The submission of the Nuclear Institute in response to the Alternative Routes to Market Consultation, April 2024

About the Nuclear Institute

Nuclear energy is an essential part of the UK's clean energy mix, making it critical that the industry has the right standards and people to support future growth and success.

The Nuclear Institute is the only professional membership body dedicated to the nuclear sector. Representing over 4,000 professionals at all levels across the nuclear industry, from new build and operations to decommissioning, we maintain the Nuclear Delta, the independently defined standard for Nuclear Professionalism and our community is a source of subject expertise. We are licensed by the Engineering Council, Science Council and Society for the Environment to charter and register those working in these disciplines.

The professional engineering community is working together to address the global challenges of sustainability, ethics and equity, diversity and inclusion. Jointly, and individually, we are committed to innovating and improving across these societal challenges, within our organisations, and ensuring our members recognise the importance of these responsibilities alongside core professional competencies. As a self-regulated profession, we recognise the importance of public confidence that engineering is safe, sustainable and inclusive to all in society.

The NI is made up of our HQ Team, our Board of Trustees (BoT), Committees plus our communities; a thriving network of Regional Branches, the Nuclear Institute Young Generation Network (YGN), Special Interest Groups, Expert Forums, and our volunteer network.

Further organisational information can be found on the NI website: nuclearinst.com

Exploring New Uses

1. **Are there any uses for nuclear energy (beyond those in this document) that you believe government should be considering? If yes, please explain what they are.**

   The uses for SMR and AMR technologies and projects going forward as suggested in the consultation are reasonable in respect of Industrial heat and power, generation of Hydrogen and Synthetic Liquid Fuels, District Heating.
   Additional applications could include any industrial operation that would need continuous low carbon power e.g., Desalination and Direct Carbon Capture and secure supply to Data Centres as this demand grows.

   The industrial potential of Small Nuclear (SN) is significant, this if enabled can reduce direct load and burden to the grid. This is a key strategy in both Net Zero and realising a significant reduction in infrastructure costs which may be required in support of other generating assets.

   For example, the use of SN to support delivery of liquid synthetic fuels to address the carbon emissions of the Transport sector is likely to be a more easily delivered and cost-effective solution than shifting directly to direct applications, which would incur significant costs of infrastructure development, delivery, and ongoing regulation of the additional assets.
   The consultation inferred use of SN in an "intermittent mode" is unlikely to be economically viable. Plants are being designed to typically operate at circa 92% capacity factors and are best suited to this whilst being able to load follow to some degree will be best suited to generation of continuous low carbon power and heat.

   It is likely to be cost punitive to operate intermittently and in effect shifting the cost, of infrastructure to allow storage towards a requirement for SN, needs to be balanced with an energy market that does shares this burden with other intermittent generating assets.

2. **To what extent do you agree that advanced nuclear can be a valuable energy source when combined with a Thermal Energy Storage System or for co-generation? Please provide an explanation for your response.**

Nuclear power plants can be invaluable to a heat energy system asthe only current low carbon generating assets that can directly provide both power and heat on a continuous basis.

The scale of the decarbonisation challenge beyond grid is significant, multiple studies conclude that heavy investment in sustainable fuel alternatives combined with deep electrification is required to deliver net-zero decarbonisation.

The role of nuclear has the potential to be deliver decarbonisation at pace across a number of areas / sectors:

- Through cogeneration SN can provide the heat necessary to decarbonise / reduce the carbon intensity of industrial processes (circa 15 % of current UK carbon emissions).
- Through cogeneration SN can provide the process heat to produce hydrogen, a key feedstock resource in the generation of alternative sustainable fuels (to replace the existing fossil fuel options) – e.g., by producing H2 itself, or pink synthetic hydrocarbons, and ammonia.
- SN can provide bulk hydrogen which can be used for medium term mitigation of failure of other assets (Dunkenflaute).
- Through connection to the domestic/industrial space heating networks, coupled with thermal energy storage, to support district heating. (Noting that space heating of homes and businesses is circa 17% of UK carbon emissions).

Note: Thermal Storage should not be a pre-requisite for SN deployments. This is a matter of cost and should not be a requirement because of shifting the burden of low-capacity factors away from other generating assets.

Evidently, a basket of measures will be required, but nuclear has a strong role to play in any future system.

The Department of Energy in the United States has already recognised the potential of nuclear beyond electrification through wider decarbonisation and has stated a potential demand of 200GW of capacity by 2050.

The UK target for nuclear on grid is 24GW and does not account for any of the non-electrical applications such as those listed above. Policy supports up to 25 % of the energy mix in the UK would be more consistent with forecast demand and wider applications.

The basis for utilising heat from nuclear power is an economic argument, not just a decarbonisation argument.

Evidence indicates that utilising heat from nuclear power can improve the LCOE of nuclear power plants, making them even more cost competitive (or indeed favourable) to existing intermittent renewable options and fossil fuel technologies which will require costly abatement.

For example, near term SMR technology vendors in collaboration with European partners have commissioned third party analysis of costs and delivery certainty for bulk Hydrogen to volume applications and this suggests:

- Hydrogen from fossil fuels*: £0.9-2.5/kg**
- Hydrogen from renewables (offshore wind): £3.3-3.8/kg

- Hydrogen from nuclear co-gen £2.3-2.8/kg***

*Does not include energy crisis and high inflation of 2020 onwards.
**Upper figure is upper range of natural gas with CCUS (see here).
***Lower figure from SOEC electrolysers with SMRs (TRL5-7 at present)

One argument for nuclear power in the context of heat, is it drives improved economics for nuclear power project investors (reducing energy generation losses) and makes a decarbonised transition more economically feasible.

The use of cogeneration or heat systems coupled with thermal energy storage, is very much dependent on the type of technology. The current GW and potential SMR fleet are PWRs and will typically deliver output temperatures of ~300 degrees Celsius. This is well suited to district heating and increasing the efficiency of industrial processes (i.e., by reducing total amount of energy demand to achieve desired process temperatures).

Future AMRs have the potential to inject much higher temperatures, with the potential for the provision of full "energy demands" for various processes – take the thermochemical splitting of water to produce hydrogen (avoiding the need for electrolysers), but AMRs are typically lower TRL and will likely incur some development costs to mitigate technical risks.

Thermal Energy storage is dependent on end application i.e., smoothing demand levels. Therefore, for district heating or space heating applications this may be sensible because demands fluctuate on a routine driven by human behaviour or working patterns.

The demands of high-volume industrial production could be considered an equivalent "baseload" of heat to maximise the on-time for the industrial processes (high-capacity factors) and further improve the economic cases for SN. An example of where cogeneration may be preferable to a system with thermal energy storage might be delivering the 2050 ambition for 20-90GW of hydrogen capacity by 2050 (as per the Government's Hydrogen Strategy Delivery Dec 2023).

The potential of Solid Oxide Electric Cells in combination with SN to generate bulk Hydrogen cost effectively is being explored by a number of technology vendors in addition and beyond more readily available electrolysers which could be developed to operate at higher temps.

3. **To what extent do you agree that advanced nuclear could be a valuable energy source for large scale industry. Please provide an explanation for your response.**

Nuclear power plants can be invaluable to a heat energy system as they are the only current low carbon generating assets that can provide both power and heat on a continuous basis. The choice of technology and application will be a feature of both developer and end user investment cases and engagement into purchase agreements respectively.

Noting the increasing focus of investors and hence industry in de-carbonization, near term technologies such as LWRs can readily provide heat and low carbon energy to delivery of; Hydrogen, District & Industrial Space heating, Synthetic Fuels, Ammonia Plastics and DACCS.

Future AMR's which can operate at higher temperatures will provide some technical benefit as a result of this in respect of efficiency to all the above applications but are likely to require investment in TRL development although these may be relevant in future utilising AMRs online for steel / foundry industries, cement production, glass production i.e., high temperature processes.

The range of application of SN is already being evidenced across a wide range of sectors by several parties including a few examples as below:
Hydrogen – ESNZ, EDF & RR SMR others in Netherlands/Sumitomo analysis and project exploration.
Data Centres – Microsoft, Google and Amazon etc
Heavy Industry – Construction, EDF Bay Hydrogen Hub Project and work in support of with Asphalt using LWR and as above reference Steel and Glass.
Aviation Fuels – RR Group, Airbus and Shell collaboration CCUS and this may build on previous work in Industrial De-carbonisation with a potential for CO2 as a feedstock for synthetic fuels which may turn abated carbon to an asset.

4. **In your opinion, what further measures should government take to enable industrial applications of advanced nuclear? Please provide an explanation of the type of support required.**

SN with an ability to deliver low carbon heat and power can deliver increased benefit but this may require development in several areas to be enabled.

1. In respect of Policy the previously published consultation on siting policy should be used to address and inform Siting Policy but it should be recognised that SN is ideally suited to co-location with industry. This may require delivery and development of siting studies in parallel with co-location and a recognition that industrial entities may wish to progress in parallel to any program under the care of Great British Nuclear, which is possible under existing regulation.
2. There will be a need for support to Regulatory upskilling which should not necessarily be borne by the first to private market developer i.e., if SN is to be enabled quickly some investment in the capability of appropriate bodies e.g., OFGEM, ONR, EA and NRW may be required. The market and developers should indicate the technology choices and site selections but should not bear the full cost of upskilling and work required by these bodies to develop understanding, clarification of roles and adjust guidance etc.
3. Regulation may need amendment to enable barriers to application and investment to be addressed e.g., Identification and resolution of barriers such limits on self-generation (off-grid applications to 300MW or similar) and lack of clarity of regulation of heat markets.
4. As previously noted (Q1,2&3) SN has a potentially broad range of applications however enabling these may require a portfolio of technology development to advance TRLs of key enabling

technology including Heat Exchangers, Electrolysers (for hydrogen), Thermal Transport and Control and Instrumentation, Digital Systems and applications of Artificial Intelligence. The above could be summarised as a portfolio approach to the support and development of a modular operating model for "system" optimization (temps, tech and user applications) of an industrial spoke and hub system. Technologies exist in the above however the challenge is in terms on systems engineering, coupling and technology integration and development of industrial partnerships which may be willing to co-invest with Government and others to underpin these.

5. Several of these technologies and solutions may require a user case demonstration for example which could be enabled through a test facility will help de-risk technologies and increased understanding of optimal heat extraction in nuclear thermal cycle, feedback mechanisms, through-life performance. Regulatory development (capability and application) would benefit from access to a test facility and enabled "sandpit" approach.
6. There is a propensity to consider SN as a technology for Heat and Grid Power and there may be a case for a series of enabled to Market studies around financing and business models for the different applications to be explored in more thorough detail this could be publicly funded to increase awareness of opportunity and benefit in the widest range of stakeholders.
7. The above (6) should not be limited to raising the awareness of HMG, Industry and Investors but should also consider the importance of public acceptance of SN and how to safeguard the societal engagement whilst reducing lead times for consenting. There may be a case for funded Social Science in support of SN to enable a transparent and value add social / community exchange. This could include support for regional skills and EDI programmes to enable roll-out at pace in the 2040s. These could be incentivised by Policy and or Inclusion in ONR / EA tags and practice guides.

5.To what extent do you agree that advanced nuclear could be a valuable energy source for hydrogen and synthetic fuel production? Please explain your answer.

Please see comments in response to question (3).

The NI suggests there should be significant confidence that nuclear is viable energy source for hydrogen and syn-fuels. The ambition and policy of the UK to support up increasingly significant capacity for hydrogen power generation (20-90GW) will likely require SN with high-capacity factors and elevated temperature, to support cost effective fuel generation at bulk.

The opportunity for SN to support Hydrogen production will need support and development of a broad range of enabling technologies which could deliver economic opportunity including:

- Demonstration facility to overcome systems engineering challenges (location of heat offtake, thermal hydraulic feedback mechanisms, etc)
- Support for SOEC and electrolyser development
- Support for thermal energy transport R&D
- Support for materials R&D
- Support for heat exchanger development
- Large scale storage and transmission of hydrogen

Support to the above should be agnostic to any future technology noting the temp ranges of SMRs vs AMRs and types of electrolysers/technologies they can support and what enabling tech may be needed. This support could be in the form of co-invested projects with HGM support in advance of SN technology maturation with market selection.

6. **To what extent do you agree government should explore the opportunity of using nuclear plants to provide district heating to help decarbonise our domestic and commercial buildings? Please provide an explanation and include suggestions on mitigating any potential barriers.**

There NI is strong agreement that the opportunity should be taken to explore the use of SN in decarbonisation of distributed heating and notes the consultation document evidences an example of this being successfully done in Switzerland. Based on existing international evidence to date:
The most common type of nuclear power plant (NPP) in operation (277 out of 438) or under construction (59 out of 70) (IAEA, 2015) is the Pressurized Water Reactor (PWR). The thermodynamic efficiency of a PWR is around 33%. Therefore, about two thirds of the heat generated by the nuclear fuel is wasted. The steam exiting the high-pressure turbine is superheated, it could be used for non-electric applications such as district heating, desalination of sea water, industrial process heating etc. (IAEA, 2003). Nuclear cogeneration plants (NCP) are defined as NPPs targeting a high thermal efficiency by generating both electricity and heat.

A PWR can be converted into an NCP without jeopardizing the reactor's safety it’s thermal efficiency could typically reach circa 66% which gives significant scope for economic applications as this would increase total energy output by at least 50%. There have been several studies of operation of a PWR as a NCP, a configuration which implies a reduced electricity output of the reactor.

Lost electricity production depends on the temperature and the amount of heat considered. Several studies pointed out that, for the temperature ranges useful to district heating networks (85–115 °C), NCP can be designed so that the amount of thermal energy (MW (th)) recovered is five to six times greater than the electricity losses (MW(e)) (IAEA (International Atomic Energy Agency), 2017, IAEA, 2016a, IAEA, 2003).

There are currently over 50 operational reactors configured to supply district heating with a number in Switzerland, CZE, Slovakia and Hungary and there may be valuable experience to be gained from these.

- Potential barriers and opportunities to applications of SN in district heating would include:
- Programmes to explore how to efficiently reduce cost and maximise efficiency of thermal transport.
- Development of heat and power regulation and ensuring clarity to potential market entrants.

- A strategic approach to public consenting and consultation and perception of risk and opportunity.
- Developing an understanding of thermal hydraulic feedback mechanisms

7. **What do you think are the opportunities and challenges associated with other potential uses for nuclear power? Please explain your answer.**

The UK has a strong independent regulator and a goal seeking approach which is significantly different from that in several other leading nuclear nations including for the USA and Canada. The challenge of harmonisation and acceptance of SN in multiple nations which may be required for economic adoption / application in support mobile power generations e.g., Maritime may prohibit this in Civil applications. In the medium-term SN projects and associated R&D should be progressed as a base potential application in delivering bulk hydrogen and synthetic liquid fuels.

Regulating Advanced Nuclear

8. **To what extent do you agree that the current regulatory pathways cover new uses? Are there any areas that are not covered? Please explain your answer.**

The NI believes that given the UK's approach to nuclear regulation (goal setting and nonprescriptive) enables and assures the majority of SN uses for nuclear power including electricity generation. Local planning and the Development Consent Order process are relatively agnostic of technology and although both (planning and 'nuclear') regulation may require some small enhancements including siting to enable co-location with end users, the NI generally considers these to be suitable for new uses.
Current Combined Heat and Power (CHP) which are mostly gas fired and sell heat, steam, and electricity to clients, this is mostly a deal between a utility/operator and large industrial user. A market for wholesale heat, hydrogen, steam, and other vectors will require developing with the associated regulation as the industry and policy moves forward.

9. **What, if any, are the main opportunities and challenges for streamlining regulation while maintaining high standards of safety, security and environmental protection? Please explain your answer.**

There are opportunities to streamline the full siting process for nuclear power plants, large and small. As identified in Q8, there is an opportunity to streamline regulation with respect to co-generation. This would mean closer integration of conventional / industry safety regulation with nuclear regulation. Nuclear regulation in the UK is enabling and has been proven in many new projects to date. It is a 'no surprises', transparent approach.
The NI feels that Regulatory Justification (under the JOPIIR Act) for nuclear facilities could be incorporated into a Generic design Assessment (GDA) or first Nuclear Site Licence to reduce timescales, cost, and duplication. The main opportunities for streamlining lie in the local

planning and DCO process. Making this more open and transparent, with a no surprises approach will provide developers with reassurance and lower project risk as the project progresses.
It is noted that Welsh Ministers are currently consulting on a unified infrastructure consenting process, where Welsh Ministers could grant consent to stations between 50 and 350 MW and above 350 MW, consenting power would rest with PINS. This could cause potential confusion and inconsistencies. The current consultation does not specify if 50 – 350 MW refers to units or power plant (multi-unit) sites. It could lead to one type of SMR being deployed in Wales consented by Welsh Ministers and a SMR of a different size or a GW site in Wales being consented under PINS. This issue would also require clarification to efficiently consent and develop new nuclear projects.

10. Following government's streamlining work to date, do you agree the next phase should focus on process efficiencies? Please explain your answer.

It is recognised that it is always good to focus on process efficiencies however continued focus on enabling new innovative practices into regulation while maintaining safety and security standards is something that could still offer revolutionary change.

11. To what extent do you agree that advanced nuclear technologies and new uses of nuclear are accommodated within the existing legal landscape? Please explain your answer.

As identified in Q 8 there is still further need to focus on regulation of nuclear whereby the technology is generating heat and/or electricity and / or hydrogen. Most ANT will be producing different kinds of energy product beyond grid, when compared with nuclear technology to date. The use of heat for industrial heat will mean regulating nuclear on different "industrial sites". In addition, use of nuclear to produce hydrogen and subsequently sustainable aviation fuels (SAF) means that industrial and nuclear safety regulation will need to be aligned and working together in an effective way.

12.What are the opportunities and the challenges of the proposed engagement approach? Please explain your answer.

There is agreement with the direction of the proposed engagement approach and believes this will help reduce risk and educate developers on the regulatory landscape in the UK which should also help in reducing time for deployment of new nuclear projects. These engagement approaches should also be an opportunity for UK regulators to understand what work has been performed elsewhere under other regulatory auspices and whether this will be acceptable and not need to be repeated in the UK. This could give valuable input into project planning and risk reduction for deployment of projects in the UK. The mechanism by which the regulators will be funded for these services will also need to be made clear.

12. Are there new or additional nuclear safeguard challenges associated with ANT innovation and/or new uses of nuclear energy? Please explain your answer.

All the ANT reactors are currently looking to use higher assay low enriched (HALEU) uranium fuels. These fuels have higher levels enrichment of uranium that may require additional regulation to be in place. In addition, many of these technologies will provide the maximum opportunities on existing industrial complexes that will need to be brought into nuclear site licence requirements. Finally, some of the fuels that are used for ANT may use nuclear fuel based on Plutonium. More stringent safeguards will be required for this and the exploration of existing regulation and its adequacy may be required.

Bringing Projects to Market

13. What else should government do to ensure that new nuclear projects can be brought to market? Please explain your answer.

It is pleasing to see Government recognise that delivering nuclear ambitions will require progress beyond the activities of GBN. Many of the uses of SN have the potential to be developer and industry lead to support applications as previously described.

It is important to clarify the role of GBN in relation to the key building blocks of a nuclear project (for instance developer capability). Developers must comply with the regulatory regime and this process should adjudicate and clarify the requirements of developers to hold a licence instrument and develop this capability when required.

GBN is currently perceived by many as the only route to UK deployment available to SMR technology vendors. This approach shifts the burden of risk to Government and seeks to mitigate this by RAB which shifts burden of overrun to the domestic consumer.

Government should confirm that GBN will not preclude the market entry of other developers subject to compliance with regulation and ensure that this message is consistently communicated. Inconsistency of understanding and communication is unhelpful and may degrade the confidence of parties seeking to bring forward private investment to support development and projects.
A policy and enabling environment must be presented that can give clarity and confidence of routes to market beyond grid i.e., to industrial clients (for heat, power and grid.)
SN offers the opportunity to mitigate risk and share the opportunity and economic benefit. The consultation appears to oversimplify the environment for SN. SN is typically delivered for a capital cost orders of magnitude below other generating assets, at lower risk and with potentially much shorter investor payback periods.

The consultation appears focused on a RAB mechanism for return to investors which may be appropriate but does not appear to acknowledge that project developers may have hybrid business models. For a project may deliver revenue by sales to industry of heat and power across multiple clients which gives an opportunity to spread revenue across several contracts. Government should confirm that GBN will not preclude the market entry of other developers subject to compliance with regulation and that both RAB, CFD's and PPA can be explored and will work with developers to enable this through structures such as advisory boards that ensure a voice for the private developer.

14. **What, if any, structures do you think are appropriate for advanced nuclear technologies? Please explain your answer.**

It is pleasing to note that Government is aware of financial structures beyond RAB and CFD and acknowledges the report of the Expert Finance Working Group on Small Reactors in 2018.This work also describes alternate delivery models and associated risk mitigation in detail. If SN is to be delivered at pace, then it is important to recognise that programmes can be continuous with several activities in parallel and delivered by multiple partners. This is best described as a continuous and gated programme with an ability to attract finance at differing stages of the delivery cycle. This reduces the risk of progression and completion progressively and mitigates the "cliff edge" of major investment failure at FID.

A feature of the nature of potential SN projects is the ability to innovate business models may be enabled. It is important to recognise the Investor, Developer, Licensee, Technology Vendor, Operator, DNO and Customers can be different and discrete parties. It is important to recognise the opportunities' that these structures can deliver in allocating risk to those parties best able to mitigate that risk, maximise investment to lower the burden on the taxpayer.

Noting that Customers can be multiple and beyond grid in respect of both heat and power it is important that hybrid combinations of PPA and CFD revenue mechanisms are enabled. This differs from a RAB model and is a route to enabling Government (Grid) to signal some stability and support by being positioned as one of several clients subscribing to an apportioned off-take.

A NPP Developer could choose to proceed with a Site Licensee, application without the Technology Vendor having completed GDA. It can be the Developers responsibility to carry out due diligence on any selected technology on behalf of the investor and negotiate contracts to align with the Investors requirement. The GDA process should be complimentary to any market-mechanism to allow the down-selection of technologies based on commercial readiness.

Further proceeding to Site Licensing without GDA may be riskier for a NPP Development Company and something the financing community would be concerned with however this is not binary and existing technologies being delivered by experienced tech vendors will be lower risk and may be within the appetite of investors and indeed this is already being evidenced outside the UK.

To manage the risk, it is more likely that there would be a requirement for the site licensing process to be progressed prior to financial close (if GDA has been completed this provides some confidence to financiers that the technology is licensable). With a GDA process the site licensing can be in train but does not necessarily have to be completed prior to financial close – especially if the project involves an experienced and existing Site Licensee or a Developer that can demonstrate understanding and knowledge of the requirements of the license instruments and their progressive nature through the project life.

15. **What are some key areas government should consider in a potential business model to bring a first-of-a-kind project to market? Please explain your answer.**

The UK unique situation, structured around HMG support mechanisms such as CfD and RAB currently dictates that projects in the UK requires HMG remains a key stakeholder, however the guiding principle that private sector investment and development will be required to deliver Government's ambition and this should be a continued area of focus for policy makers beyond the near term achievement of FID for Sizewell C.

SN should address the traditional struggles within the industry associated with the risk and quantum of potential delays and cost overruns but some of the challenges, but risk particularly for FOAK around market perceptions, may remain and the communication of appropriate understanding to interested parties should be open and lead by non-conflicted parties who are recognised as credible and appropriate.

Allocating risks and responsibility as indicated above should be the focus of contracting and creating the environment for private finance and pace with SN.
The construction industry has experience of sharing the consequences of the risks and encouraging the participants to cooperate in managing and mitigating risks. Working collaboratively, communicating, and developing behaviour across the contracting structure to manage the consequences of risks. Small nuclear provides a better environment than GW projects for risk management in that the consequences will, in large part, be much smaller. With the cost of a project below £2.5 billion, the consequences of cost overruns and delays are so much smaller than for large nuclear projects and it is important that Government recognises this and its influence on investor appetite.

In terms of nuclear third-party risks, small reactor designs are being simplified to reduce the probability of safety events occurring, and some technologies being designed such that a nuclear incident with the release of radiation cannot occur. Together with the lower fissile inventory in small reactors, this reduces third party risk by a further order of magnitude. This significantly reduces the risk to the project, the country and in turn HMG in providing cover for the consequences of a nuclear incident.

The risks associated with decommissioning and decommissioning funding will be much reduced, partly by the projects being smaller and more containable and in part as the scale of the units

allows easier management of cleaning etc. This should improve confidence in decommissioning plans and funding requirements.
With smaller consequences of risks the private sector is much more able to manage the consequences. The role for Government backstopping some of the consequences of risks that sit with the private sector will be minimal and will be a true backstop and only called upon in extreme circumstances which is consistent with a role it may play in other infrastructure projects.

16. How do you think the support required for projects should differ for later, nth-of-a-kind projects compared with a first-of-a-kind project? Please explain your answer.

While both FOAK and nth-of-a-kind nuclear projects may require government support, the nature and extent of support will vary based on technological maturity, regulatory framework, supply chain readiness, and public acceptance. These are not binary and should be viewed in proportion to the opportunity to reduce the burden of project finance. Considerations will include:

- The main risks HMG should consider in the FOAK phase are around: siting, reputational, political, change in law, change in regulation.
- Third party liability over and above the liability of the Site Licensee which can covered by insurance.
- Any nuclear liability that the vendors can accept (particularly for FOAK projects).
- The backstop provided by the equity providers.
- Project insolvency once the project is truly a nuclear project (nuclear fuel is on site) as the project could not be abandoned leaving a nuclear site without appropriate controls.

17. What financial risks sit with government and cannot be transferred to private actors? What is the minimum protection that government will need to provide to mitigate financial risks to taxpayers? Please explain your answer.

As previously described (Q15,16 & 17) SN could innovate business models, recognising the Investor, Developer, Licensee, Technology Vendor, Operator, DNO and Customers can be different and discrete parties. It is important to recognise the opportunities' that these structures can deliver in allocating risk to those parties best able to mitigate that risk and maximise private investment to lower the burden on the taxpayer.

SN using hybrid business models using PPA's and CFDs and the existing mechanisms e.g., the requirements for a Funded Decommissioning Plan (FDP) which are required through project consenting reduce the magnitude and consequence of risk.

SN projects are no more or less risk to the taxpayer than other infrastructure projects of similar magnitude or failure in other sectors e.g., the collapse of multiple energy providers in recent years through insolvency, the historic support of several banks in the financial crises or potential

Government intervention in the event of a utility or water company facing insolvency. Government in these cases acted as intervenor of last resort and the residual risk delta that markets may not be able or willing to cover may still exist.

The Government risk which needs to be considered - and properly modelled - is that the plant ceases operation (for whatever reason, not just operator insolvency) prematurely i.e., before the FDP "pot" is big enough. In those circumstances, the shortfall or net cost to the taxpayer could vary enormously (e.g., between cessation in year 1 versus year 25). It follows that either this risk should be insurable and/or that HMG may be asked to underwrite it as insurer of last resort. There might be several ways of configuring that, but spreading the risk across several designs and fleets would be one.

18. How should government mitigate insolvency risk at privately funded nuclear plants? How can this be achieved without imposing undue costs on taxpayers? Please explain your answer.

Government should adopt the approach that any insurer would do, i.e., by spreading the risks and impacts over as wide a market as possible - e.g., all the SMR plants/fleets that might be built as part of the 24 GW target. In effect Government can "self- insure" (assuming Treasury will not allow any departments to pay premiums or hedge) - it is best placed to act as an underwriter.

The risk should be considered proportionally and in context:

- Similar provisions don't exist for all established industries/plants -one of the key concerns about premature closure of heavy industrial chemical and steel plants is the taxpayer having to fund safe shutdown and decommissioning. The nuclear sector is much better prepared and provisioned for such eventualities.
- Government will be insurer/intervention of last resort in the case of unexpected failure of critical infrastructure, nuclear or not. It's an issue that has to be addressed come what may - and shouldn't be raised as something peculiar to privately funded SN projects and precedent experience exists in other sectors.
- If technically backed by bill-payers, partially or completely through the Revenue Support Mechanisms (CfD or RAB), SN projects are effectively taxpayer-backed and carrying risk.
- The risk of a given off-taker becoming insolvent (based on its credit rating, balance sheet, debt etc) could be calculated and the off-taker given a rating which would need establishing across a range of off-takers. This would create a range of deltas between agreements/credit ratings and the risk may be covered by a charge to the developer drawn through or incorporated in the FDP.

19. **What support infrastructure, or other enablers, would help bring projects to market, in addition to those highlighted above? Should government introduce measures to help private developers bring projects to market? Please explain your answer.**

The Government risk which needs to be considered as described Q19 - is that the plant ceases operation prematurely i.e., before the FDP "pot" is big enough. This being mitigated will support investor confidence. This may be enabled by:

- Adding a small premium to each FDP payment in the early years
- Enabling the grid will take any available power (where feasible) at a reserved price or have a "reserve" CfD arrangement which be actioned.
- Inclusion of nuclear within the green taxonomy will increase the pool of potential investors of nuclear projects. This will enable all technologies that produce a minimum carbon footprint throughout their lifetime to be treated on a level playing field. The consultation related to inclusion of nuclear within the green taxonomy should be brought to the public as soon as possible.

20. **To what extent do you agree that government will always need to put measures in place to protect citizens, consumers, and taxpayers, even where a nuclear project is entirely privately financed? Please explain your answer.**

If it is assumed that this question is exploring protection of the public purse / taxpayer, then this should be viewed in the context of matching power plant lifecycles to other asset lifecycles which may be the source of revenue for the investors and is unlikely to be significant or material.

At present, it is more likely that a longstanding and ongoing industry user will need to replace its power plant every 20-30 years, whereas SN plants are designed to last and attract revenue over a longer period 60-80 years. It is likely that industries will choose to refresh/replace assets in their established locations due to the financial costs of relocating and will hence refresh.

The energy market will be subject to periodic fluctuation, but this is against an anticipated increasing demand and likely to be subject to trending price increase. SN offering cheaper and less volatile retail energy prices for long periods may change the economics of those decisions in the future.

PPAs and CfDs are generally shorter than many asset lifecycles including the power plants to which they attach and will mitigate public risk as they can attract a rainbow of customers for their outputs. This is an improved commercial environment which may be less readily available to other "critical" infrastructure projects.

21. To what extent do you think companies wishing to negotiate with government should be tested against suitability criteria before entering negotiations? Please explain your answer.

It is for Government to determine and negotiate off-take agreements with SN Developers should they wish to enter an agreed contract i.e., Revenue Support Mechanism but it should not be assumed that such a contract is a prerequisite of progression and/or attracting investment.

The existing regulatory oversight of ONR provides assurance of the stability of the Licensee and should not be confused by Government assessment or test unless as a feature of due diligence in support of any contract.

22. What do you think the criteria should be to warrant entering negotiations with government? Please explain your answer.

Not applicable

Supporting Future Technology

23. What further steps should government take to support R&D for Advanced Nuclear Technologies? Please explain your answer.

For the UK to meet its net zero targets by 2050, significant effort is required to decarbonise industry and increase the capacity of the hydrogen economy. To achieve this, nuclear power plants for heat and power cogeneration will need first deployments in the 2040s; an associated RD&I programme must begin today to overcome the technological, market, and social barriers in suitable timeframes.The UK has an ambition for 24GW of nuclear capacity by 2050 and challenging Net Zero targets which require a capable UK supply chain enable delivery which is likely to need support in adavcne of orders.
Further steps are suggested below:

- SN with an ability to deliver low carbon heat and power can deliver increased benefit but this may require development in several areas to be enabled:
- In respect of Policy the previously published consultation on siting policy should be used to address and inform Siting Policy but it should be recognised that SN is ideally suited to co-location with industry. This may require delivery and development of siting studies in parallel with co-location and a recognition that industrial entities may wish to progress in parallel to any program under the care of Great British Nuclear, which is possible under existing regulation.
- There will be a need for support to Regulatory upskilling which should not necessarily be borne by the first to private market developer i.e., if SN is to be enabled quickly some investment in the capability of appropriate bodies e.g., OFGEN, ONR, EA and NRW may be required. The market and developers should indicate the technology choices and site

selections but should not bear the full cost of upskilling and work required by these bodies to develop understanding, clarification of roles and adjust guidance etc.

- Regulation may need amendment to enable barriers to application and investment to be addressed e.g., Identification and resolution of barriers such limits on self-generation (off-grid applications to 300MW and lack of clarity of regulation of heat markets.
- As previously note SN has a potentially broad range of applications however enabling these may require a portfolio of technology development to advance TRLs of key enabling technology including Heat Exchangers, Electrolysers (for hydrogen), Thermal Transport and Control and Instrumentation, Digital Systems and applications of Artificial Intelligence.

The above could be summarised as a portfolio approach to the support and development of a modular operating model for “system” optimization (temps, tech and user applications) of an industrial spoke and hub system. Technologies exist in the above areas however the challenge is in terms on systems engineering, coupling and technology integration and development of industrial/community partnerships which may be willing to co-invest with Government and others to underpin these.

- Several of these technologies and solutions may require a user case demonstration for example which could be enabled through a test facility will help de-risk technologies and increased understanding of optimal heat extraction in nuclear thermal cycle, feedback mechanisms, through-life performance. Regulatory development (capability and application) would benefit from access to a test facility and enabled “sandpit” approach.
- There is a propensity to consider SN as a technology for Heat and Grid Power and there may be a case for a series of enabled to Market studies around financing and business models for the different applications to be explored in more thorough detail this could be publicly funded to increase awareness of opportunity and benefit in the widest range of stakeholders.
- The above (6) should not be limited to raising the awareness of HMG, Industry and Investors but should also consider the importance of public acceptance of SN and how to safeguard the societal engagement whilst reducing lead times for consenting. There may be a case for funded Social Science in support of SN to enable a transparent and value add social / community exchange. This could include support for regional skills and EDI programmes to enable roll-out at pace in the 2040s.These could be incentivised by Policy and or Inclusion in ONR / EA tags and practice guides.

The opportunity for SN to support Hydrogen production will need support and development of a broad range of enabling technologies which could deliver economic opportunity including:

- Demonstration facility to overcome systems engineering challenges (location of heat offtake, thermal hydraulic feedback mechanisms, etc)
- Support for SOEC and electrolyser development
- Support for thermal energy transport R&D
- Support for materials R&D

- Support for heat exchanger development
- Large scale storage and transmission of hydrogen

Support to the above should be agnostic to any future technology noting the temp ranges of SMRs vs AMRs and types of electrolysers/technologies they can support and what enabling tech may be needed. This support could be in the form of co-invested projects with HGM support in advance of SN technology maturation with market selection.
The interventions, R&D and Innovation as above can also accelerate cross-sector manufacturing capability for UK plc including offshore wind, hydrogen and co-generation as well as enabling the potential for international market capture in multiple sectors going forward.

24. To what extent do you agree that there are current or future gaps or constraints in the UK R&D landscape for Advanced Nuclear Technologies, either for that high TRL R&D and demonstration or earlier stage R&D? Please explain your answer.

The UK nuclear R&D landscape is multi-faceted and funded through multiple government and industry stakeholders across all Technology Readiness Levels. Early-stage R&D (TRL 1to 3) is funded through UKRI's Research Councils with the majority of funding coming from EPSRC. The funding for nuclear related R&D for this early-stage R&D is comparatively modest when compared to funding into other industry sectors. Furthermore, there is a requirement for enhanced R&D through postgraduate related programmes like the Centres for Doctoral Training (CDTs) that have provided breakthroughs in nuclear-related research together with a pipeline of highly prized talent into the sector. This should be enhanced or at least maintained at previous levels of funding as an important entry route for academic talent and to maintain confidence in the sector.

At the more mature stages (TRL 7 - 9) R&D tends to be more focussed on technological innovations and funded through the Nuclear Industry and Innovate UK which has experience in curating co-invested projects. It's important that although there is a mature pipeline in place for this funding, it must be continued at similar levels which might be focussed on developing industry to compete in the global market for SN which is developing rapidly.
Gaps do exist however in the areas of fuel development, Advanced Nuclear Technology reactor demonstration and the testing of materials and fuels in irradiated environments where access to thermal and fast neutrons are required and typically accessed through the use of Materials Test Reactors.

There continues to be a gap in R&D related programmes at the middle stages of R&D (TRL 4 - 6). For new and advanced nuclear technologies this has been recognised through the implementation by DESNZ of the Energy Innovation Programme incorporating Nuclear and focusing on a number of the technology gaps around areas such as advanced fuels, ANT demonstration (High Temperature Gas Reactors), materials R&D for harsh environments, and digital technology.

The level of funding for the nuclear element of this programme has been reduced over the last few years. We believe the programme through DESNZ will address these gaps as long as the funding is secured over a multi - year, enduring basis taking into account the levels of funding required to deal with the scale of the challenge. There is also a potential opportunity to secure co-investment in projects if industry can be persuaded of a route to market , inside or outside the UK.

Making best use of other like-minded Government programmes and deriving best practice from other nations are all key to enabling the acceleration of R&D to market. This should include continued engagement with entities such as the Generation IV International Forum, OECD NEA and IAEA where the U.K. continues to play a leadership role both in future policy making for Nuclear and in leading the technical approaches, strategies and R&D that are progressed. Finally enabling these new technologies to be regulated will required continued, early engagement with the regulators involved. Enabling this engagement should be a government priority in addition to ensuring the investments required in R&D continue as highlighted above.

25. To what extent do you agree that there are current or future gaps or constraints in the UK supply chain for Advanced Nuclear Technologies? Please explain your answer.

The extent to which gaps and constraints exits is dependent upon the overall market demand for ANTs which is maturing faster in the USA than the UK. The global demand is likely to be significant and addressable to UK companies if they have capacity and are cost competitive.
The breadth of the scope of supply for an ANT encompasses most aspects of the engineering supply chain. The UK supply chain is not homogenous, and it should be remembered that most of the supply ANT projects will be conventional i.e., not needing nuclear qualification. The future market is dependent upon the offering of the individual developers.
Areas of R&D arising from adding the applications and interfacing with industries that can utilise the high temperature heat etc will require development. This is described in response to Q4, 5 & 6.
ANTs do not have the maturity of the SMRs which are derivatives of the Pressurised Water and Boiling Water Reactors (PWRs and BWRs) and have been in operation globally for over 50 years. SMRs are likely to adopt; modular build approaches and incorporate technological developments in their design, manufacture, build and operation which will challenge the supply chain. Any support to the delivery of SMRs should be considered as developing supply chain competitiveness and foundations for future AMR’s.

All of the ANTs have technical novelty and risk which requires development due several features including: operation at higher temperatures, utilising differing heat transfer mediums, differing pressures etc. ANTs will place unique demands on equipment and the supply chain. A small number of UK companies have capability which can support early entry e.g., TerraPower have selected the US arm of a UK company for pumps and X-Energy have selected acted in a similar manner for their blowers. Both are aiming for operational plant in 2030. If the UK is to play a significant part in the supply of ANTs, then the pace of progress should match that of ANTs elsewhere in the world which may be ahead of the UK.

There are no firm plans for ANTs in the UK at present. The HTGR was deemed preferred and there have been long term discussions with both JAEA (UK Penultimate Power and NNL) and X-Energy.

There are various figures estimated for the global market both in terms of value (eg £3 Trillion) and output (250 Gigawatts). But more important for the UK supply chain is what could be the accessible market for UK based technology reactors or UK suppliers with global competitiveness along with what share of foreign built plant would be available to UK suppliers.

On the assumption of a requirement for a globally competitive 'state of the art' manufacturing supply chain being required to support ANTs in the mid 2030's then there are significant gaps/constraints that will need to be addressed. This seems a better lens, as spreads risk of delay due to HMG processes and looks to access global markets.

The demands of component service will demand high engineering capability and extensive qualification and testing with limited manufacture which may be a valid opportunity for adding further value to NAMRC and other elements of HVMC which may support adding of other applications to the plant and adopting a modular build approach. Noting that much of any future SN will not be "nuclear" development of advanced manufacturing and increased competitiveness will be vital to enable increased market share for UK companies.

With processes the NAMRC has demonstrated that its F4N programme is beneficial in introducing new companies to some nuclear requirements and that may be a continued need and of benefit as more companies less familiar with the industry becoming involved. There are though other considerations that will need to be addressed.

It is unlikely that an ANT will be presented to the supply chain fully engineered and in consequence there will be changes which will need a system to manage them. It should be assumed that an ANT developer will take full advantage of the technologies that are now available. It should therefore be presumed that there will be a requirement for an overarching electronic system with which all suppliers will need to interface with. This system would cover every aspect of the build of the ANT and operation through life, it is likely that to be competitive in 5 to 10 years and ongoing from then the most successful will need to embrace Industry 4.0 more completely.

A programme and support to the increased adoption of Digital tools and AI in the sector should be enabled to explore and identify opportunities for through life cost reduction and how to enable these. This would be complimentary support of AI and Digital tools as described in Q4. In addition to the above and to further support the cost effectiveness of the UK supply chain there may be a case for introducing less technical but potentially more valuable support to business and manufacturing improvement. Many suppliers in the current UK supply chain lack familiarity with true volume production (not simple repeat manufacture), the New Product Introduction (NPI) process and subsequent Continuous Improvement (CI) once into production. The requirements of Equipment Qualification (EQ) will be new to many.

The UK is well positioned and could develop broad cross sector programmes in support of NPI, CI and EQ through the NAMRC or similar.

To determine potential capacity gaps and constraints in the UK supply chain it is first necessary to build a picture of what the supply chain would need to look like in five to ten years and then to compare that to the current supply chain status.
Consideration should be given to enabling the development of a 5-, 10- and 15-Year model of the Supply Chain requirements and logistics. This model, which should be curated by an organisation that is not conflicted, could be used to inform medium term investments in capacity development.

Any model should include the following minimum scope:

- Commodities with nuclear qualification. For example, electrical connectors to operate in the containment need to be qualified to demonstrate that they can operate in all conditions including faults such as a LOCA.
- Volume production of relatively high value items with nuclear applications. For example, the global market for industrial valves is reported to be about $100Bn. Nuclear valves are reported to make up about 1% of the market. Major valve manufacturers therefore utilise modern manufacturing methods. For a nuclear plant the requirements range from the off the shelf to the most sophisticated of the nuclear valves (e.g. main steam) which require to be qualified to requisite standards for operating.
- Specialist nuclear power plant equipment. For example, there are companies that specialise in supplying equipment to nuclear power for example plant pumps, so they have a heavy focus on nuclear.
- Specialist nuclear power plant systems. For example, HVAC and RMI (Reflective Metal Insulation) are both systems that utilise 'variations on a theme'. Suppliers need to demonstrate the systems suitability for a nuclear power plant application. The contract will often include detail design, manufacture and installation.

Based on the above then the following are how the future should be enabled develop:

- UK content is to be maximised for a reactor and project supply chains.
- Reactors are from 20MW upwards [Micro reactors different]
- Fully modular approach with minimal site activity i.e. focus upon manufacturing.
- Notional rate of production of 12 per year i.e., manufacture is productionised.
- Earliest start date 2030 for production (SN & ANT) globally.
- Suppliers to be globally competitive will need to increase capacity and efficiency.
- Suppliers of key equipment to be also potential suppliers to other reactors

- The successful technologies are as present proposed plant i.e., they will be within current manufacturing capability with improving competitiveness.

Other

26. **Please add any comments or reflections which have not been covered in the previous questions.**

    None to add.

27. **The Public Sector Equality Duty (PSED) requires government to have due regard to the need to eliminate unlawful discrimination, harassment, victimisation, and other conduct prohibited by the Equality Act 2010, advance equality of opportunity between people who share a protected characteristic and those who do not and foster good relations between people who share a protected characteristic and those who do not.**
    Do you have any views about the implications of the policy measures explored in this consultation on people with protected characteristics? If you have identified any positive or negative impacts in the consultation, please provide any relevant evidence.
    None to add.

28. **Do you have any views about the implications of the policy measures explored in this consultation on environmental protection? If you have identified any positive or negative environmental impacts in the consultation, please provide any relevant evidence.**

None to add.