> Only a handful of SMRs are based on proven technologies

Some designs rely on highly innovative fuels or coolant systems, or novel unproven materials that make deployment before 2040 unlikely. Many designs act as vehicles for developing new science or technology, without due consideration of market demand, commercial operation and support. Only a handful of SMRs are based on proven technologies that could be deployed before 2030 to address the UK's low carbon and affordable energy needs. Fewer still are being developed by credible engineering organisations with a track record of successful delivery. One such example is the UK SMR being developed by a Consortium of leading UK industrial companies, led by Rolls-Royce.

> A market for 7 GWe of SMR power plants will exist in the UK by 2035, in addition to the large nuclear programme already underway

A study by the UK National Nuclear Laboratory (NNL) suggests that a market for 7 GWe of SMR power plants will exist in the UK by 2035 with further opportunity beyond this to 2050. This is in addition to the large nuclear programme already underway (NNL, 2014)[11]. Globally, the SMR market could be as large as 85 GWe in the same time period (Figure 2). The UK SMR Consortium is uniquely qualified and positioned to capitalise on this opportunity.

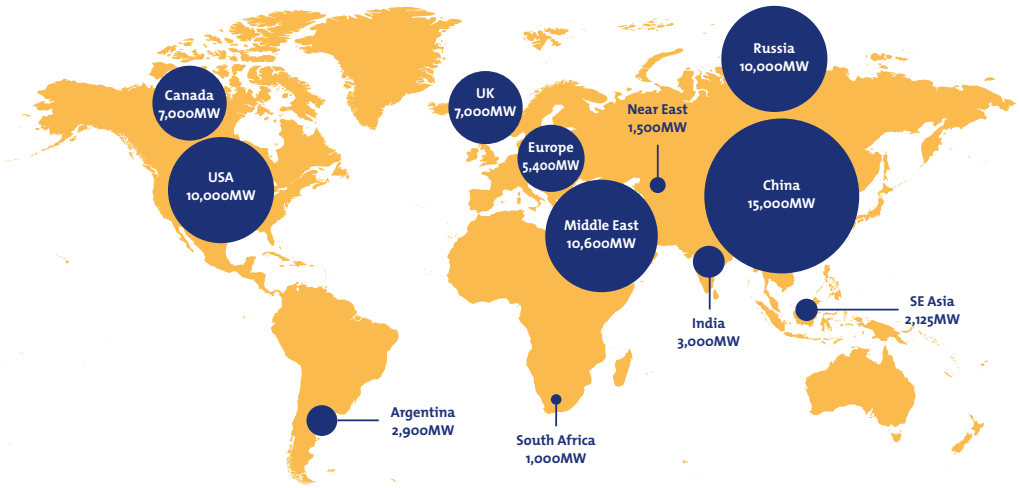


Figure 2. Projected SMR market demand in 2035. Developed from figures from SMR Feasibility Study, (NNL, 2014)[11]

Affordable energy

Whilst SMR energy is low carbon, it must also be affordable. Clearly, SMR power station providers need to answer the fundamental questions of affordability in terms of generation cost as well as overnight capital cost and levelised cost of electricity (LCOE). Also of key importance is confidence that SMRs will meet the required delivery time frame and are able to make UK Industry more competitive.

SMR designs seek to address the basic economic challenges that larger plants have struggled to overcome in recent years. Specifically:

- Reduced overall capital cost to enable conventional project financing.
- Improved certainty of construction, manufacture and project delivery.
- Competitive levelised cost of electricity.

To an energy utility, an SMR is simply a means of generating electricity to sell to customers. To that end, any SMR design must be tailored to meet the requirements of energy utilities and be safe, reliable, financially attractive and as simple to operate and maintain as possible. The UK SMR is designed from the ground up based on the requirements of energy utilities and operators. This ensures the closest possible match between customer requirement and plant design, enhancing the ability of a utility company to deliver safe, low carbon, affordable energy to consumers.

> An independent review of the UK SMR programme concluded that "Rolls-Royce might be overly pessimistic in the capital cost estimates for portions outwith the nuclear island"

SMRs are attractive because they can produce large savings for a relatively small investment outlay. They avoid the complex challenges associated with nuclear mega-projects that require tens of billions of pounds of investment to progress - and a general track record of overspend and delay (University of Leeds, 2017)[12]. By reducing plant size, and therefore capital costs, SMRs can be financed via conventional project approaches, with financing limited to under £2.5 billion. This reduced funding requirement increases the number of energy utilities and operating companies that could potentially afford to invest in a new nuclear power station.

The capital cost of the UK SMR can be reduced from a First-of-a-kind (FOAK) baseline to Nth-of-a-kind (NOAK) over a relatively short period of time, perhaps as little as eight years. This is less than the time required to construct a single large reactor. The levelised cost of electricity (LCOE) generated by a FOAK UK SMR power station is forecast under £75 per MWh and this reduces to a forecast £65 per MWh by station number five. In the medium term the target is even lower at £60 per MWh (Figure 3). Learning can be achieved through the development of multiple power plants in series, with lessons learned from one project quickly incorporated into the next. This will produce learning rates in manufacturing that are consistent with those regularly achievable in other high value sectors. The resulting reduced cost of SMR power plants will make them attractive to commercial investors, eliminating the need for Government to financially support construction.

> In the medium term the levelised cost target is £60 per MWh

Our approach has been deliberately conservative in order to avoid under estimating cost. An independent review of the UK SMR programme has validated this approach, concluding "Rolls-Royce might be overly pessimistic in the capital cost estimates for portions outwith the nuclear island." (R Maudslay, K Henry, J Roberts & A Bowles, 2017)[13]

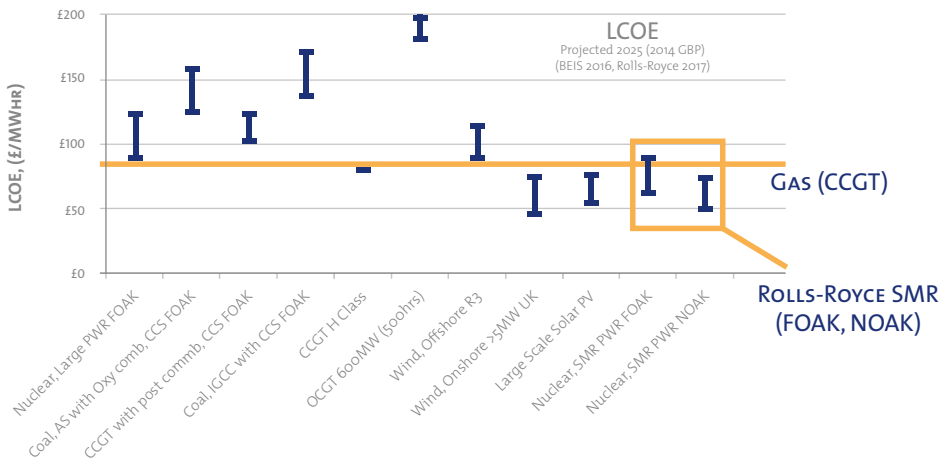


Figure 3. LCOE of various energy generation technologies in 2025 (projected). Figures from BEIS, 2016[4] and Rolls-Royce, 2017.

Certainty of delivery

Around the world, there are multiple new reactors currently under development. However many have experienced delays during construction including plants in Finland, France, the USA, and the UK. The additional cost of borrowing incurred by these delays runs to billions of pounds, often underwritten by loan guarantees from national Governments.

The reduced size of SMR power plants and their relative flexibility present a clear opportunity. Innovation in how the systems, components and buildings are conceived and arranged will improve construction certainty, enhance security, reduce total cost and provide confidence in delivery (Figure 4). The tried and tested use of technology and manufacturing capability readiness levels to manage the maturity of the design and manufactured/procured products provide structure and rigour to the development programme. These, together with integrated production and product readiness, have been successfully used in recent Rolls-Royce major aero engine delivery programmes and in the PWR3 reactor for the UK's Royal Navy submarines.

Current construction techniques rely heavily on site-specific labour, with many thousands of workers required to be engaged in constructing the power station in-situ. In addition, a modern, large nuclear power station construction site presents complex project management challenges, with multiple build activities taking place simultaneously across a vast area of land within a strict security, health and safety regime. If this were not complex enough, simple tasks such as lifting and manoeuvring heavy components can be delayed by days or weeks due to adverse weather conditions such as wind, rain and snow.

> SMRs produce large savings for a relatively small investment and avoid the complex challenges associated with nuclear mega-projects

> The reduced size of SMR power plants and their relative flexibility present a clear opportunity. Innovation will improve construction certainty, enhance security, reduce total cost and provide confidence in delivery

Moving activities off-site into controlled factory environments reduces construction time and risk

In response to this, the UK SMR design team has sought to significantly reduce the amount of on-site construction required by adopting modern design principles, such as modularity, standardisation and commoditisation. Moving activities off-site into controlled factory environments allows operations to continue unabated during bad weather, with security, quality and health and safety more readily controlled.

Of course, learning effects will theoretically put downward pressure on cost curves but they are only realised as a benefit if each individual power plant is constructed and commissioned on time and on budget, and within a timeframe that allows the investor to recoup an attractive return. Therefore, improving the certainty of construction, manufacture and overall project delivery is key to realising the promise of SMRs.

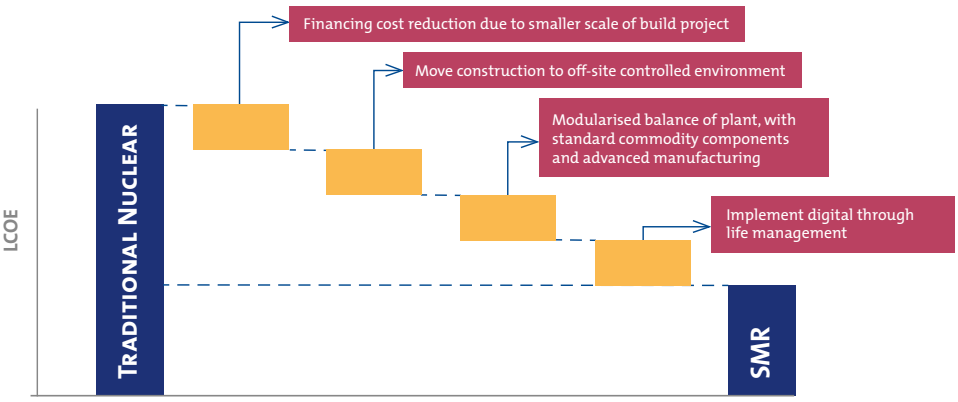


Figure 4: How SMR can achieve a lower LCOE compared to traditional nuclear

Fleet deployment benefits

Fleet deployment reaps multiple benefits enabling investment in capability and capacity

SMRs should not be considered as single power plants, rather they are designed and intended to operate as part of a broader fleet. This fleet deployment reaps multiple benefits that large reactors have been unable to realise. A fleet order book provides confidence to the supply chain, allowing companies in the sector to make longer term strategic investment in capability and capacity. A key role for Government is to enable this fleet approach through enhanced energy policy.

Fleet deployment enables the level of investment required in the civil engineering and construction sectors to affordably realise modular design benefits. Further, the infrastructure required by SMRs in the civil and construction industry are likely to have significant additional benefits to other major infrastructure programmes in the UK over the coming years. Companies in these sectors will be able

to amortise infrastructure and capability investment over multiple projects. The result will be significant cost and delivery improvements to a raft of broader UK infrastructure programmes such as High-Speed Rail, increased airport capacity, house building and urban regeneration.

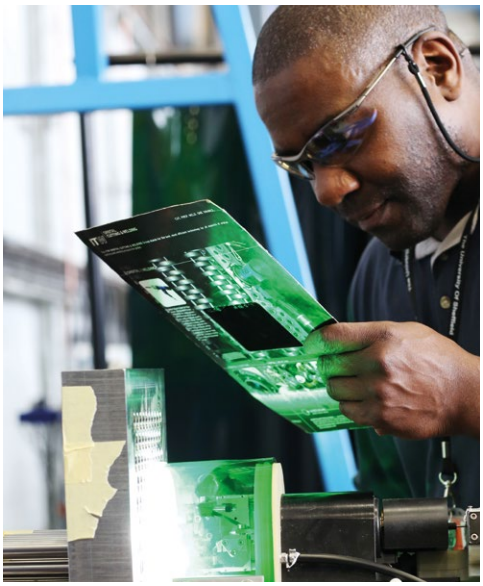
Nuclear plants contain many high value components that are fabricated using a range of complex technical processes. According to research carried out by the Nuclear Industry Association (NIA), in theory the UK supply chain has the capability to manufacture nearly all of the components for the large new build nuclear programme, with the main constraint being the capability to manufacture the largest components (NIA, 2012)[15]. In practice however, capacity is a pressing issue given that the 30 year hiatus between the construction of Sizewell B in the late 1980s and the present day new build programme has eroded much of the UK's nuclear industry experience. Many of the high value components of the large new build reactors are not going to be made in Britain but overseas; the low volumes associated with a small number of large plants do not encourage the investment required to regain competitive supply chain capacity.

Fleet deployment of a UK SMR design would provide significant confidence to the UK nuclear supply chain, allowing for the rapid development of capacity to meet the needs of an SMR programme. In turn, this new manufacturing capacity could be enhanced by the latest in manufacturing technology already being developed by world-leading researchers in the UK – notable examples being the High-Value Manufacturing (HVM) Catapult centres like the Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC) and the Advanced Forming Research Centre (AFRC).

A UK SMR fleet deployment programme would also be well placed to take advantage of the latest in secure digital technologies, adapting existing solutions and implementing new ideas to provide a level of data fidelity and information not seen before in the nuclear industry. Digitally enabled through-life asset management will allow operators to manage their fleet assets efficiently and effectively, reducing unplanned outages and improving security of supply. The UK leads the world in secure digital technologies, and a UK SMR fleet deployment programme is the perfect vehicle to demonstrate this capability.

The UK SMR is designed for its full lifecycle, including the challenge of decommissioning and safe end-of-life disposal of the fleet. The design meets the latest regulatory standards, incorporating lessons learned from the Fukushima nuclear plant accident. The UK is widely acknowledged to have amongst the highest standards of nuclear safety and regulation in the world, with the Generic Design Assessment (GDA) process established as the industry benchmark for reactor certification. The UK SMR will approach GDA as it was originally intended, using the Office for Nuclear Regulation and Environment Agency process as a means to improve and enhance the safety and security of plant design whilst minimising any environmental impacts of fleet deployment.

> New manufacturing capacity could be enabled by the latest in manufacturing technology already being developed by world-leading researchers in the UK



Advanced welding research at the Nuclear AMRC

> Using our capability in digital technology will dramatically reduce through-life cost

Regional powerhouses and countrywide £100bn boost

SMRs are key to Industrial Strategy nuclear sector deal

Creating jobs and Brexports

Once in a lifetime opportunity for UK companies to design & build entire Gen III+ plant

Supply chain secured (including for defence)

40,000 skilled UK jobs

Need to recognise the urgency in the SMR opportunity, and need for a clear roadmap, given other nations are already pressing ahead

£400bn global export market, mostly outside EU

SMRs can boost the UK's Industrial Strategy

The UK Government's recent Industrial Strategy Green Paper, aims to move beyond short-term thinking and focus on delivering long-term sustainable success (BEIS, 2017)[16]. The Government has identified the nuclear industry as a priority area, and whilst the Green Paper acknowledges that Government has a role to play in supporting and enabling new nuclear developments it highlights the need for UK industry to be the driving force behind growth and the low-carbon economy.

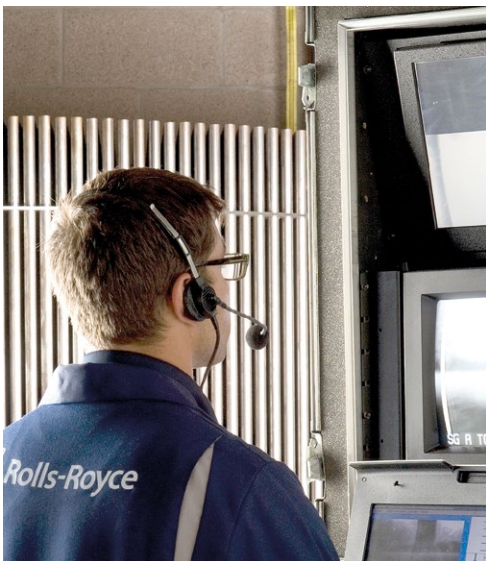
The UK has historically occupied a position of nuclear industry strength, with UK companies producing innovative products and services for the global market. However, recent mergers and acquisitions have resulted in a thinning of UK ownership in the nuclear industry. Moreover, this comes at a time when UK Government investment in nuclear research and development capability has also reached a record low, as was detailed in the 2011 House of Lords Select Committee on Science and Technology review into Nuclear Research and Development Capabilities (HoL, 2011)[17]. Whilst recent funding announcements (BEIS, 2016)[18] have signalled Government intent to start reversing this trend, it will be some time before these programmes deliver industrial impact and they are still small in comparison to international competition (HoL, 2011)[17].

Given that the nuclear sector has been identified by Government as a target for a 'sector deal' a UK SMR programme would provide the perfect mechanism for the deployment of such a deal. Currently, much of the existing nuclear industry in the UK involves servicing Government contracts - either in management and decommissioning of legacy facilities owned by the Nuclear Decommissioning Authority (NDA), the development of systems and technology for naval programmes or the maintenance of the national deterrent. But to be truly world-leading, the UK nuclear industry must move to a position of developing and exporting commercial products and services. An SMR would be the ideal vehicle to encourage this transition with a UK SMR programme fostering development of all 10 'pillars' of the Government's proposed Industrial Strategy Green Paper (BEIS, 2017)[16].

Developing and operating the UK SMR requires investment in science and innovation to provide supporting technology. This development will be driven by an expansion of the highly-skilled workforce required within the nuclear sector (Cogent, 2015)[19]. And with additional support the industrial and academic institutions already engaged in nuclear skills development can be bolstered to meet the challenge. The UK SMR is a homegrown British solution that does not rely on imported (or intermittent) energy. Building SMR plants will therefore improve UK energy security and infrastructure, supporting national business growth both directly during construction and operation and indirectly through the provision of clean, affordable energy. Strategic Government intervention is essential to ensure the rapid development and deployment of SMR plants across the country and return the UK to the top-table of the global nuclear industry with world-leading technology, intellectual property and capability.

> A UK SMR programme would foster development of all 10 'pillars' of the Industrial Strategy and provide a secure source of low cost, low carbon electricity

> The UK SMR is a homegrown British solution that does not rely on imported or intermittent energy



The UK nuclear industry requires a highly-skilled workforce

This is a very different vision of the UK nuclear industry compared to the existing landscape which is currently centred on the operation of:

- A retiring fleet of unique advanced gas-cooled reactors;
- Nuclear fuel cycle related facilities (predominantly Sellafield site, as well as fuel facilities at Capenhurst and Springfields);
- Legacy facilities (multiple former research sites, Sellafield and power plants in a shutdown state – both Magnox and soon AGR);
- Defence nuclear capability (including Royal Navy facilities, Dounreay and Aldermaston)

The UK nuclear supply chain currently supports around 40,000 jobs, with a projected increase to 65,000 jobs anticipated due to the planned large nuclear new build programme (NIA, 2012)[15]. This will level off at around 47,000 jobs upon construction completion.

Nuclear jobs are highly skilled, with a wide range of disciplines

A UK SMR programme could create up to 40,000 additional highly skilled UK nuclear supply chain jobs

But whilst the jobs created by UK large plant new build are significant, the potential is limited by the competitive balance between UK supply chain and strong international supply chains, some of which have been supported by significant national Government efforts to enhance and expand capability (Choi et al, 2009[20], Grubler, 2010[21], Zhou et al, 2011[22]).

Nuclear jobs are highly skilled, with a wide range of disciplines required to successfully deliver any project or programme. Current civil nuclear jobs are concentrated outside of the South-East of the UK, (Figure 5) and this brings significant value to the regions. Investment and expansion of the nuclear industry through the development of a UK SMR programme could provide Government

with an additional means towards rebalancing the economy, creating new opportunities and bringing well paid jobs to the regions and rural areas. This is complementary to existing policy relating to strategic developments in, for example, Wales, the Northern Powerhouse or Midlands Engine regions.

> Our UK SMR programme effectively doubles the size of the UK nuclear industry

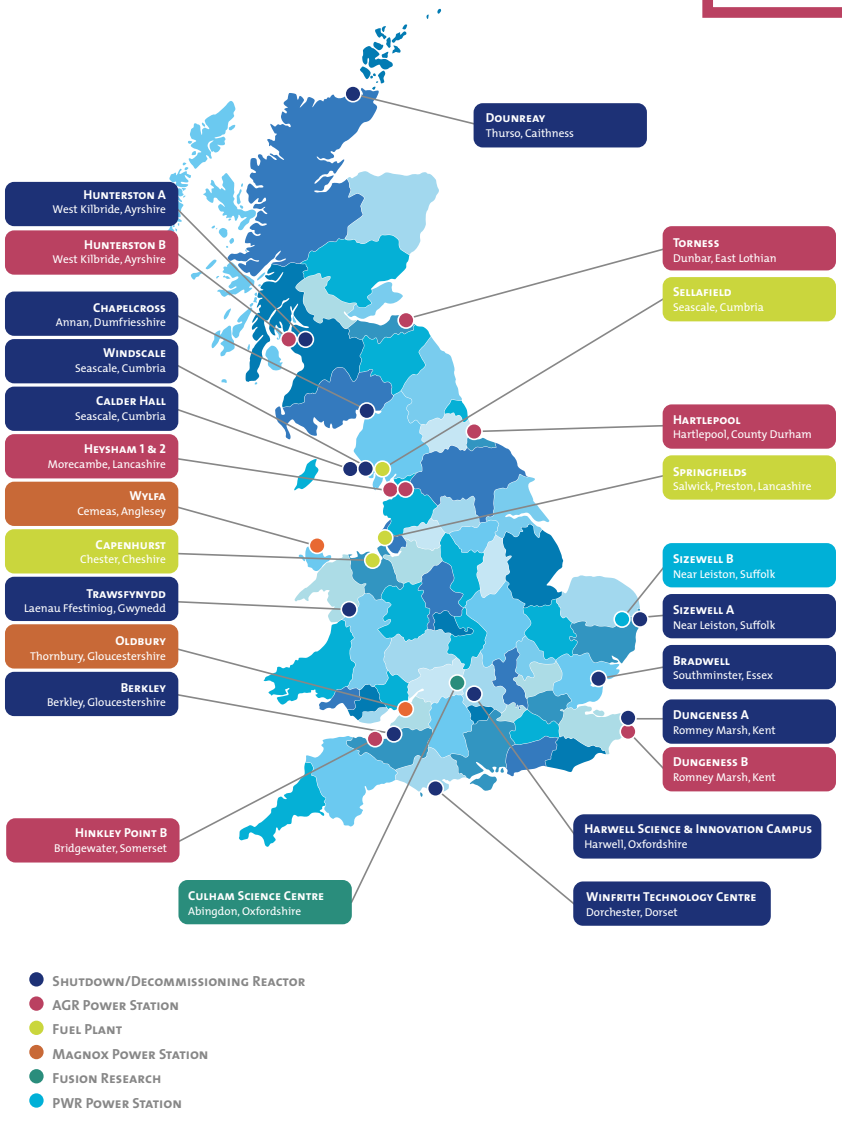


Figure 5. UK nuclear sites. Most are located away from the South-East and provide substantial economic benefit to the regions of the UK. (Image courtesy of NIA)

Design, development and production of a UK SMR fleet has the potential to create up to 40,000 additional highly-skilled UK nuclear supply chain jobs between 2030 and 2050. These would be located largely outside of the South East around the sites of the new nuclear plants. Investment in a UK SMR programme effectively doubles the size of the UK nuclear industry within a period of 15 years, with enhanced levels of jobs generating greater technical expertise as compared to other reactor programmes.

Exports

The international market is currently forecast to be around £400 billion by 2035 and most of this is anticipated to be outside the EU

A UK SMR programme could add over £100 billion to the value of the UK economy, locally and nationally, not only through domestic sales but also through exports. Indeed, current projections suggest the international market for SMRs could be substantially larger than the UK domestic market. The international market is currently forecast to be around ten times larger, at around £400 billion by 2035 and most of this is anticipated to be outside the EU (NNL, 2014)[11]. No single reactor vendor is likely to capture the totality of the international market, but a clear opportunity exists, particularly for vendors who are able to secure early orders.

Realising international export opportunities will require market confidence in the UK SMR, the correct and appropriate international treaties and access to project financing. The UK SMR is designed to meet the criteria required to be eligible for UK Government's UK Export Finance. This is significant and provides a range of international customers with the means to engage in substantive discussions around future opportunities. Indeed, the UK SMR Consortium has already been approached by interested Governments, operators and utilities from around the world.

There has never been a greater need for low carbon, low cost, electricity

Broader economic benefit

The provision of safe, secure and reliable low carbon electricity at affordable prices will underpin UK industry, providing certainty and confidence. This will foster investment and development within the UK economy, and the sustainable lower cost will provide much needed relief to households and businesses.

A UK SMR fleet would allow people to adopt new technology whilst minimising their energy bills and carbon footprint, for example whilst charging electric cars. Supporting the electrification and decarbonisation of outdated fossil fuel based infrastructure will bring broader societal benefits as we change the way we heat our homes and commute to work.

The increasing prevalence of electric cars and the need for low carbon heat may make energy demand harder to predict. But this can be countered by the flexibility of SMRs which allows plant to be deployed quickly. Therefore, having an indigenous UK SMR design that could be reliably constructed within a short timescale (under five years) financed by commercial investment with no government financial support, would place the UK economy in a strong position.

Technology and capability developed for our UK SMR will also support advances in other sectors such as transportation infrastructure.

An independent review led by Richard Maudslay, concluded:

"A UK SMR programme managed by a Rolls-Royce led Consortium with appropriate full and ongoing Government support would offer the UK the best opportunity to design, manufacture and construct the next generation of nuclear plants and would help to deliver a national nuclear strategy."

Sustaining nuclear skills

The UK nuclear industry experienced a period of decline in the 1980s and 1990s - recruitment numbers went down and new UK talent was under-developed. Today, as the current generation of nuclear technical experts approaches retirement, recent seed funding from Government is starting to enable the development of the next generation of nuclear technologists. The UK SMR programme would provide a national focus for this development, drawing in the broadest possible range of technical domains and combining them. This would bring substantial opportunity for the development of individual skills, as well as the cross-disciplinary, multi-functional working that nurtures and accelerates the development of world-class talent.

Rolls-Royce employees receiving UK Nuclear Skills Awards

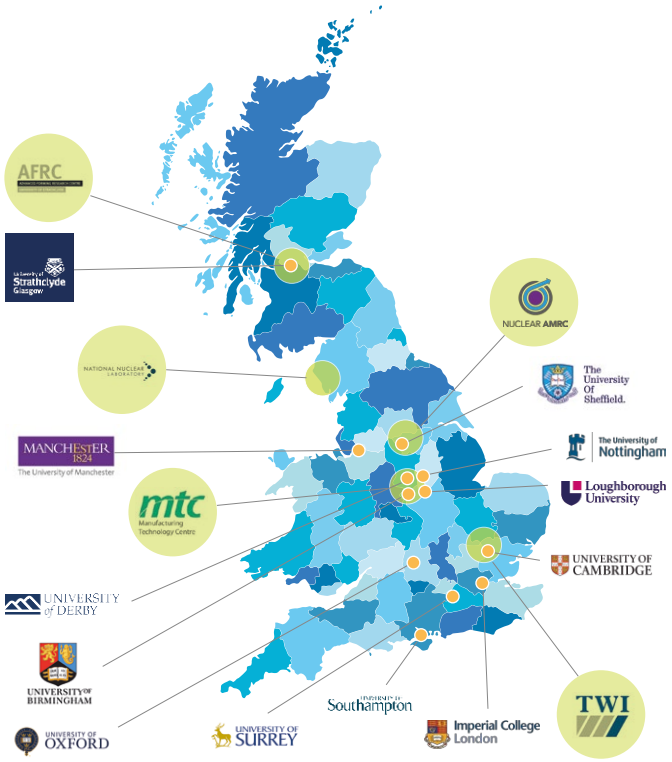


Figure 6. Academic organisations already involved in the development of UK SMR (Rolls-Royce, 2016[23])

> The benefits of developing a new generation of UK talent would be immediate and long-lasting.

In fact, the UK SMR programme has already engaged a wide range of UK organisations in support of development efforts that have been underway since late 2015 (Figure 6). As the programme continues to grow and evolve, an additional range of opportunities will require the support of leading minds from across the UK. This will open up further opportunities for academic and industrial organisations not yet involved. Many of the future operators of the UK SMR are currently still in school and a substantial UK development programme would provide an inspirational opportunity to encourage both girls and boys to follow Science, Technology, Engineering and Maths (STEM) pathways.

Much of the expertise required to construct a fleet of UK SMRs is found in areas such as civil engineering, project management, safety engineering, controls, electrical power and mechanical engineering. These skills are readily transferable to other programmes and other sectors. The spin-off benefits of developing a new generation of UK talent would be immediate and long-lasting. A pool of talent would be ready to engage across a wide range of national, local and private development infrastructure projects. The UK SMR programme would also enable the development of a large number of subject matter experts - a key goal of nuclear skills strategies such as the Nuclear Skills Strategic Plan (Cogent Skills, 2015)[19].

Advantages to the UK's nuclear deterrent programme

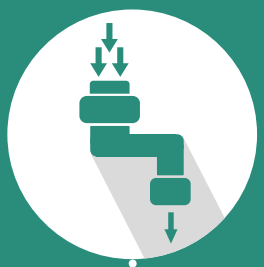
A UK SMR programme would increase the security, size and scope of opportunities for the UK supply chain significantly, enabling long-term sustainable investment in people, technology and capability

One particular application for deployment of the talent developed through the UK SMR programme would be in the ongoing maintenance of the UK's independent nuclear deterrent. Currently, the UK Government is required to invest funding to sustain the skills and capability necessary for the maintenance of the Royal Navy's nuclear submarine programme. Recent decisions in Parliament have committed the UK to continue with independent deterrence for another generation, and therefore the need to maintain the relevant skills and capability remains paramount.

The indigenous UK supply chain that supports defence nuclear programmes requires significant ongoing support to retain talent and develop and maintain capability between major programmes. Opportunities for the supply chain to invest in new capability are restricted by the limited size and scope of the defence nuclear programme. A UK SMR programme would increase the security, size and scope of opportunities for the UK supply chain significantly, enabling long-term sustainable investment in people, technology and capability.

Expanding the talent pool from which defence nuclear programmes can draw from would bring a double benefit. First, additional talent means more competition for senior technical and managerial positions, driving excellence and performance. Second, the expansion of a nuclear-capable skilled workforce through a civil nuclear UK SMR programme would relieve the Ministry of Defence of the burden of developing and retaining skills and capability. This would free up valuable resources for other investments.

A similar story can also be told around creating talent in major infrastructure delivery to assist in the construction of the High-Speed 2 and High-Speed 3 rail programmes, or the third runway at Heathrow.



Reduced reliance on foreign gas imports; backstop for 'intermittent' generation

All British solution so we don't have to rely on imports

Future energy demand is hard to predict – SMRs can be deployed quickly when required

Securing homegrown energy

Helping the UK deliver on its 2050 decarbonisation commitments, delivering carbon-free, emission-free electricity by 2030 through UK industrial leadership

SMRs can complement existing and planned nuclear plants

We need a mix of energy generation technologies to meet our clean energy targets

Keeping valuable IP within the UK

Making it happen

Government support for SMRs

We believe that the UK SMR under development by the Rolls-Royce led UK Consortium is the right technology to meet the energy challenges facing the UK in the 21st century

In 2016 the UK Government launched the first phase of an 'SMR Competition' to select the best design of SMR for the UK (HMG, 2016)[24]. The time is now right for the Government to move forward with pace towards establishing the conditions required for a UK SMR to flourish, as the rest of the world continues to develop SMR technology and the UK is in danger of being left behind. A key role for Government is to provide a fertile 'ecosystem' for UK SMR development, starting with policies and support for an indigenous UK SMR market.

Once the technology has been selected and the development funded and underway, the UK Government must proceed with enabling the identification of a viable first-of-a-kind site in support of an appropriate power plant operator. It is very important that the UK public is engaged throughout this process to ensure that every effort is made to take into account local, regional and national sentiment in relation to plant siting, development and construction. Multiple sites will be required across the UK to enable large-scale fleet deployment. Initial feasibility studies have identified a substantial number of potential sites for SMR power plants (ETI, 2015)[25], but further work is needed to develop these options and ensure a consensus.

In tandem with developing siting options, the UK SMR must progress efficiently through Generic Design Assessment (GDA), with Government sponsoring a suitably timely 'slot' with the UK regulatory authorities. Upon completion of GDA, the UK SMR becomes a viable proposition for independent private investment. Up until that point, including the completion of the Critical Design Review, Government support will be required to sustain and grow the design development programme. The cost of this will be around £500m matched against industry funding. In addition to furthering UK SMR development, this investment will also expand the UK skills base in reactor design, high integrity civil engineering, project management and advanced secure digital technology.

In tandem with developing siting options, the UK SMR must progress efficiently through Generic Design Assessment (GDA), with Government sponsoring a suitably timely 'slot' with the UK regulatory authorities

Development and strengthening of the UK nuclear supply chain must also take place. Government guarantees around UK deployment will provide confidence to the UK supply chain to invest in capability and capacity. Channelling Government support through existing local and regional funding mechanisms will ensure that the whole of the UK benefits from the UK SMR programme.

As a UK SMR design approaches maturity and the FOAK build is realised, Government support in providing export finance will play a crucial role in ensuring that the UK SMR is not just a national programme but an international success. This international deployment will ensure that the highly skilled jobs created through the UK SMR programme are sustainable into the middle of the 21st century and beyond.

Commitment of a Rolls-Royce-led UK SMR Consortium

We believe that the UK SMR under development by the Rolls-Royce led UK Consortium is the right technology to meet the energy challenges facing the UK in the 21st century. Rolls-Royce is committed to leading the development of the UK SMR Consortium, so long as the conditions in the UK are viable.

The UK SMR Consortium brings together some of the most respected and innovative engineering organisations in the world. Rolls-Royce, ARUP, Laing O'Rourke, Nuvia and AMEC Foster Wheeler all have a successful track record of delivering large-scale, complex engineering and infrastructure programmes. There is also significant opportunity to engage a broad range of UK small and medium sized businesses to promote a wider, more innovative, approach. As a leading UK engineering company, Rolls-Royce is highly experienced at developing and enhancing UK supply chains to produce high integrity systems and components for safety critical applications. We will bring this expertise to bear on the UK SMR programme.

> The UK SMR Consortium has a highly successful track record of delivering large-scale, complex engineering and infrastructure programmes

Rolls-Royce has spent the last 20 years developing a network of over 30 UK University Technology Centres and has been a key player in developing the HVM Catapult Advanced Manufacturing Centres. We know how to engage the whole of the UK knowledge base to develop new technologies and solutions that can be rapidly deployed onto real products and services. Many of the technologies that are developed in support of UK SMR will have further application across the nuclear sector and beyond.

The conditions are now right and the time has therefore come for UK Government and the private sector to start working together in earnest to capitalise on the SMR opportunity. This is the moment to develop and deploy an energy generation programme that is safe and reliable; that secures local, home-grown energy supplies; that creates jobs and export potential; and provides UK domestic and business consumers with low-cost, low-carbon electricity. The multiple benefits of a UK SMR programme have the power to shape the UK's future for the better. We should start realising them now.

UK SMR: now is the time to embark on a national endeavour

Rolls-Royce

ARUP

amec foster wheeler

NUCLEAR AMRC

NUVIA

LAING O'ROURKE

Rolls-Royce: the only UK nuclear reactor designer, manufacturer, operations and support for 60 years

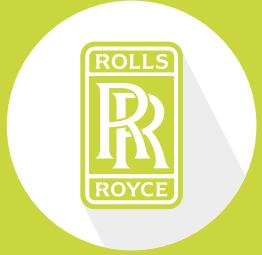
Our consortium all have deep experience of delivering massive and complex infrastructure projects on budget and on time

Rolls-Royce and its UK partners have a global reputation for engineering excellence

Technically the right choice

SMRs are the next nuclear reactor development, using proven technology to generate revenue to re-invest in R&D funding for future technologies

Rolls-Royce is the only existing UK nuclear island systems designer, supply chain integrator and manager



Rolls-Royce unique nuclear experience, in defence and civil markets, makes it the natural choice to lead Britain's SMR development

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