The NEA Small Modular Reactor Dashboard

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Nuclear Technology Development and Economics

The NEA Small Modular Reactor Dashboard

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The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;

– to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

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Compilation of information for The NEA SMR Dashboard

When completing the assessments for The NEA SMR Dashboard, the OECD Nuclear Energy Agency (NEA) has exclusively used information from verifiable public sources. These sources are available on the NEA website (www.oecd-nea.org/dashboard-ref).

The majority of the sources are from third party references (e.g. governments, regulators, financiers, operators). None of the sources are from the SMR designers, except for some relating to fuel type, enrichment, reactor specifics and public announcements of financing. The NEA has used its best efforts to search available public sources which have been used to compile the assessment results.

Prior to publication, the SMR designers were consulted by the NEA and provided with a list of the sources used to compile the assessment. They were given the opportunity to comment on the draft assessments and supplement further information which could be independently verified. If this further information was independently verified, it has been used in the final published assessment.

The criteria to obtain the assessment

The assessments are driven by objective criteria applied to information compiled from public sources. They are not the subjective judgement of analysts. The criteria used for the evaluation is in the “Track Progress of SMRs” section of this document. The information used in the assessment was provided to the SMR designers for their awareness prior to publications. In this context, the SMR designers were provided with an opportunity to comment and provide further information that could be independently verified. The assessments in no way reflect the opinion of the OECD or the NEA.

Foreword

Henry Ford is famously credited for saying "If I had asked people what they wanted, they would have said faster horses." But Ford was guided by his own vision for transformative innovation that would change the world. His innovation in factory manufacturing and standardisation drove down costs and enabled the widespread deployment of automobiles that reshaped entire societies.

Later, when Alfred Sloan took the helm of General Motors, he learned from the Ford business model, which focused on standardisation to drive down costs, and took the next innovative step to deliver on his own vision of "a car for every purse and purpose". Sloan understood that the automobile market had many sub-markets with diverse customers looking for variations on the basic product. General Motors overtook Ford in the US car market within a few years.

Today, the most valuable automobile manufacturer in the world is Tesla.

Progress in our societies is often linked to innovation in technology and industry. As the 21st Century approaches middle-age, the world is poised for a new wave of innovations, particularly in the area that is perhaps the one most central to social progress, economic growth, and the health of the environment – the production of energy.

The strongly stated desire of the global community to reduce emissions of carbon, the need to provide a path for nearly a billion energy-impoverished people to improve their lives, and the recently-reinforced imperative to assure energy security and reliability for all countries has accelerated the need for and the pace of innovation. No area of energy technology has seen a more transformational surge of innovation than nuclear energy.

We today bear witness to a wave of innovation in Small Modular Reactors that has the potential to reshape modern society. With a shift from conventional large-scale construction to factory manufacturing to drive down costs and leaps in technology that will allow flexible and diverse applications, a portfolio of SMR products is racing to the market. Among other hard-to-abate sectors, these technologies will enable the replacement of coal for on-grid power generation; replace diesel generators for off-grid mining and industrial operations; replace fossil fuels for cogeneration of heat and power for heavy industries and district heating; and enable large-scale water treatment and desalination to produce clean potable water.

As the applications and needs are varied, so are the SMRs. Innovative designs range in sizes from smaller than 5 megawatts electric to larger than 300 megawatts electric. They vary in outlet temperatures from about 285°C to nearly 900°C, with some advanced designs in research and development seeking to exceed 1 000°C. This wave of SMR innovation includes various reactor concepts – some based on existing light water designs, others based on next generation concepts – and various configurations – some land-based, others mobile, and marine-based.

Some of these technologies are available to the market now, with many others following in the next 5 to 10 years. The NEA SMR Dashboard will help governments understand the pace of progress to commercial deployment of these technologies as they consider the paths available to achieve net zero by 2050.

Acknowledgements

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Executive summary

Nuclear innovation in small modular reactors (SMRs) has the potential to address multiple energy policy priorities around the world. These policy priorities range from decarbonising electricity and deep decarbonisation of hard-to-abate sectors to ensuring security of energy supply in an uncertain world, providing options to alleviate energy poverty and promoting economic development and prosperity.

Nuclear energy already plays an important role in many countries' energy systems, supplying approximately 10% of the world's electricity from 444 nuclear power reactors in operation. These reactors are mainly gigawatt-scale, providing on-grid non-emitting baseload electricity.

Nuclear energy can play an even larger role. Recent NEA analysis (NEA, 2022a) finds that meeting the average of the International Panel on Climate Change (IPCC, 2018) pathways consistent with a 1.5°C scenario will require tripling global installed nuclear capacity to reach 1 160 gigawatts by 2050. This can be achieved through a combination of long-term operation of existing nuclear reactors, large-scale Generation III nuclear new builds and SMRs for both power and non-power applications.

Innovation in SMRs is advancing in several countries. This includes SMRs at various stages of development, from fundamental research on new concepts, to commercial deployment and operation of mature designs. This pipeline of innovation includes a range of reactor concepts – from incremental innovation in existing light water reactor technologies to breakthroughs in advanced Generation IV reactor concepts. This pipeline also includes SMRs in a variety of configurations – some land-based, some multi-module, some marine-based, some transportable. These innovations incorporate new materials, a range of coolants and innovative fuels. The innovation pipeline is poised to produce a range of commercial SMRs of different sizes, with a range of outlet temperatures, and new attributes and potential benefits in the areas of safety, flexibility, and economics, as well as spent fuel and waste management.

The pipeline of SMRs has the potential to support a variety of energy policy priorities, including decarbonisation of electricity as well as decarbonisation of new applications where large-scale nuclear and variable renewables may have limitations. These new markets and applications range from coal replacement for on-grid power, to fossil cogeneration replacement for industries or district heating and diesel replacement for off-grid mining. In many cases, SMRs would be a game-changer to reach net zero in different regions and settings.

The Nuclear Energy Agency (NEA) SMR Dashboard looks beyond technology readiness level (TRL) and assesses progress across six additional enabling conditions: licensing readiness, siting, financing, supply chain, engagement and fuel. In each area, the NEA defines objective criteria that reflect substantial progress towards first-of-a-kind (FOAK) deployment and commercialisation.

The NEA SMR Dashboard has exclusively used information from verifiable public sources. This preliminary edition benefited from consultations with SMR designers that were provided with an opportunity to comment on their draft assessments and supplement further information which could be independently verified.

The compilation of The NEA SMR Dashboard reveals substantial progress towards SMR deployment and commercialisation in NEA and non-NEA member countries, with much of this progress taking place during the past two years. Future editions will continue to track momentum and may include additional SMRs.

Energy policy priorities: The role of SMRs

Nuclear energy is a strategic asset that creates opportunities for economic and environmental benefits. Small modular reactors (SMRs) can help countries address a range of energy policy priorities, from decarbonising electricity and deep decarbonisation of hard-to-abate sectors, to ensuring security of energy supply, alleviating energy poverty and promoting economic development and prosperity.

Existing nuclear power plants displace 1.6 gigatonnes of carbon dioxide emissions annually

As highlighted in *Meeting Climate Change Targets: The Role of Nuclear Energy* (NEA, 2022a), the world is not on track to meet the decarbonisation objectives of the Paris Agreement. Global emissions are expected to rise by 16% by 2030 and the window for climate action is rapidly narrowing.

In late 2022, nuclear energy supplied approximately 10% of the world's electricity from 444 nuclear power reactors in operation providing 394 gigawatts of capacity. Nuclear energy is the largest source of non-emitting electricity generation in OECD countries and the second largest source world-wide after hydro-power. Existing nuclear capacity displaces 1.6 gigatonnes of carbon dioxide emissions annually and since 1971 has displaced 66 gigatonnes of carbon dioxide – the equivalent of two years of global emissions (NEA, 2021a).

The nuclear energy sector can support climate change mitigation efforts in a variety of ways:

- **Long-term operation**: First, existing global installed nuclear energy capacity is already playing a role and its long-term operation can enable the existing fleet to continue making a contribution for decades to come.
- **Large-scale new build**: Second, there is significant potential for large-scale Generation III nuclear new builds to provide non-emitting electricity in existing and embarking nuclear power jurisdictions.
- **Small modular reactors**: Third, SMRs are leading a wave of near-term and medium-term nuclear innovation that has the potential to open up new opportunities, including power and non-power applications as part of nuclear hybrid energy systems.

Box 1. What is a small modular reactor?

Small

SMRs are smaller, both in terms of power output and physical size, than conventional gigawatt-scale nuclear reactors. SMRs are nuclear reactors with power output less than 300 megawatts electric (MWe), with some as small as 1-10 MWe.

Modular

SMRs are designed for modular manufacturing, factory production, portability, and scalable deployment.

Reactors

SMRs use nuclear fission reactions to create heat that can be used directly, or to generate electricity.

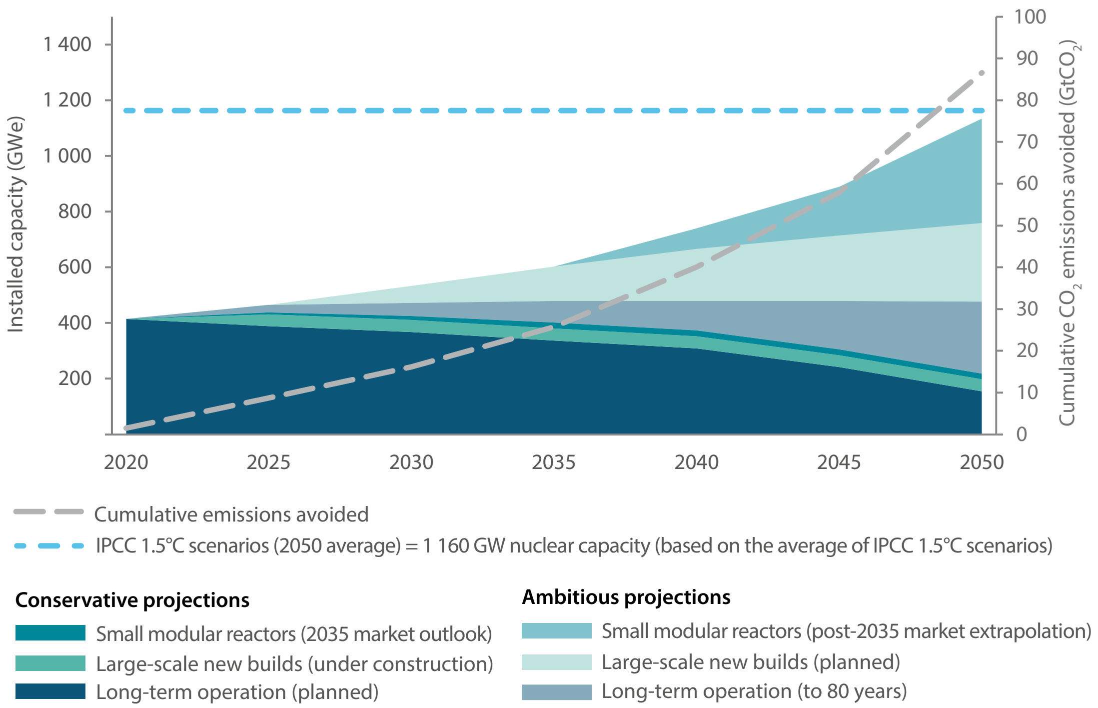
Pathways to net zero call for installed nuclear capacity to triple by 2050

In 2018, the IPCC considered 90 pathways with emission reductions sufficient to limit average global warming to less than 1.5°C. The IPCC found that, on average, the pathways for the 1.5C scenario would require installed nuclear capacity to reach 1 160 gigawatts by 2050, up from 394 gigawatts in 2020 (IPCC, 2018).

This growing role for nuclear power will complement variable renewables, which are set to rapidly grow in all climate mitigation pathways. For example, the International Energy Agency's Net Zero scenario (IEA, 2021) foresees that by 2050 renewables will account for 88% of the world electricity sector, and 67% of the world energy supply. The world will need all low-carbon sources of power, in particular variable renewables, hydropower and nuclear power, which are characteristically different and will play different roles in the energy systems of the future. In particular, nuclear energy will enable variable renewables by supporting system reliability and security of energy supply.

While the IPCC nuclear target is ambitious for nuclear energy, it is not beyond reach. As illustrated in Figure 1, recent NEA analysis (NEA, 2022a) finds that this target can be achieved through a combination of the long-term operation of existing plants and building large-scale Generation-III new builds and SMRs. It will also include leveraging both power and non-power applications of nuclear energy, including nuclear heat for industry and district heating, nuclear-based hydrogen and synthetic fuels.

Figure 1. **Full potential of nuclear contributions to net zero**



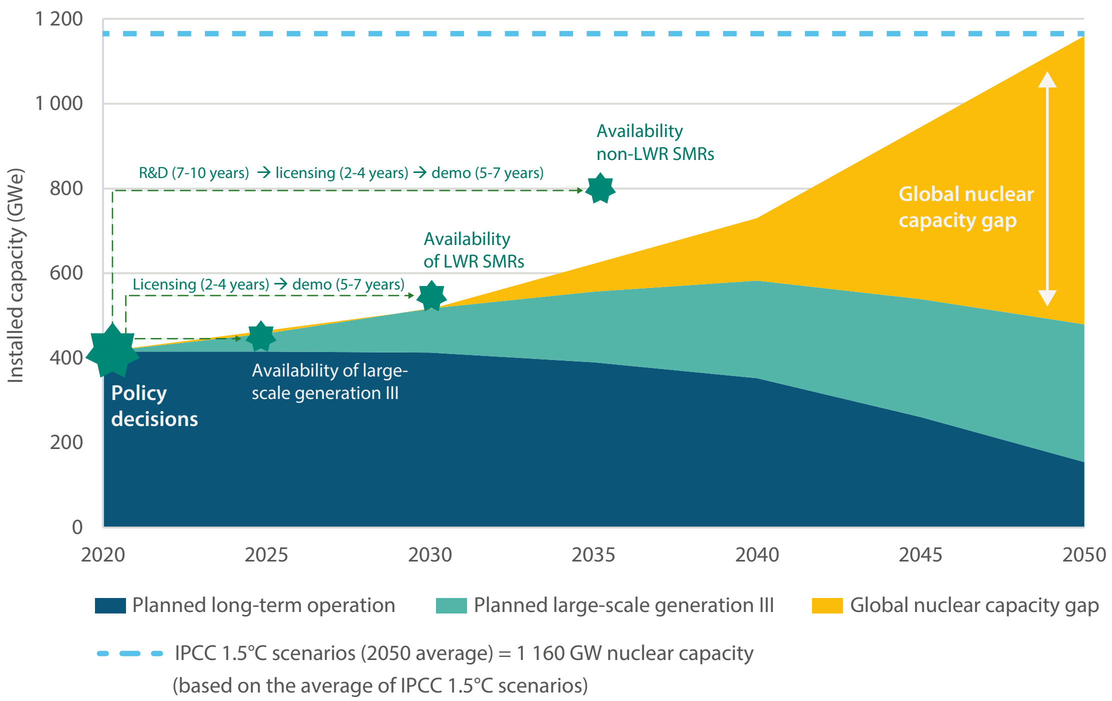
Source: NEA (2022a).

The world faces a gap in global installed nuclear capacity of 681 gigawatts by 2050

While nuclear energy has the potential to play a much larger role in climate change mitigation efforts, it faces a number of challenges. According to current policy trends for large-scale new builds and long-term operation, nuclear capacity in 2050 will amount to 479 gigawatts – well below the target of 1 160 gigawatts of electricity set out above.

As Figure 2 below underlines, in light of the deployment timelines of existing and future nuclear technologies, addressing this global nuclear capacity gap will require near-term policy decisions to enable their deployment over the next three decades.

Figure 2. **Global installed nuclear capacity gap (2020-2050)**



Source: NEA (2022a).

SMRs will have an essential and increasingly important role to play in addressing the nuclear capacity gap and supporting decarbonisation targets. The NEA estimates that by 2050 SMRs could reach 375 gigawatts of installed capacity in an ambitious case, contributing to more than 50% of this capacity gap (NEA, 2022a). In particular, one of the key features of SMRs is that they target applications of nuclear energy to support the decarbonisation of otherwise hard-to-abate sectors that do not require (or cannot support) gigawatt-scale nuclear power generation and/or where variable renewables face limitations.

There is a pipeline of innovative SMRs that can help the world stay at net zero past 2050

The SMR technology pipeline translates into a range of technology readiness levels (TRLs) and regulatory readiness levels (RRLs). Some SMR technologies are already demonstrated (at lab and commercial scales), while others are still in research and development. Timelines for deployment vary based on technology and regulatory readiness levels, with some designs expected to be demonstrated and commercialised before 2030 and others to follow later in the 2030s.

However, this difference of deployment timeline does not mean that less mature SMRs will not have a role to play in meeting decarbonisation objectives. In fact, at least two windows of opportunity can be identified for SMRs (see Figure 3):

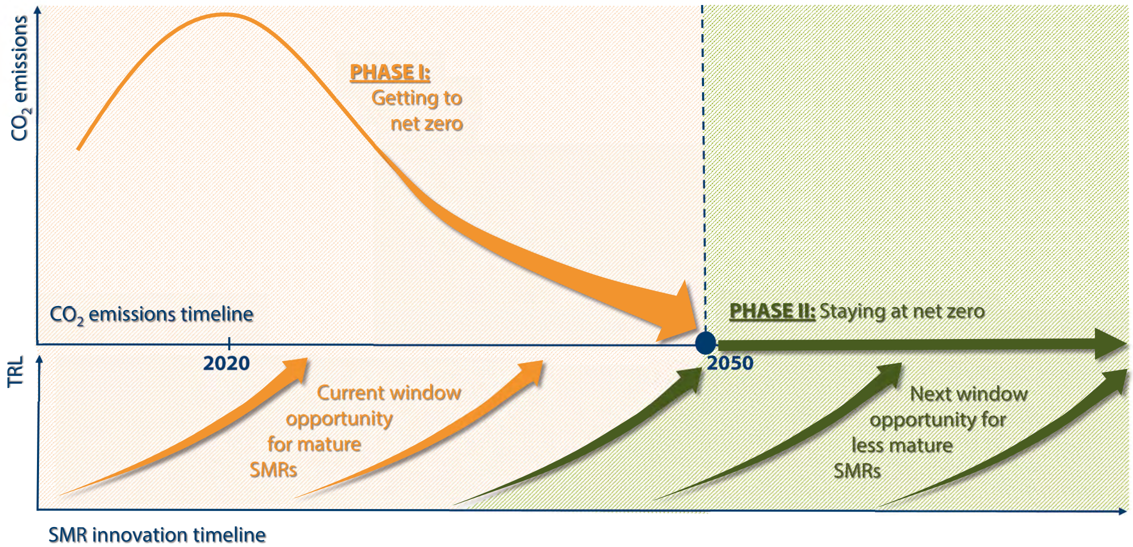
- **Phase 1**: SMRs and advanced reactors with high levels of technology and licensing readiness will play a central role in getting to net zero by 2050 by supporting decarbonisation efforts that are expected to gain pace in the 2030s and 2040s.

- **Phase 2**: SMRs and advanced reactors currently with lower levels of technology and licensing readiness could be deployed at scale from the 2040s to supply electricity, heat and hydrogen as well as to contribute to the long-term sustainability of nuclear energy after 2050 when associated with advanced nuclear fuel cycles.

In light of development and deployment timelines, policy support today is necessary for SMRs with high and low levels of technology and licensing readiness to meet their net zero windows of opportunity.

Figure 3. **Windows of opportunity for SMRs to support net zero objectives**

Near-term SMRs will contribute to net zero by 2050, with more innovative designs contributing to staying at net zero post-2050



Potential benefits and attributes of SMRs

Compared to traditional large-scale nuclear reactors, SMRs bring a number of attributes that underpin their future commercial viability.

Safety

SMR designs build on lessons learnt from over 60 years of experience in the nuclear energy sector to enhance safety and improve flexibility. Many SMR designs incorporate the concept of passive safety, meaning they do not require active interventions or backup power to safely shut down.

Lower power output and smaller cores of SMRs will increase the efficiency of passive safety systems. For example, many SMRs based on light water reactors (LWR) have very large water inventories for passively cooling the reactor systems, even under extreme circumstances (e.g. loss of offsite power). A higher reliance on passive cooling systems facilitates design simplification as well as operation and maintenance operations, which further supports their economics (NEA, 2021b).

The benefits of smaller inventories combined with high passive safety may lead to reduced offsite emergency planning zones (EPZ). This will facilitate plant siting and potentially reduce grid requirements for on-grid SMRS, which also supports their economics (NEA, 2021b).

Flexibility

The Clean Energy Ministerial NICE Future flexibility campaign (NREL, 2020) defines nuclear flexibility as: “The ability of nuclear energy generation to economically provide energy services at the time and location they are needed by end-users. These energy services can include both electric and nonelectric applications utilizing both traditional and advanced nuclear power plants and integrated systems.”

SMRs are designed to integrate into energy systems, offering much needed flexibility to enable high shares of variable renewable energy.

Pathways to net zero with high shares of variable renewables are characterised by rapidly increasing flexibility needs and by reduced options with the phasing out of fossil fuel plants. SMRs can be an important part of the flexibility solutions that will support variable renewables’ integration to maintain security of electricity supply.

By leveraging the maneuverability capabilities of existing Gen II reactors, SMRs could achieve enhanced load following modes thanks to inherent design features and the optimisation of multi-module unit operation.

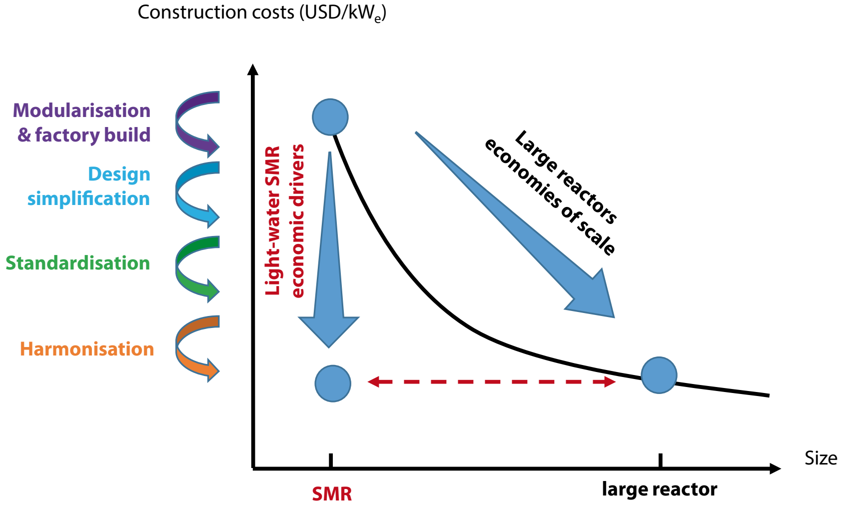
More generally, the flexibility of SMRs also covers deployment capabilities (e.g. lower siting constraints) and diversity of products (e.g. combined heat and electricity production).

Costs and competitiveness

Economies of scale have historically led the nuclear sector to increase the size of reactors. SMRs aim to follow a different approach based on economies of multiple (or serial construction). Several technical features such as design simplification, standardisation and modularisation, as well as factory manufacturing, will underpin this new economic paradigm. The benefits of serial construction have been well-documented in other industries, including the shipbuilding and aircraft industries, and SMR developers are taking stock of the lessons learnt from these sectors (NEA, 2021b).

The competitiveness of SMRs is best expressed in relative terms compared to alternative technological options for the specific applications targeted by SMRs. For instance, the Canadian SMR Roadmap (Canadian Small Modular Reactor Roadmap Steering Committee, 2018) concluded that SMRs could be a particularly attractive solution for remote regions where the alternative would be diesel generators that cost several hundreds of USD/MWh. Similarly, for on-grid coal replacement, SMRs are expected to become increasingly competitive compared to gas power plants as carbon constraints increase to meet net zero climate goals.

Figure 4. **SMR key economic drivers to compensate for diseconomies of scale**



Source: NEA (2021b).

SMR competiveness should also benefit from several features that can improve financial conditions. For instance, one SMR project will be smaller, scalable and more affordable compared to large reactor projects. These attributes should appeal to a broader class of private investors and financiers.

Spent nuclear fuel and waste management

The nuclear sector is implementing proven solutions to manage spent nuclear fuel and nuclear waste. Regarding radioactive waste management, there is today a strong international scientific consensus that deep geological repositories (DGRs) are a safe and effective approach to permanently dispose of high-level waste (HLW). The progress made so far on DGRs in several countries, with Finland, Sweden and France leading the way, has proven that DGRs are viable industrial-scale solutions for final disposal of HLW.

Some advanced SMR designs are being developed to support innovative strategies for the back-end of the fuel cycle, where spent fuel could potentially be reused. These reactors have the potential to reduce the quantity of HLW that have to be managed by DGRs and the uranium resource requirements for the front end of the nuclear fuel cycle.

Innovation in SMR technologies will require innovation in nuclear waste management and disposal solutions, building on the existing knowledge base.

Different SMRs for different applications

There is growing momentum for SMRs around the world

Countries are supporting SMR development through different approaches by facilitating the creation of a domestic programme and/or construction of demonstration and/or first-of-a-kind (FOAK) units. For these projects, progress extends beyond technological readiness to include other important factors for the commercialisation of SMRs.

Figure 5. **Locations of SMR designer headquarters of a selection of SMRs**

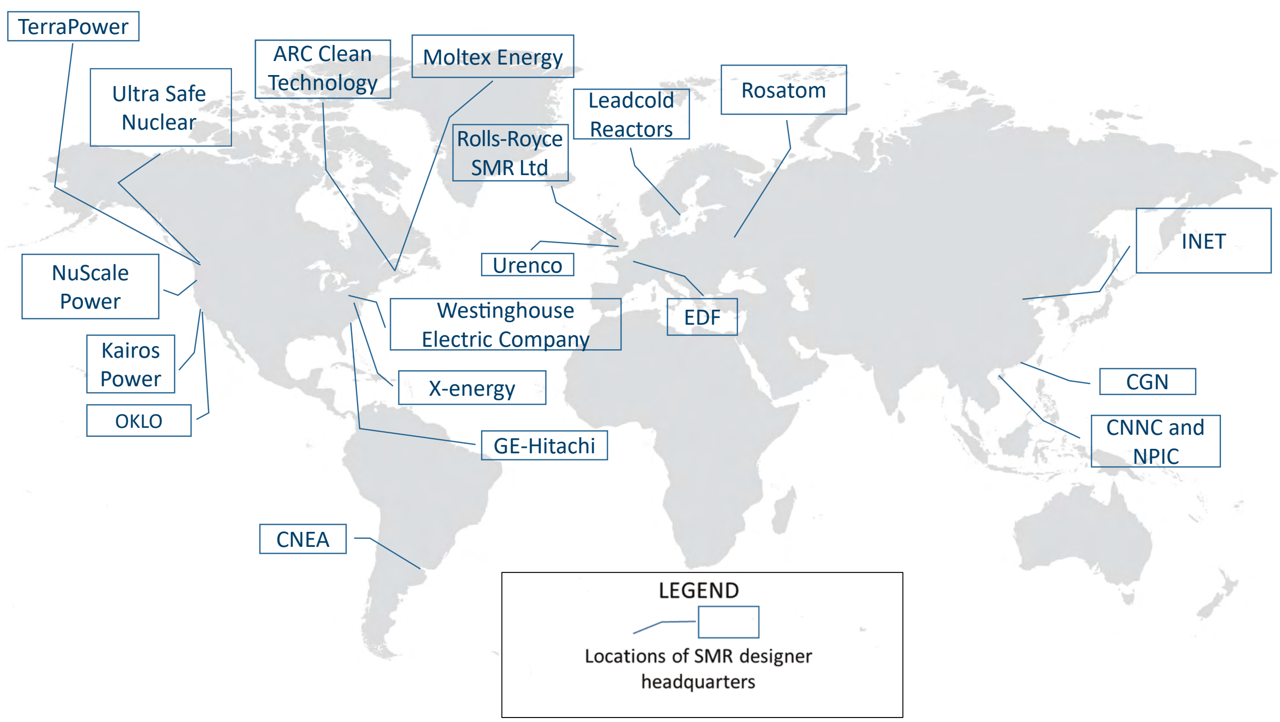
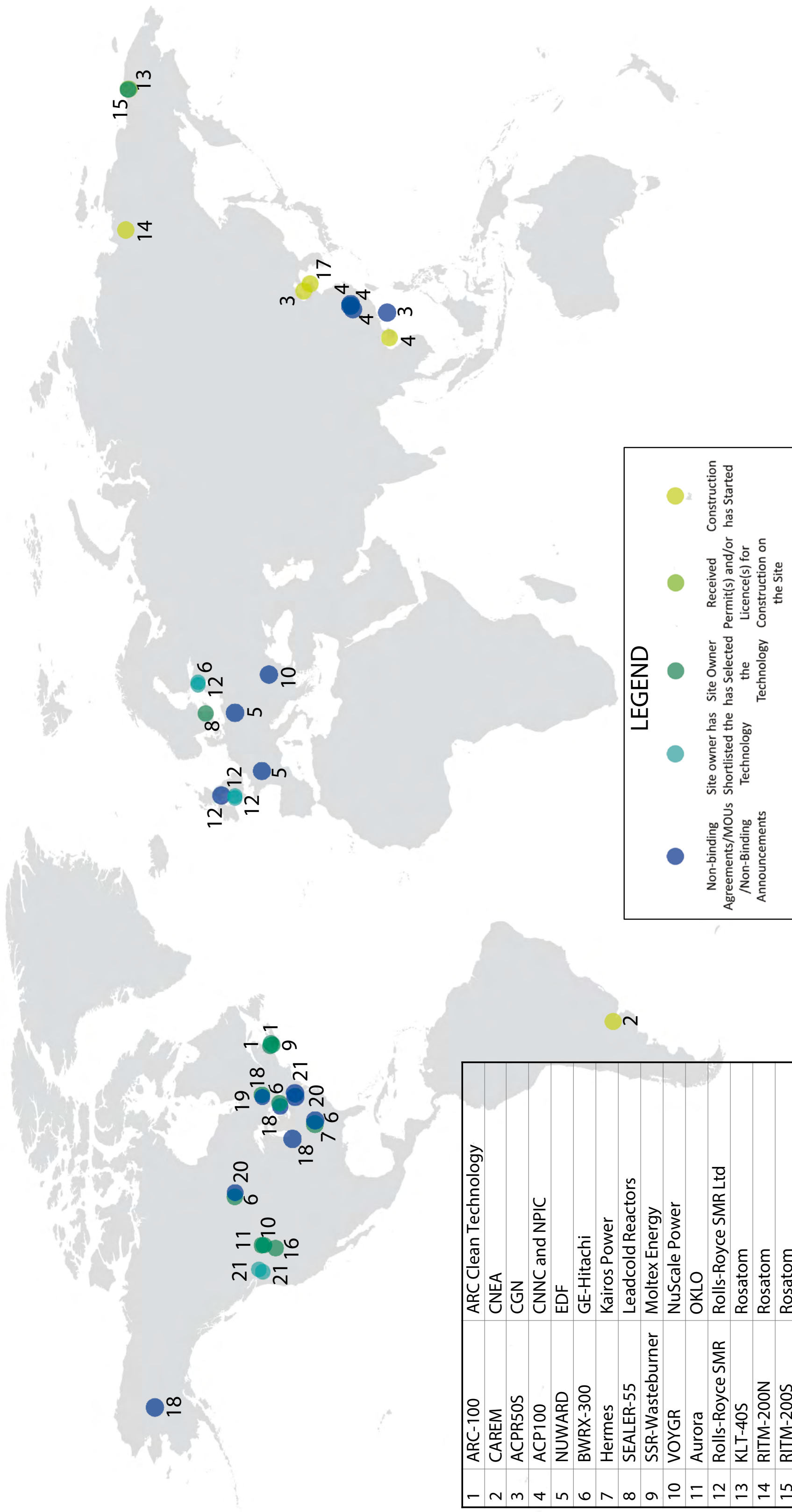


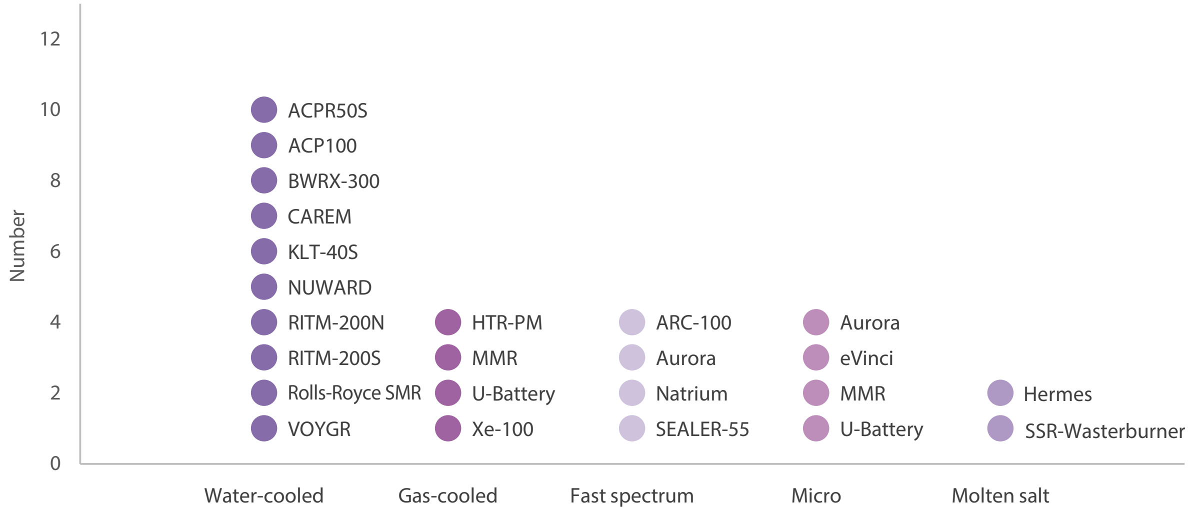
Figure 6. **Locations of sites of a selection of SMRs**



1	ARC-100	ARC Clean Technology
2	CAREM	CNEA
3	ACPR50S	CGN
4	ACP100	CNNC and NPIC
5	NUWARD	EDF
6	BWRX-300	GE-Hitachi
7	Hermes	Kairos Power
8	SEALER-55	Leadcold Reactors
9	SSR-Wasteburner	Moltex Energy
10	VOYGR	NuScale Power
11	Aurora	OKLO
12	Rolls-Royce SMR	Rolls-Royce SMR Ltd
13	KLT-40S	Rosatom
14	RITM-200N	Rosatom
15	RITM-200S	Rosatom
16	Natrium	TerraPower
17	HTR-PM	INET
18	MMR	Ultra Safe Nuclear
19	U-Battery	Urenco
20	eVinci	Westinghouse Electric Company
21	Xe-100	X-energy

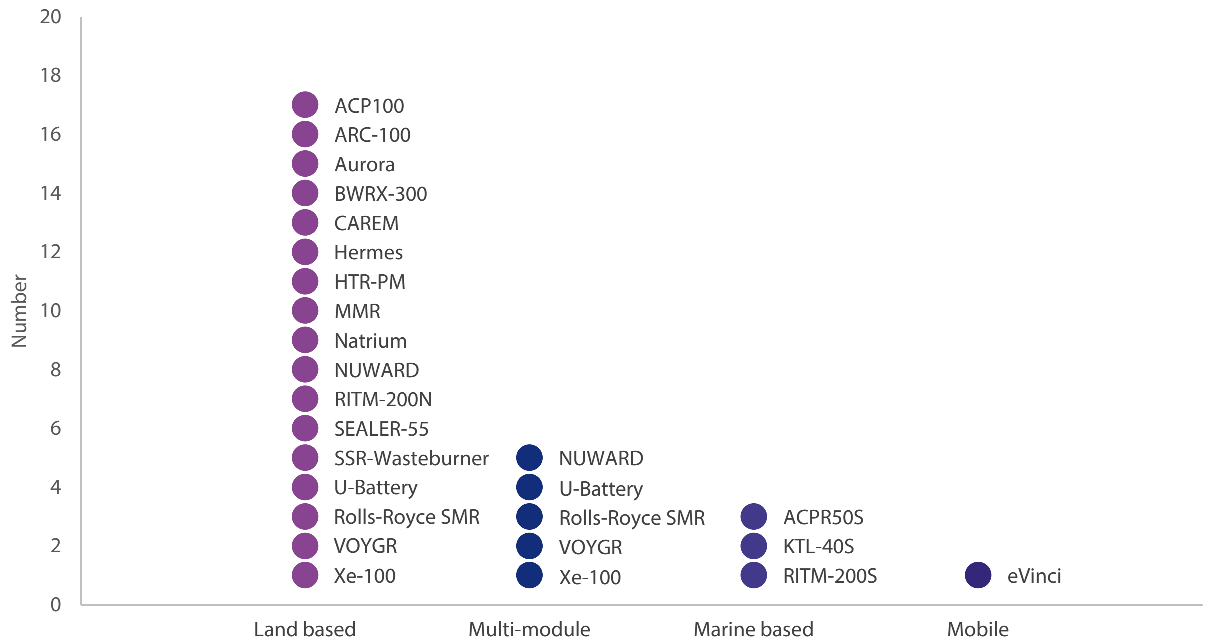
There is a lot of development under way around the world (Figures 5 and 6) in advanced nuclear technology, with various reactor concepts (Figure 7) and configurations (Figure 8). The range of reactor concepts now extends beyond traditional water- or gas-cooled designs to include fast spectrum, molten salt and even micro-reactors.

Figure 7. **Reactor concepts**



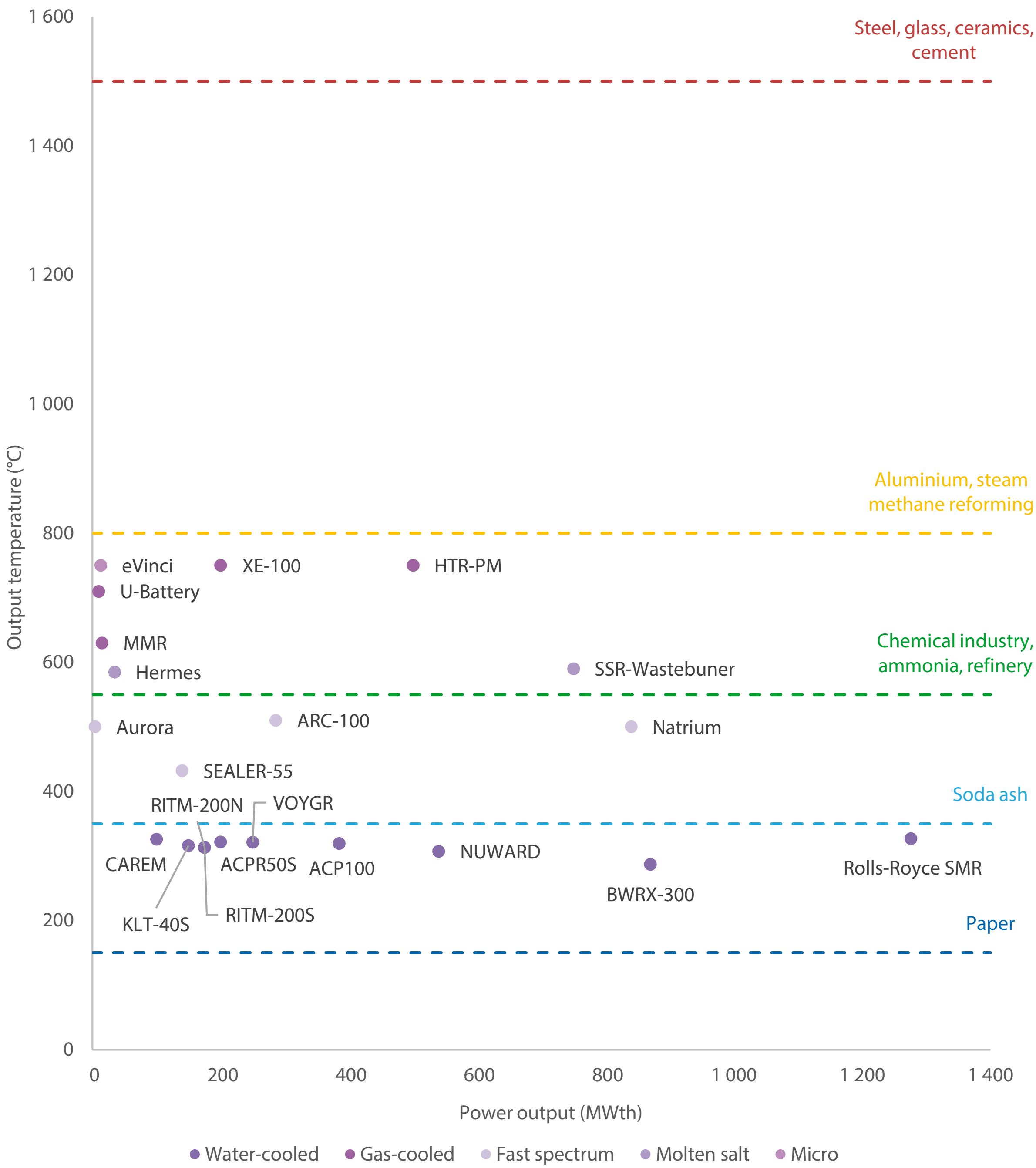
The configurations are no longer limited to being land-based, with some marine-based reactors now operating. Additional novel deployment pathways are also planned, including reactor systems consisting of multiple modules and mobile reactors designed for portability.

Figure 8. **Reactor configurations**



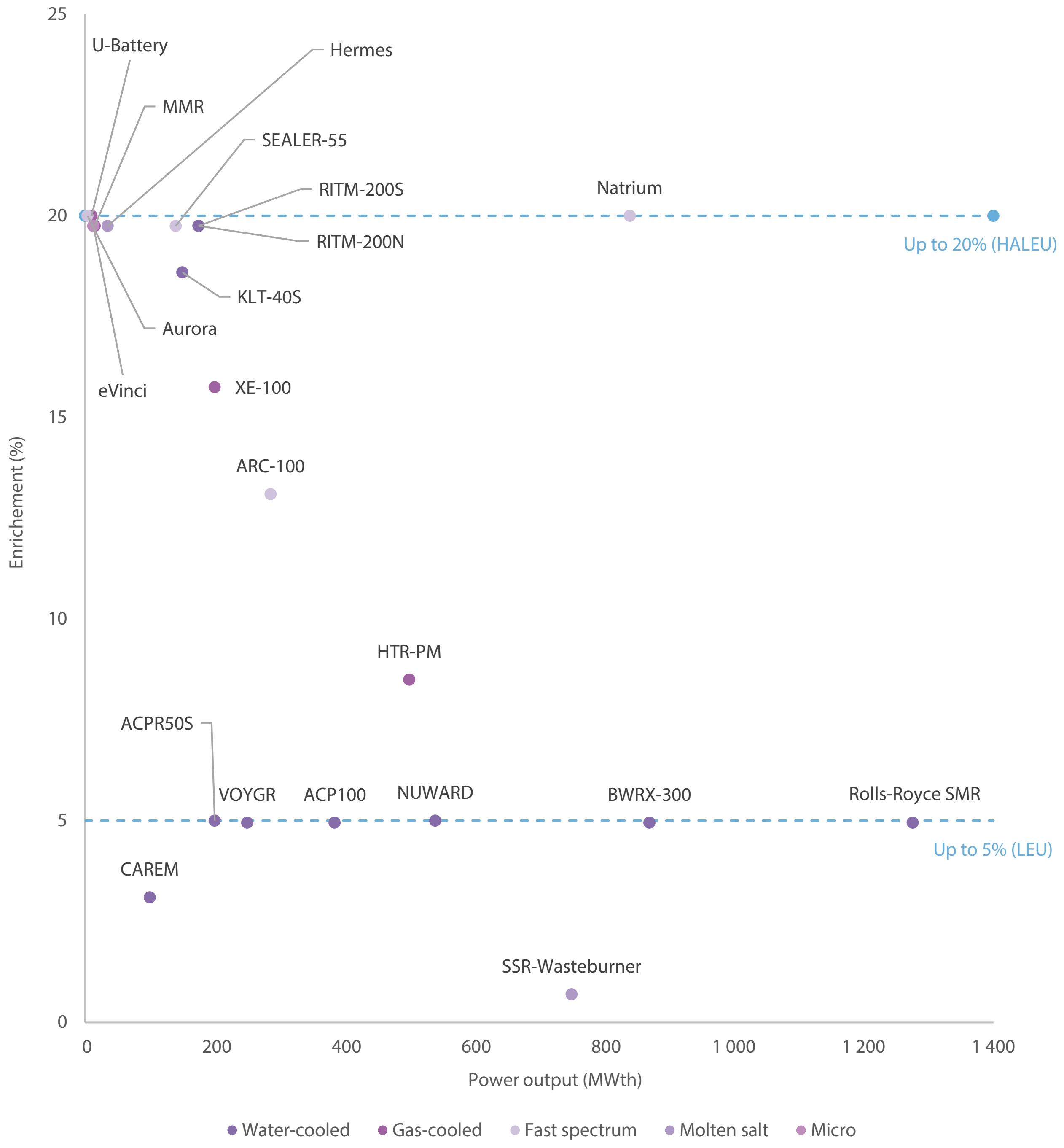
As a class of reactors, SMRs are defined by their smaller size, but there exists considerable variety within this class of reactors; they vary by power output, temperature output, technology and fuel cycle. A number of SMRs are based on existing commercially deployed light water technologies, while others are based on advanced design concepts. They offer a range of sizes, from as small as 1 MWe to over 300 MWe, and a range of temperatures, from 285°C to more than 850°C to meet the specific energy needs of hard-to-abate industrial sectors (see Figure 9 below).

Figure 9. **SMRs: Range of sizes and temperatures for heat applications**



SMR designs with various fuel cycles will meet different market needs with reactors of different sizes and temperatures (Figure 10). For example, energy demand from the industrial and the transportation sectors offers the potential for a subset of SMR technologies to support emission reductions through the direct use of nuclear-generated heat, or process intermediates such as hydrogen that may be produced using nuclear heat along with electricity.

Figure 10. **SMR concepts by type, thermal power and enrichment**



SMRs can help bridge the gap in global installed nuclear capacity by 2050 by reaching into hard-to-abate sectors

SMRs are being developed to target hard-to-abate sectors and applications where variable renewables and large-scale nuclear energy have limitations:

- **Coal replacement for on-grid power**: There are over 3 000 coal power plants in the world (amounting to 2 terawatts of installed capacity) that are expected to be phased out in the coming decade to meet net zero goals. In Europe alone – excluding countries that oppose nuclear or are phasing it out – coal power plants provide 34 gigawatts of installed electric capacity from units that range from 50 to 700 megawatts electric in size (IEA, 2022). Larger SMRs, in the range of 200-300 megawatts electric, could be well suited in terms of capacity to unlock large-scale coal replacement. SMRs could further take advantage of the existing balance of plant and local infrastructures to drive down plant replacement costs whilst maintaining local economic activity.
- **Fossil fuel cogeneration replacement for industries**: Many SMR designs will operate at higher temperatures and could create the first real non-emitting alternative to fossil fuel cogeneration by offering combined heat and power solutions for industrial customers. The oil sands, chemicals and ammonia sectors are among the industries that could be first movers for SMR commercial deployment.
- **Diesel replacement for off-grid mining**: Several smaller SMRs, including micro-SMRs as small as 1 to 10 megawatts electric, are under development for off-grid applications, including as an alternative to diesel generators at mining and resource extraction sites.
- **Fossil fuel replacement for district heating**: Several countries and regions rely heavily on district heating from fossil fuel cogeneration plants. According to an EPRI (2022) review of nuclear district energy, heating makes up 50% of energy consumption and contributes to 40% of the energy-related carbon emissions globally. Most of this heat is building heat provided by on-site boilers and furnaces. While this is typically powered by fossil fuels, there is an opportunity to use nuclear power for district heating. Large-scale nuclear power plants have been interfacing with district heating networks and the EPRI review cites examples from 27 facilities in 11 countries. While these examples are all large nuclear power plants, there is an opportunity for SMRs to provide district heating value and, due to their smaller footprint needed for a site, they may have an advantage over larger facilities.
- **Energy and water**: In 2016, the water sector accounted for approximately 4% of global electricity demand. In 2018, the IEA projected that demand for electricity from the water sector would continue to increase around the world with the need of additional water and wastewater transportation and treatment (IEA, 2018). Demand for water is driven by the need for clean, sometimes desalinated, potable water as well as industrial needs from a range of sectors, such as power generation, resource extraction, industrial processes and agriculture (Sedlak et al., 2021). The role that SMRs could play in meeting demand for water across these applications is being studied by stakeholders, including the EPRI (2023).
- **Hydrogen and synthetic fuels**: Large and small nuclear reactors are particularly well suited to meet the growing demand for low-carbon hydrogen as well as synthetic fuels. For instance, high-temperature reactors can be coupled with either high-temperature electrolysis or with thermochemical cycles to deliver large-scale production of hydrogen. The possibility to locate SMRs near industry demand hubs is another attractive feature that underpins the competitiveness of nuclear-produced hydrogen as the otherwise significant transport and distribution costs are drastically reduced (NEA, 2022b).
- **Merchant shipping**: Some SMRs are under development with the aim of providing a non-emitting alternative for marine merchant shipping propulsion. This a civilian version of the nuclear submarines and nuclear icebreakers that have been operating for several decades. Successful deployment of SMRs for marine merchant shipping could yield significant emissions reductions as shipping remains a very hard-to-abate industrial sector.

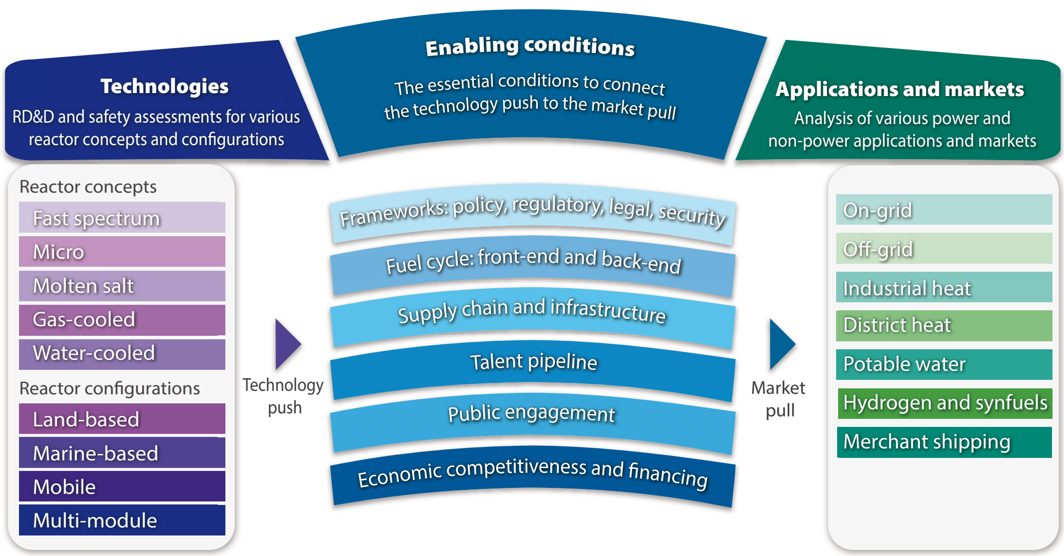
Conditions for success

Beyond technical feasibility, there are several other necessary conditions for the success of SMRs. In 2022, the NEA launched its SMR Strategy to provide an Agency-wide framework to co-ordinate NEA activities related to SMRs and report its progress to its members in a structured manner. These activities address the conditions essential to member countries seeking to accelerate the deployment of SMRs as they move towards net zero emissions.

The NEA SMR Strategy is a comprehensive map of the SMR landscape, from conception through development to deployment and implementation in real world applications and markets. It connects the technology push of the landscape with the market pull for innovative nuclear concepts, addressing the full set of conditions for success.

The NEA SMR Strategy is structured around three themes: technologies; enabling conditions; and applications and markets.

Figure 11. **NEA SMR Strategy**



Action by governments and industry are required to address the global nuclear capacity gap and ensure that the pipeline of innovative SMRs can help meet net zero climate goals. Doing so implies looking beyond technical feasibility to connect the technology with the market demand for new nuclear energy concepts.

On the technologies side, several innovative nuclear concepts are under development and nearing commercialisation and deployment. Some are based on traditional light water reactor concepts while others are Generation IV concepts, many of which use new coolants and moderators. Various reactor configurations are also envisaged, with both land-based and marine-based approaches proposed, as well as mobile and multi-module configurations.

Strategic partnerships will be key to successful technology development, as the centre of gravity for nuclear technology development has shifted towards the private sector. Collaborations with national laboratories and research institutions will continue to be essential for successful research, development, and demonstration, as well as safety assessments and access to critical research infrastructure. Through core NEA activities and NEA-serviced bodies, including the Generation IV International Forum (GIF), the NEA SMR Strategy integrates the perspectives from all the key players of the SMR ecosystem to support multilateral collaborations that will foster the licensing and deployment of SMR technologies.

On the demand side, markets are signalling the need for innovative technologies to address energy and climate challenges, including in hard-to-abate industrial sectors. A key market around the world for SMRs and Generation IV reactors is on-grid to replace coal power generation. Beyond on-grid power generation, however, several other markets are signalling interest in SMRs and Generation IV reactors: off-grid heat and power to replace diesel generators in remote regions including for mining operations; high temperature heat to replace fossil fuel cogeneration in heavy industries such as chemicals processing and potash production for the fertiliser industry; and marine propulsion to replace bunker fuel for merchant shipping.

These markets represent emerging – and often disruptive – applications of nuclear energy technologies. Near-term policy and investment decisions will play a key role in shaping overall market outcomes. Public policy and private sector decision-makers alike are looking for authoritative assessments of SMR power requirements, temperature ranges, as well as other operational and technical requirements for specific applications to be able to understand and map market demand. The NEA already contributes authoritative assessments in these areas and is well positioned to play a central role in this field through the NEA SMR Strategy. The NEA contributions include: understanding technological and market challenges associated with sector coupling; legal, logistical and regulatory challenges related to the mobility and transportability of nuclear modules and reactors; end-user decision-making criteria and timelines, as well as an understanding of the competitive landscape in each specific market and the innovative business models for nuclear reactor ownership, delivery and operation that SMRs may bring.

There are several enabling conditions for success to connect supply and demand. Technologies must be a good fit to connect with the specific market applications. Governments and international organisations have a role to play in creating the enabling frameworks – including policies, regulatory readiness and legal aspects. Safe and secure SMR fuel supply chains are essential, as is a responsible plan for the management of the back-end of the fuel cycle. Similarly, supply chains more broadly and infrastructure, as well as human resources (a pipeline of talent, public engagement and trust) are all essential enablers of SMR and Generation IV reactor innovation. Equally importantly, production costs must be competitive and a mix of public and private financing is required to enable demonstration and deployment of nuclear innovation.

Tracking progress on SMRs

The NEA SMR Dashboard considers factors beyond technology readiness levels (TRLs) to provide a comprehensive assessment of progress towards commercialisation and deployment of SMR and Generation IV technologies. It augments data from other sources that focus on technical attributes and TRLs. Taken together, assessments about technical readiness coupled with The NEA SMR Dashboard's assessments of licensing, siting, financing, supply chain, engagement and fuel reveal which SMR technologies and projects are moving fastest from concept to commercialisation in various markets around the world.

The NEA SMR Dashboard captures progress of SMRs in six key areas:

i. Licensing;
ii. Siting;
iii. Financing;
iv. Supply chain;
v. Engagement;
vi. Fuel.

In each area, the NEA defines objective criteria that reflect substantial progress towards FOAK deployment and commercialisation. The progress criteria are applied using verifiable public sources.

It is difficult to compare SMR technologies advancing in different contexts and jurisdictions, characterised by unique regulatory structures and approaches, siting requirements, financial models and policy environments, among other differences. Objective criteria have been defined to reflect substantial progress irrespective of differences across contexts and jurisdictions. The public information used to populate The NEA SMR Dashboard captures a "snapshot" in time based on the latest public information at the time of drafting.

The six areas and progress criteria are described below.

Licensing

The licensing process is critical for any SMR to reach market, but there are currently no SMRs licensed to operate outside of the People's Republic of China (China) or Russia. Various nuclear safety regulators have been advancing efforts to get ready to regulate innovative SMRs. Many are working to develop new approaches and pathways for licensing – for example, in some cases by collaborating to review a SMR design internationally from the earliest stages.

The progress criteria for licensing closely follows international licensing norms, including pre-licensing interactions with regulators, design approval, construction and the issuance of operating licenses. A bonus is given to SMRs with licensing activities in multiple jurisdictions at any level.

Siting

Siting requirements vary greatly between different SMR configurations: a multi-modular land-based reactor will have a very different process of finalising a site than a floating reactor design.

The grading scale reflects one unifying factor against which all SMR designers could be assessed: whether the site owner has publicly selected the SMR for their site. The next factor is whether the site has been licensed and is ready for that specific SMR to be constructed. A bonus is given to SMR technologies making progress at multiple sites at any level.

Financing

Securing financing is critical for any SMR technology to reach market. However, transparency is understandably difficult to achieve as information may be considered commercially sensitive. Different SMR projects are also likely to require different levels of financing. Different business models are possible and different SMR designers will pursue different strategies. There are numerous paths to success with a combination of public and private financing, including a range of approaches to private financing e.g. through debt, equity or bonds, or by becoming publicly traded.

The NEA SMR Dashboard does not aim to audit any designer or validate the scale of financing required to bring a technology to market. Instead, public announcements on financing an SMR are utilised to indicate progress in this category. The progress criteria are based on the number or size of announcements in the public domain.

The financing category therefore has two pathways for accession through the progress criteria: there are a significant number of financing announcements in the public realm for a particular SMR, or there are public announcements indicating the designer has raised significant funding. The pathways converge when it can be easily verified from public announcements that an SMR first-of-a-kind is considered fully financed, irrespective of the size of investments.

Supply chain

In most cases, a designer is not alone in developing an SMR – there are exceptional cases where the designer can provide the full set of needed engineering, procurement, and contracting. Contracts and partnerships must be in place to develop a supply chain for designing, constructing and operating the reactor. This category maps the maturity of the supply chain for each reactor through public announcements by suppliers and partners. Announcements from suppliers, engineering, procurement and construction organisations are all considered, as are announcements from universities, labs and research institutions when they are supplying research and development services to an SMR project.

The progress criteria are based on the increasing level of commitment of memoranda of understandings, binding contracts, and formal partnerships, joint ventures or consortia. A supply chain is considered to be mature when construction of the first-of-a-kind SMR is ongoing, and a well-developed supply chain is indicated by the construction of an 'nth-of-a-kind' (NOAK) SMR.

Engagement

Engagement with communities is vital to the success of an SMR. In some regions, a project cannot advance without building strong engagement with Indigenous communities from the onset.

The progress criteria will reflect the number of engagements with communities associated with the SMR project. Memoranda of understandings, endorsements, town hall meetings and benefit-sharing agreements will be considered from the following stakeholder groups:

- National governments;
- Subnational governments;
- Indigenous governments;
- Labour unions;
- Non-governmental organisations;
- Civil society organisations;
- Community organisations;
- Universities;
- End users and customers;
- Advisory boards.

Fuel

The majority of light water reactor SMR designers plan to use low-enriched uranium fuel in the same form that is currently commercially available. Many other SMRs plan to utilise fuels that span a range of compositions and levels of enrichment, with enormous variation within those categories. Most such fuels have never been licensed to operate in a reactor or are not commercially available. There are multiple steps to achieving fuel qualification, and they differ between regulators. There are nevertheless clear indicators of the progress of an SMR towards a safe and secure supply of licensed and qualified fuel for operation.

The SMR progress criteria is based on their progress towards commercial supply of qualified fuel. Once a licensed and operating fuel fabrication facility exists for a fuel, it is considered alongside others already being used in operating plants. For SMRs at this level of maturity, the next stages include contracts for fuel supply and a license to operate the reactor with the specific fuel.

Criteria definitions

The area of evaluation and the indicator of progress is summarised in Table 1 below.

Table 1. **The NEA SMR Dashboard progress criteria definitions**

Licensing	No information	Pre-licensing	Licence/construction/design certification application submitted	Design approved	Licence to construct approved	Licence to operate approved
	* Bonus for multiple jurisdictions					
Siting	No information	Non-binding agreements/MOUs/ non-binding announcements	Site owner has shortlisted the technology	Site owner has selected the technology	Received permit(s) and or licence(s) for construction on the site	Construction has started on the site
	* Bonus for multiple sites					
Financing(1)	No information	At least one announcement	Five or more announcements or USD 100 million	Ten or more announcements or USD 500 million	FOAK is fully financed	FOAK financed + progress for NOAK finance
Supply chain(2)	No information	Supplier days/ events/workshops/ trade shows/ non-binding agreements/MOUs/ non-binding announcements	Binding contracts for services & materials	Partnerships/joint ventures/consortia - all with EPCs	FOAK construction ongoing/ complete	NOAK construction ongoing
Engagement(3, 4)	No information	One or more engagements	Three or more engagements	Five or more engagements	Seven or more engagements	Ten or more engagements
Fuel	No information	Non-binding agreements & studies with national labs for RDD/Lab-scale production of fuel	Contracts/agreements with fuel supply chain (uranium/conversion/enrichment/ fabrication)	Operating fabrication facility producing fuel, or uses same fuel as existing/generation-III commercial reactors	Contracts for fuel for FOAK	Fuel loading has begun

(1) **Types of financing announcements in scope**: Funding from private investors; government grants; loans; loan guarantees; cost sharing agreements; public-private partnerships; equity partnerships; announcements of becoming publicly traded; announcements of sizeable investments; power purchase agreements; financing approval from rate payers; export credit financing; bank financing; multilateral development bank financing.

(2) **Types of suppliers of interest in scope**: Engineering, procurement and construction organisations; universities, labs and research institutions when they are supplying research and development services to an SMR project.

(3) **Types of stakeholders for 'Engagement' in scope**: Subnational governments; Indigenous governments; labour unions; non-governmental organisations; civil society organisations; community organisations; universities; end users and customers; advisory boards.

(4) **Types of announcements for 'Engagement' in scope**: Memorandums of understanding; endorsements; town hall meetings; benefit-sharing agreements.

The NEA SMR Dashboard

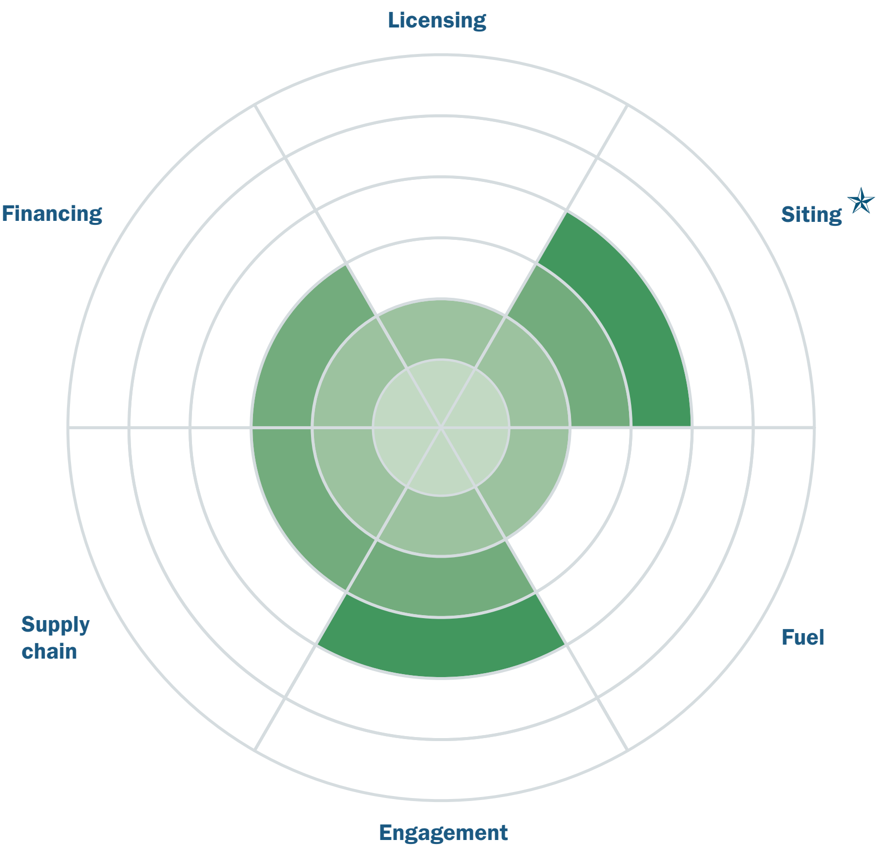
The NEA SMR Dashboard for the following technologies is presented in the following pages. Only technologies for which the requisite publicly-available information was assessable and for which the relevant designers were willing to participate are included. Future editions, which are expected to be issued at least annually, may include additional SMRs.

Table 2. **SMRs assessed in The NEA SMR Dashboard**

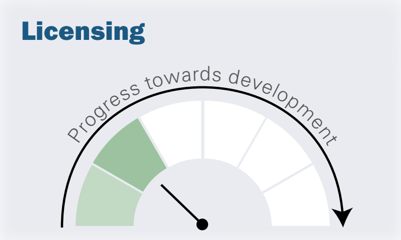
Name	Design organisation	Headquarter (city/region)	Country	Thermal power (MWth)	Outlet temperature (°C)	Spectrum (thermal/fast)	Fuel type
ARC-100	ARC Clean Technology	Saint John, New Brunswick	Canada	286	510	Fast	Metallic U-Zr alloy
CAREM	CNEA[1]	Buenos Aires	Argentina	100	326	Thermal	UO_2 pellets
ACPR50S	CGN[2]	Shenzhen	China	200	321.8	Thermal	UO_2 pellets
ACP100	CNNC[3] and NPIC[4]	Hainan Province	China	385	319.5	Thermal	UO_2 pellets
Nuward	EDF[5]	Paris	France	540	307	Thermal	UO_2 pellets
BWRX-300	GE-Hitachi/ Hitachi-GE	Wilmington, North Carolina	United States	870	287	Thermal	UO_2 pellets
Hermes	Kairos Power	Alameda, California	United States	35	585	Thermal	TRISO pebble
SEALER-55	Leadcold Reactors	Stockholm	Sweden	140	432	Fast	Uranium nitride
Stable Salt Reactor - Wasteburner	Moltex Energy	Saint John, New Brunswick	Canada	750	590	Fast	Molten salt fuel
VOYGR	NuScale Power	Portland, Oregon	United States	250	321	Thermal	UO_2 pellets
Aurora	OKLO	Sunnyvale, California	United States	4	500	Fast	Metallic U-Zr alloy
Rolls-Royce SMR	Rolls-Royce SMR Ltd	Manchester	United Kingdom	1 358	325	Thermal	UO_2 pellets
KLT-40S	Rosatom	Moscow	Russia	150	316	Thermal	UO_2 pellets
RITM-200N	Rosatom	Moscow	Russia	190	321	Thermal	UO_2 pellets
RITM-200S	Rosatom	Moscow	Russia	198	318	Thermal	UO_2 pellets
Natrium	TerraPower	Bellevue, Washington	United States	840	500	Fast	Metallic U-Zr alloy
HTR-PM	INET[6]	Beijing	China	500	750	Thermal	TRISO pebble
MMR	Ultra Safe Nuclear	Seattle, Washington	United States	15	630	Thermal	TRISO prismatic
U-Battery	Urenco	Stoke Poges	United Kingdom	10	710	Thermal	TRISO prismatic
eVinci	Westinghouse Electric Company	Cranberry Township, Pennsylvania	United States	13	750	Thermal	TRISO
XE-100	X-energy	Rockville, Maryland	United States	200	750	Thermal	TRISO-X pebble

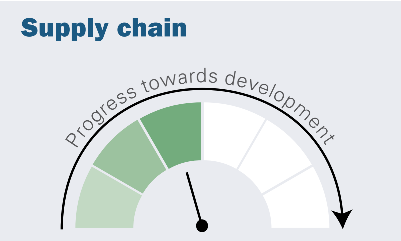
(1) Argentina's National Atomic Energy Commission; (2) China General Nuclear Power Group; (3) China National Nuclear Corporation; (4) Nuclear Power Institute of China; (5) Electricité de France; (6) Tsinghua University Institute of Nuclear and New Energy Technology.

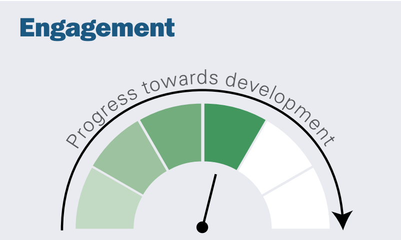
ARC-100

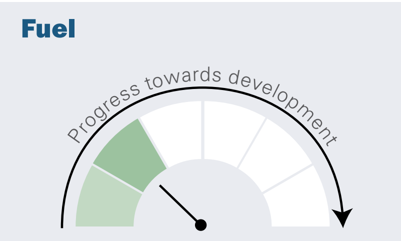


Active in multiple jurisdictions or countries.









Design organisation	ARC Clean Technology
Thermal Power (MWth)	286
Outlet Temperature (°C)	510
Spectrum (thermal/fast)	Fast
Fuel type	Metallic U-Zr alloy
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of ARC-100's progress to deployment

Licensing

The ARC-100 reactor is in Phase 2 of the pre-licensing Vendor Design Review (VDR) process with the Canadian Nuclear Security Commission (CNSC).

Siting ☆

The ARC-100 reactor has been shortlisted by New Brunswick Power, the primary electric utility in the Canadian province of New Brunswick for deployment at their Point Lepreau Nuclear Generating Station. Canada's Belledune Port Authority also shortlisted ARC-100 to generate firm heat and power for industrial users at the port's announced Green Energy Hub.

Financing

In 2021, ARC-100 was granted public funding from the Government of New Brunswick and the US Department of Energy's (DOE) Advanced Reactor Concepts program totalling more than USD 50 million. In 2022, ARC Clean Energy announced the closing of its Series A funding round with CAD 30 million (USD 24 million) from combined private and New Brunswick public funding.

Supply chain

ARC Clean Technology has signed contracts with Hatch, GE Hitachi and AECOM to support the deployment of the ARC-100 SMR. It also signed a commercial agreement with OARO as its digital security solutions provider and received funds from the University of New Brunswick to support early-stage assessments and studies for the reactor. In the Canadian 2022 Provincial Strategic plan for the Deployment of Small Modular Reactors, the Government of New Brunswick set out its objective to advance supply chain readiness for SMRs, including ARC-100, in collaboration with Canadian Manufactures and Exporters and Opportunities New Brunswick. ARC Clean Technology has hosted and participated in multiple supply chain events.

Engagement

ARC Clean Technology has support from the province of New Brunswick for siting the ARC-100 reactor. ARC Clean Technology is engaged with the University of New Brunswick's Centre for Nuclear Energy Research to further education in nuclear engineering and to nurture a talent pipeline. ARC Clean Technology is also a Member of the Atlantic Clean Energy Alliance and a Member of Canada Deuterium Uranium (CANDU) Owners Group to increase knowledge sharing in the network. They also have a partnership with the Canadian Nuclear Isotope Council to work on the global supply chain of medical radioisotopes, and Cross River Infrastructure Partners LLC to develop industrial hydrogen projects that would use the ARC reactor technology.

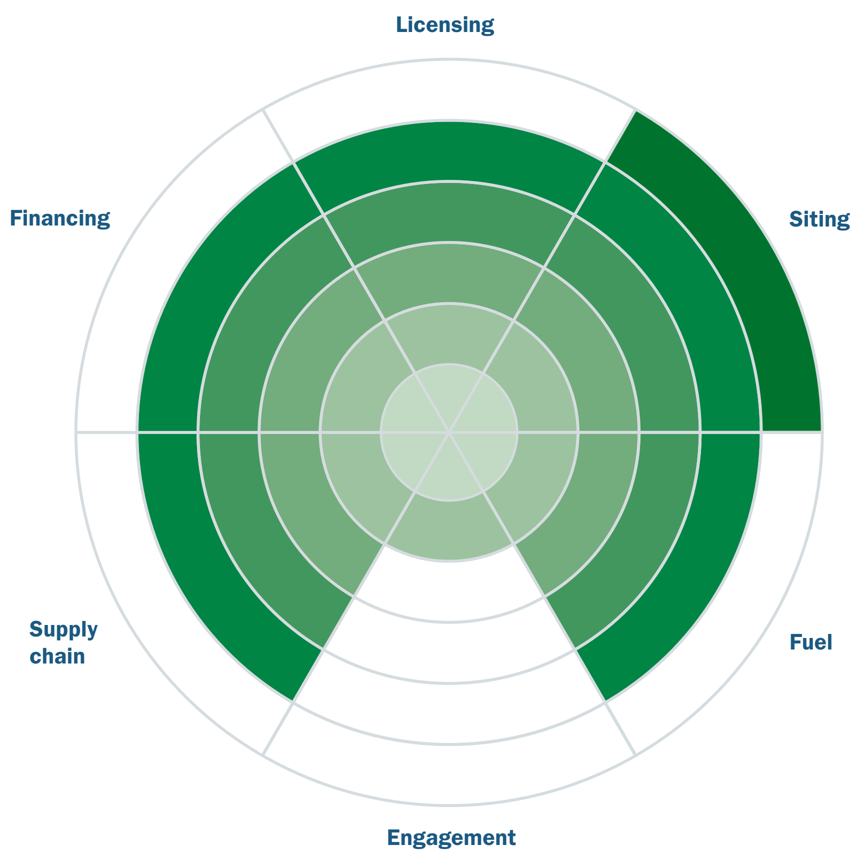
Fuel

HALEU is a technically proven fuel type; however, there is presently no commercial supply from OECD countries.

ARC Clean Technology signed a letter of intent with Centrus for HALEU supply and is partnering with Canadian Nuclear Laboratory to develop a fuel manufacturing process.

Note: The exchange rate applied is the currency relevant average for the year 2021. In this case, the price of CAD 1.254 equals the price of USD 1.000.

CAREM



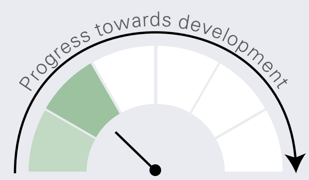
Licensing

Siting

Financing

Supply chain

Engagement



Fuel

★ Active in multiple jurisdictions or countries.

Design organisation	Argentina’s National Atomic Energy Commission
Thermal Power (MWth)	100
Outlet Temperature (°C)	326
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of CAREM's progress to deployment

Licensing

The CAREM prototype reactor license for construction was approved in 2010. In 2013, the CAREM prototype reactor was authorised to start construction, which began in 2014.

Siting

The CAREM reactor is under construction on the nationally owned site of Atucha, where Atucha I and II are already located. The Autoridad Regulatoria Nuclear (ARN) granted the authorisation for site use and construction to the Comisión Nacional De Energia Atómica (CNEA) in September 2013. First concrete was poured in February 2014.

Financing

The Argentinian government has written into national law that the government will fully finance the construction of the CAREM first-of-a-kind (FOAK) reactor.

Supply chain

CAREM construction started in 2014 and is still ongoing as of 2022. Nucleoelectrica Argentina SA has been contracted by the CNEA to complete CAREM's construction. CNEA remains the responsible authority ensuring overall co-ordination along the supply chain. Under current planning, up to 70% of the components are to be manufactured in Argentina.

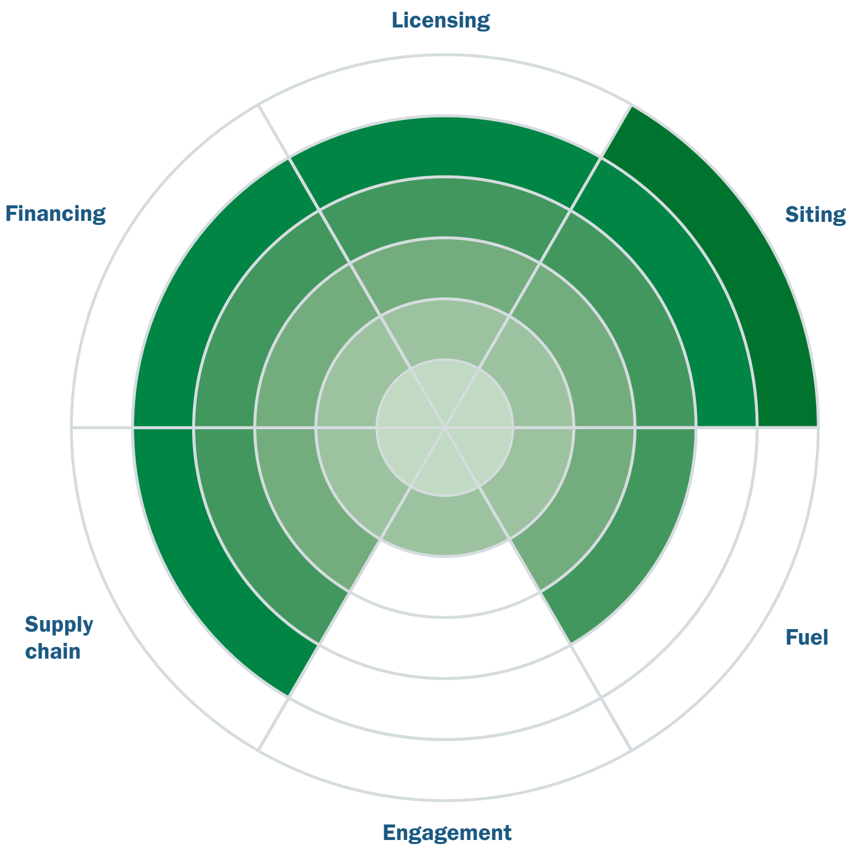
Engagement

Argentina has co-operation agreements with Bolivia that established a legal framework for the development of collaborative activities in the field of peaceful uses of nuclear energy, including but not limited to engagement on the CAREM reactor. Argentina also has a Memorandum of Understanding with Indonesia to establish bilateral co-operation on nuclear energy, including CAREM.

Fuel

Combustibles Nucleares Argentinos S.A. (CONUAR S.A.) was contracted to manufacture fuel for CAREM in 2013. This contract for fuel supply is still ongoing.

ACPR50S



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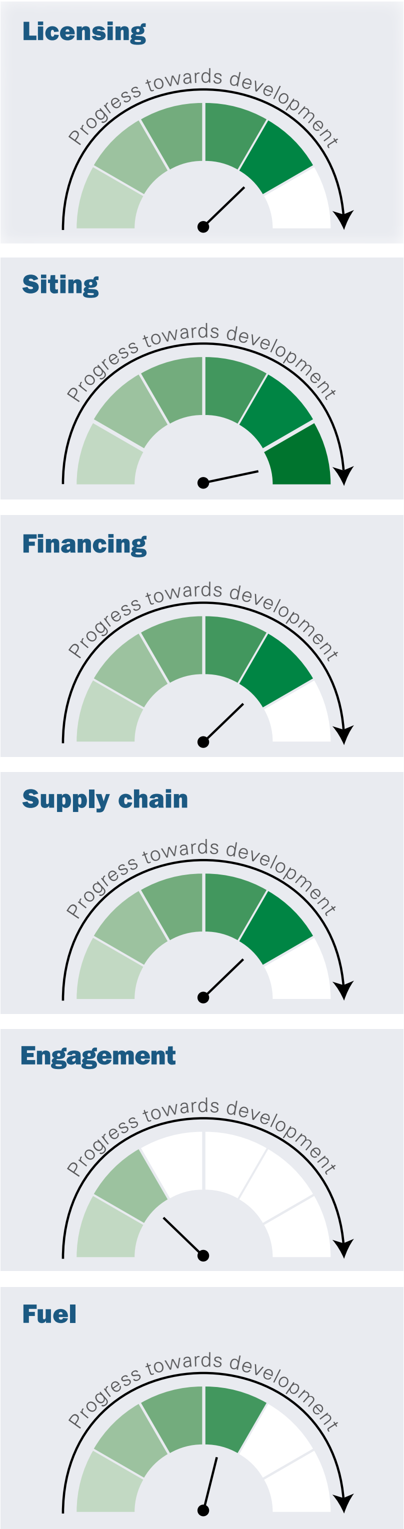


Design organisation	China General Nuclear Power Group
Thermal Power (MWth)	200
Outlet Temperature (°C)	321.8
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of ACPR50S's progress to deployment

Licensing

A first demonstration project of the floating nuclear power plant ACPR50S is already under construction. The first version of the preliminary safety analysis report was submitted to the National Nuclear Safety Administration in 2017, followed by the construction permit. The project has also benefitted from interactions with China Ship Research and Design Center and Lloyd's Register to define safety requirements for floating nuclear power plants.

Siting

In 2017, the China Shipbuilding Industrial Corp. (CSIC) indicated that the first ACPR50S unit would support China National Offshore Oil Corp. (CNOOC) drilling platforms in the Bohai sea. Chinese officials have also announced that floating nuclear power plants should support deep-water oil and gas exploration in the South China sea.

Financing

China's National Development and Reform Commission (NDRC) approved the ACPR50S reactor design in January 2016 as part of the 13th Five-Year Plan for innovative energy technologies. The ACPR50S demonstration project is wholly owned by China General Nuclear Power (CGN), a state-owned enterprise under direct management of the Chinese central government.

Supply chain

The supply chain for ACPR50S demonstration project involves the following Chinese companies: CGN as the owner, main designer, operator; the Nuclear Power Technology Research Institute (CNPRI) as technical support organisation for design requirements for floating reactors; Dongfang Electric as pressure vessel manufacturer and reactor module assembler; and Bohai Shipbuilding Heavy Industry, a subsidiary of the China Shipbuilding Industrial Corp. (CSIC), as shipbuilder. Construction has been underway since 2016, when the purchase agreement for the pressure vessel was signed between CGN and Dongfang Electric.

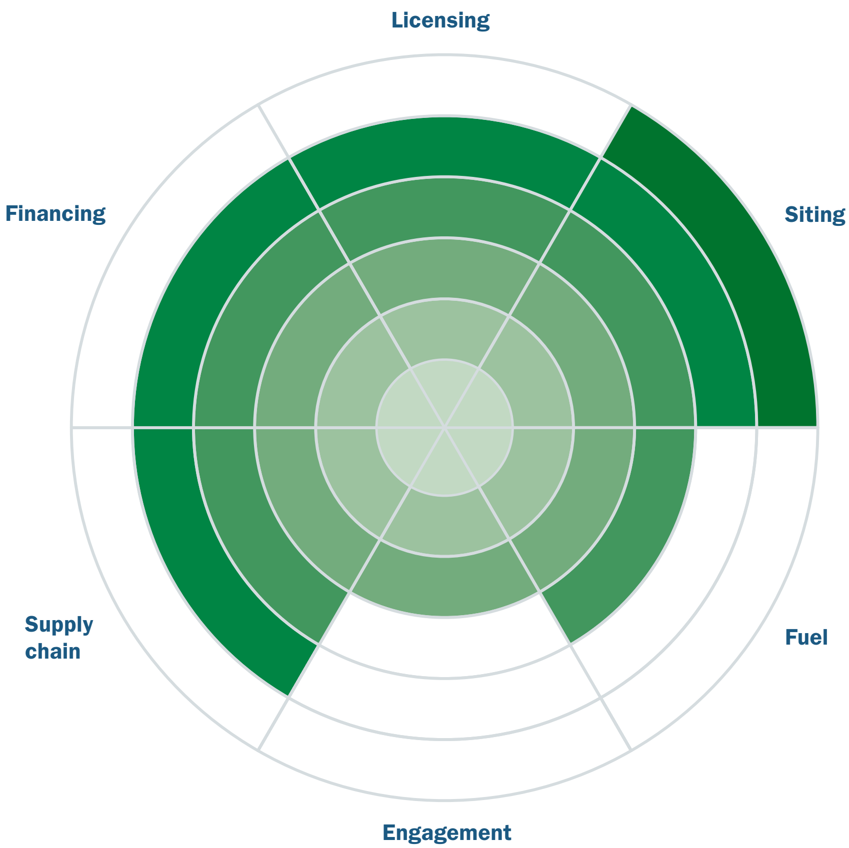
Engagement

In 2016, CGN and China National Offshore Oil Corporation (CNOOC) signed an agreement to work together on the development of floating nuclear power plants.

Fuel

The ACPR50S design is based on existing Gen-II/III light-water reactor technology and therefore relies on well-established fuel supply chains.

ACP100



★ Active in multiple jurisdictions or countries.

Design organisations	China National Nuclear Corporation and Nuclear Power Institute of China
Thermal Power (MWth)	385
Outlet Temperature (°C)	319.5
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Licensing

Siting

Financing

Supply chain

Engagement

Fuel

Assessment of ACP100's progress to deployment

Licensing

China's National Nuclear Safety Administration approved the ACP100 preliminary safety analysis report in 2020. Construction of the first demonstration ACP100 reactor began in 2021.

Siting

In 2016, the Hainan provincial government agreed to host the first two ACP100 units on the existing Changjiang nuclear power plant site. Construction started in July 2021. In 2013, China National Nuclear Corporation (CNNC) also signed agreements with Hengfeng county, Shangrao city in Jiangxi province, and with Ningdu county, Ganzhou city in the Jiangxi province.

Financing

On 2 September 2020, during an executive meeting of the State Council, the Hainan Changjiang Nuclear Power Phase II project was approved. The project includes two ACP100 reactors, and is also known as the Linglong One units. The Hainan Changjiang Nuclear Power Phase II project is listed in the National Plan and jointly funded by CNNC and China Huaneng Group. The People's Republic of China's National Development and Reform Commission approved the construction of a demonstration ACP100 in June 2021 and it began construction in July 2021. The ACP100 demonstration project is wholly owned by CNNC's China National Nuclear Power, a state-owned enterprise under direct management by the Chinese central government.

Supply chain

The supply chain for ACP100 demonstration project involves the following Chinese companies: China National Nuclear Power (a subsidiary of CNNC) as the owner and operator; the Nuclear Power Institute of China (NPIC) as the reactor designer; China Nuclear Power Engineering Group as the plant construction company; Shanghai Boiler Works Limited as the supplier of the reactor vessel; and Dongfang Electric Corporation as the supplier of other reactor internals. The steam generators will be delivered by a CNNC subsidiary. As of December 2022, installation of the main equipment is underway.

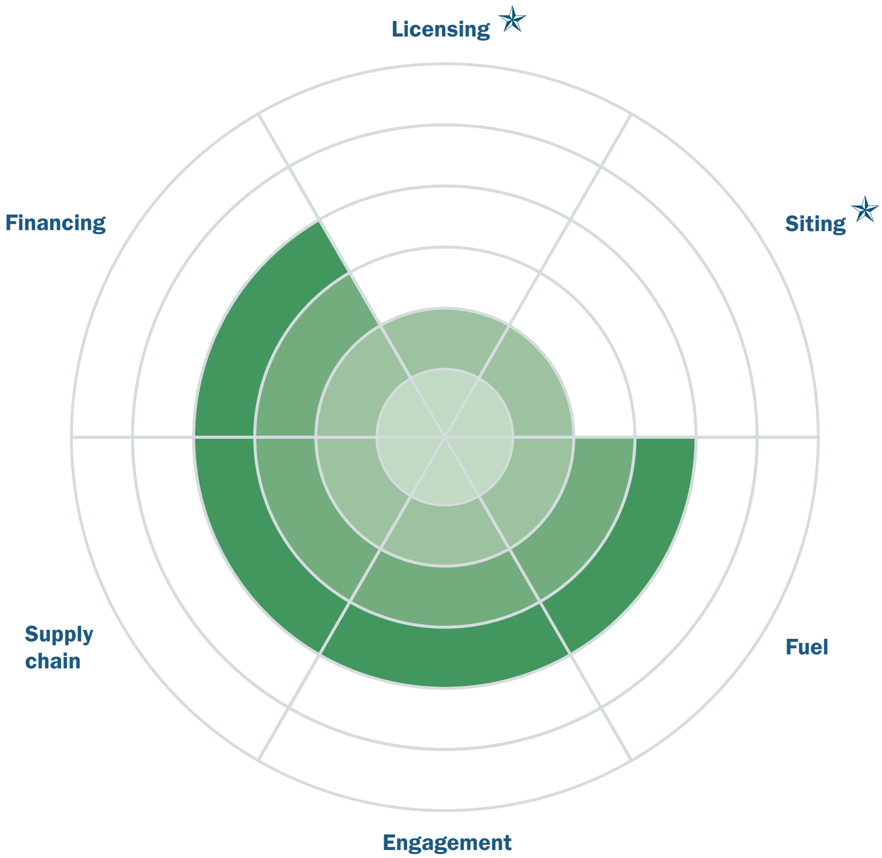
Engagement

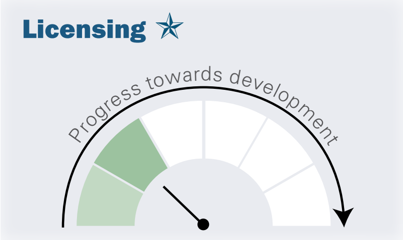
CNNC has agreements in place with Shangrao and Ganzhou cities in the Jiangxi province for new ACP100 projects. Further inland units are planned in Hunan and possibly Jilin provinces.

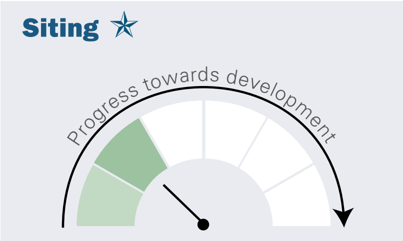
Fuel

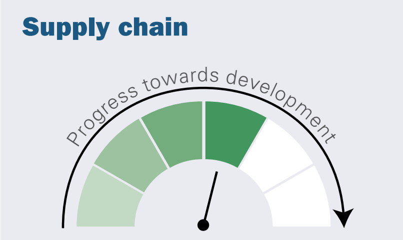
The ACP100 design is based on existing Gen-II/III light-water reactor technology and therefore relies on well-established fuel supply chains.

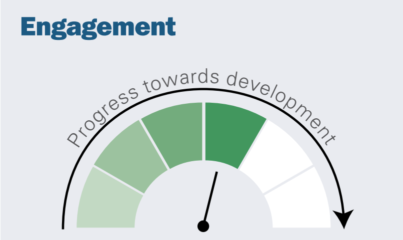
NUWARD

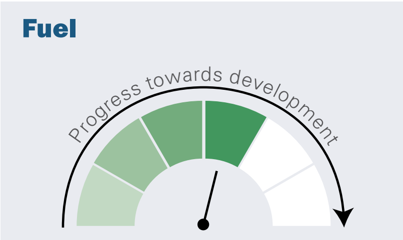












☆ Active in multiple jurisdictions or countries.

Design organisation	Electricité de France
Thermal Power (MWth)	540
Outlet Temperature (°C)	307
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of NUWARD's progress to deployment

Licensing ✯

The Autorité de Sûreté Nucléaire (ASN), Radiation and Nuclear Safety Authority (STUK) and State Office for Nuclear Safety (SUJB) - the nuclear safety authorities in France, Finland, and the Czech Republic, respectively – are collaborating on the pre-licensing review of the NUWARD reactor design.

Siting ✯

Électricité de France (EDF), architect-engineer for NUWARD, owns 18 licenced nuclear sites in France that could be suitable for the NUWARD FOAK and has committed to commence construction with first concrete poured by 2030.

In addition, EDF has signed a cooperation agreement with Respect Energy to conduct siting studies for NUWARD in Poland.

Financing

The French government has provided more than EUR 500 million (USD 592 million) in funding for NUWARD development.

Supply chain

NUWARD is in a partnership between: Commissariat à l'énergie atomique et aux énergies alternatives (CEA) for research and qualification; EDF for systems integration and operation; Naval Group for structures and modular experience; TechnicAtome for compact reactor design experience; Framatome for reactor core and fuel design; and Tractebel for the conventional island and the balance of plant. In 2022, EDF signed five co-operation agreements with Polish companies, Uniserv, Telefonika Kable, Polimex Mostostal, Sefako and Zakłady Remontowe Energetyki (ZRE) Katowice, as strategic partners in nuclear development.

Engagement

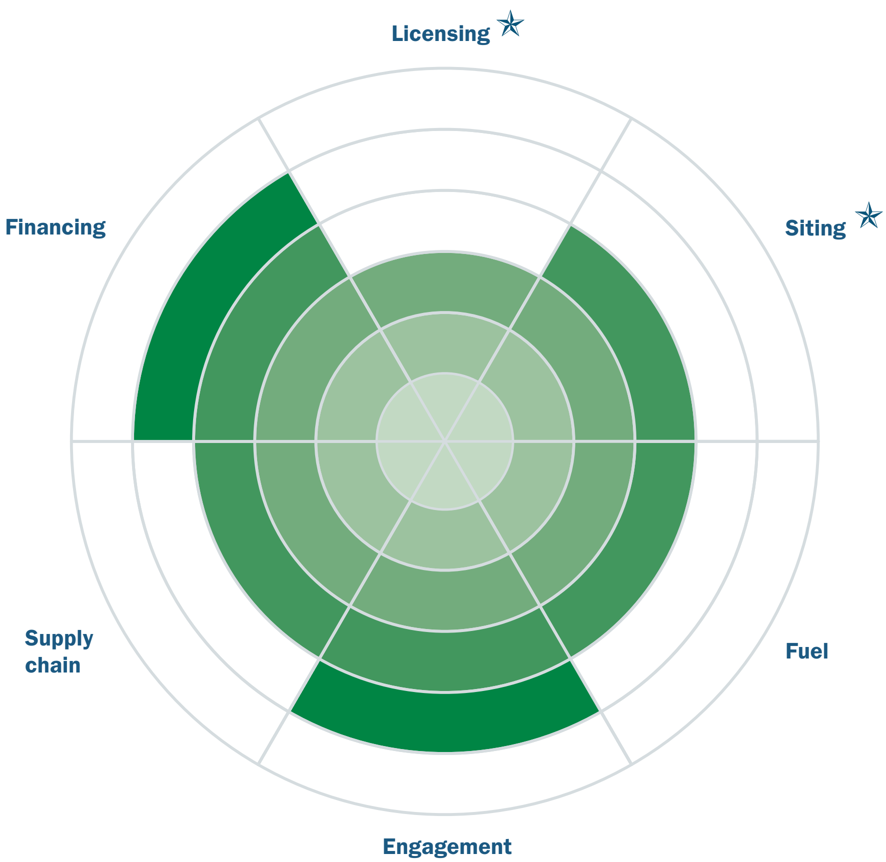
In 2021, the NUWARD International Advisory Board was created to provide advice on subjects such as economics, technical features, licensing and regulatory approaches and public acceptance. In 2022, the French President stated public support, and EDF advanced various engagements, including: signature of a co-operation agreement with Fortum, a Finnish stated owned company, for the development of new nuclear projects in Finland and Sweden; renewal of a co-operation agreement with Eletronuclear, a nuclear operator in Brazil; signature of a memorandum of understanding (MOU) with ČEZ to co-operate in preparation of SMR technology, assessment of energy, financial and technical feasibility, co-operation of public, private and academic sectors and licensing; and signature of a co-operation agreement with Respect Energy in Poland.

Fuel

The NUWARD SMR utilises fuel that is the current industry standard for water-cooled reactor technologies which are similar in design. There are no barriers expected in the fuel supply chain for this SMR.

Note: The exchange rate applied is the currency relevant average for the year 2021. In this case, the price of EUR 0.845 equals the price of USD 1.000.

BWRX-300



Active in multiple jurisdictions or countries.

Design organisation	GE-Hitachi/Hitachi-GE
Thermal Power (MWth)	870
Outlet Temperature (°C)	287
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

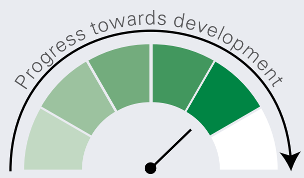
Licensing

Siting

Financing

Supply chain

Engagement



Fuel

Assessment of BWRX-300's progress to deployment

Licensing ✭

GE Hitachi has entered Phase 2 of the Canada Nuclear Safety Commission's (CNSC) pre-licensing Vendor Design Review (VDR), and is engaged with the US Nuclear Regulatory Commission, which is reviewing "Licensing Topical Reports" related to the BWRX-300 design.

In October 2022, Ontario Power Generation (OPG) submitted an application to the CNSC for a license to construct one BWRX-300 reactor at OPG's Darlington site in Ontario, Canada.

Siting ✭

In October 2021, the CNSC renewed OPG's license to prepare its Darlington site for new nuclear capacity. In December 2021, Ontario Power Generation announced that it had selected the BWRX-300 for its Darlington site. The operator SaskPower also selected the GE-Hitachi BWRX-300 for potential deployment in Saskatchewan, Canada. The Tennessee Valley Authority (TVA) is analysing the viability of SMRs, and has partnered with GE Hitachi to advance the potential deployment of a BWRX-300 at the Clinch River Nuclear site. Fermi Energy has shortlisted GE Hitachi through a targeted call for tenders related to the potential deployment of a SMR in Estonia, with the final technology decision expected in 2023.

Financing

GE Hitachi has attracted private and public funding supporting the development of the BWRX-300, or the direct project to deploy the first-of-a-kind (FOAK) reactor at Darlington. This includes almost CAD 1 billion (USD 0.797 billion) in public financing support from the Canadian federal government through the Canadian Infrastructure Bank and additional awards through Advanced Research Projects Agency-Energy funding from the US Department of Energy. In November 2021, the Province of Ontario enabled OPG to recover costs associated with the construction and operation of the project from the electricity ratepayer through a regulatory amendment.

Supply chain

Given GE Hitachi's experience developing Generation III/III+ Boiling Water Reactors similar to the BWRX-300 SMR, there is an opportunity to leverage existing supply chains. To support the FOAK BWRX-300 in Canada, GE Hitachi is collaborating with OPG to design, plan, license, and prepare the Darlington site. With an interest in deploying the SMR in the US, TVA has separate agreements in place with both GE Hitachi and OPG related to sharing information and best practices, and to co-ordinate on design and licensing requirements for the BWRX-300 across jurisdictions. Additional services related to the development of the BWRX-300 includes a collaboration with a UK architecture firm to provide input into the design.

Engagement

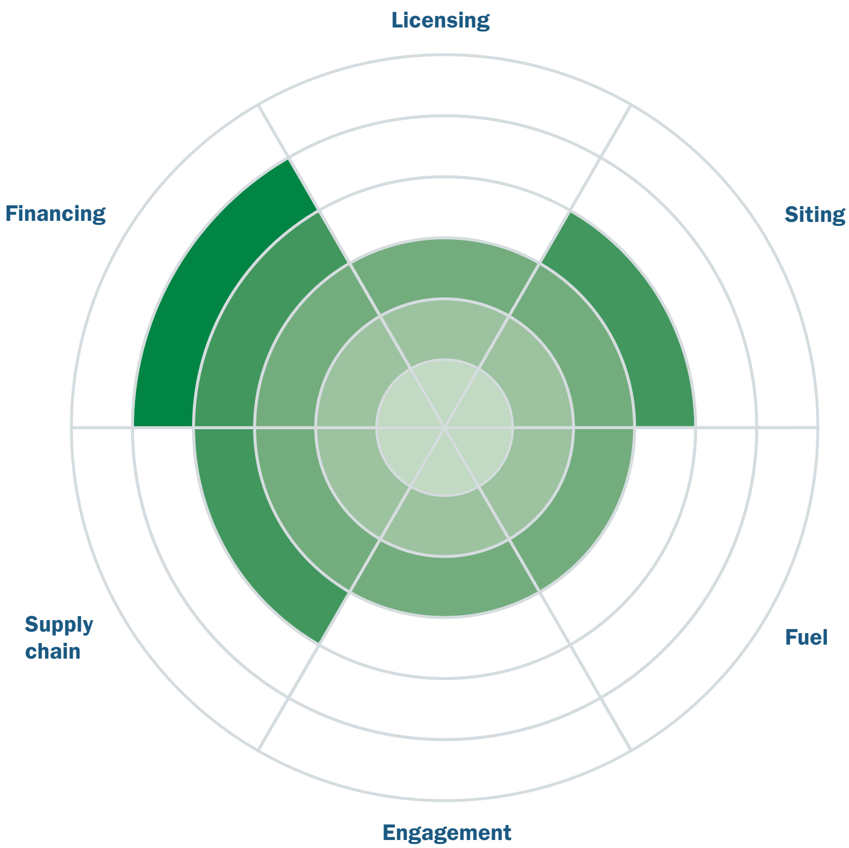
In Canada, the Darlington project has been endorsed by provincial and federal governments. GE Hitachi has formed a collaboration with the First Nations Power Authority to engage communities on SMRs, and to train individuals from Indigenous communities in Canada to support its workforce. GE Hitachi also has an agreement in place with the Saskatchewan Industrial and Mining Suppliers Association to engage with local suppliers to advance the potential deployment in Saskatchewan. Internationally, GE Hitachi has established a series of MOUs, including an MOU with Synthos Green Energy exploring the potential deployment in Poland, as well as MOUs with Fermi Energia in Estonia, ČEZ in the Czech Republic, and Karnfall Next in Sweden.

Fuel

The BWRX-300 reactor uses fuel that is proven, commercially available, and currently being used in operating boiling water reactors. There are no barriers expected in the fuel supply chain for this SMR. An MOU has been signed with Cameco to work towards establishing a potential supply of uranium fuel for the BWRX-300 reactor fleet.

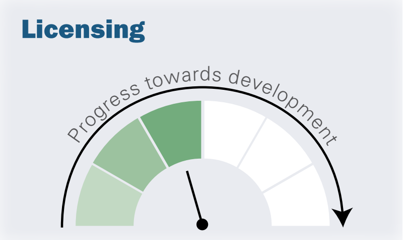
Note: The exchange rate applied is the currency relevant average for the year 2021. In this case, the price of CAD 1.254 equals the price of USD 1.000.

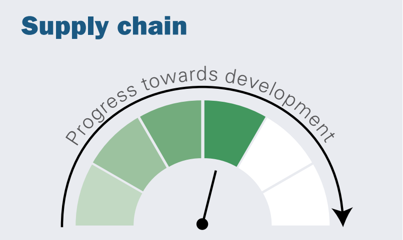
Hermes

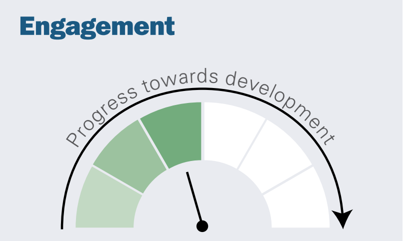


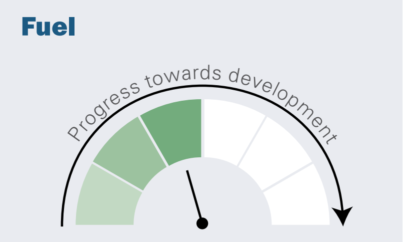
★ Active in multiple jurisdictions or countries.

Design organisation	Kairos Power
Thermal Power (MWth)	35
Outlet Temperature (°C)	585
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO pebble
Fuel (LEU/HALEU/HEU)	HALEU









Assessment of Hermes' progress to deployment

Licensing

Hermes is a 35 MWth demonstration reactor supporting the development of Kairos Power's 320 MWth commercial KP-FHR technology. Kairos Power has submitted an application for a construction permit for Hermes to the US Nuclear Regulatory Commission (NRC) under a regulatory pathway that is distinct from the licensing process for commercial reactors. The Safety Review and Environmental Review are currently underway through the NRC, and are expected to be completed by the end of 2023.

Siting

Kairos Power is partnering with the Tennessee Valley Authority (TVA) to deploy the Hermes test reactor on 185 acres purchased on the East Tennessee Technology Park campus in Oak Ridge, which was previously reclaimed from the US Department of Energy. The construction permit application to build the one-of-a-kind Hermes reactor on this site was submitted to the US Nuclear Regulatory Commission in November 2021.

Financing

Kairos Power has received several grants from the US Department of Energy, including a USD 629 million cost-shared award over seven years as part of the Advanced Reactor Demonstration Program initiative. This funding will support the design, licensing and construction of Hermes. Kairos Power plans to invest more than USD 100 million to deploy Hermes.

Supply chain

Kairos Power is working with Materion to secure a supply of salt coolant for high-temperature molten salt reactors. The two companies jointly commissioned a Molten Salt Purification Plant at Materion's Elmore facility in 2022. Kairos Power is also collaborating with TVA, who is providing engineering, operations, and licensing support for Hermes. Kairos Power has received the American Society of Mechanical Engineers certification to manufacture U-stamped pressure vessels at its facility in Albuquerque, New Mexico which supports Kairos Power to do manufacturing in-house. Kairos Power is also working with Oak Ridge National Laboratory to develop corrosion-resistant alloys for use in molten fluoride salt environments.

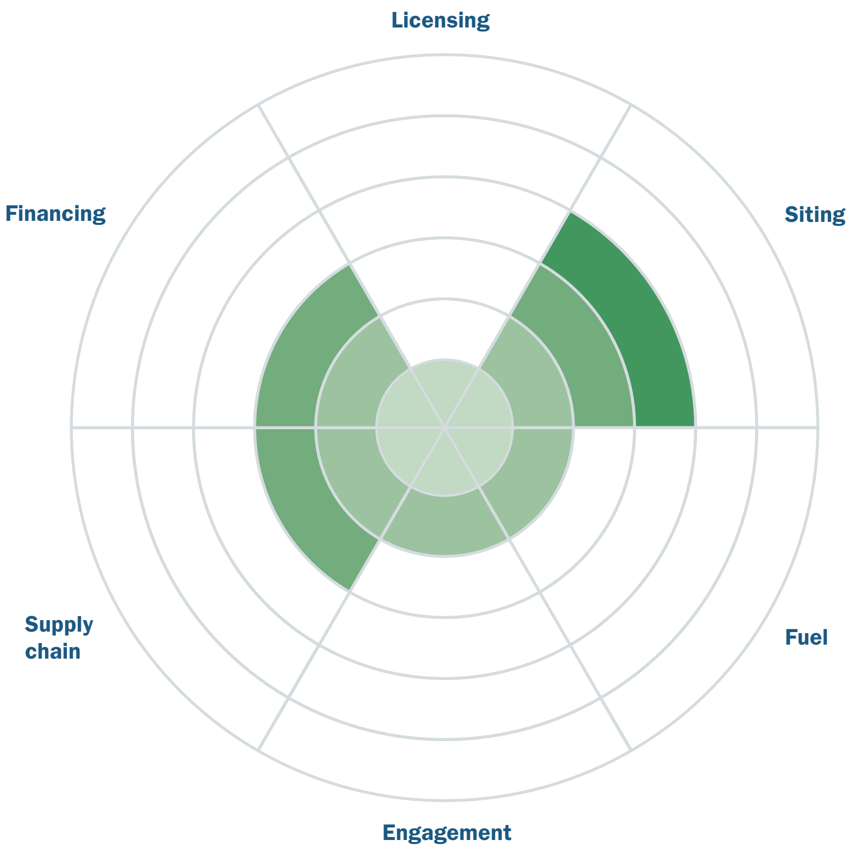
Engagement

Kairos Power's activities to advance the deployment of nuclear technologies has received endorsement in New Mexico from Senator Martin Heinrich, Albuquerque Mayor Tim Keller, and in the state of Tennessee from Governor Bill Lee, Commissioner Bob Rolfe, Lt. Governor Randy McNally, Congressman Chuck Fleischmann, as well as multiple Tennessee senators.

Fuel

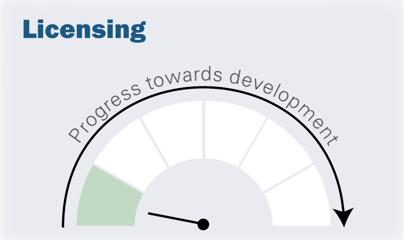
TRISO fuel, or TRi-structural ISOtropic fuel, has been tested since 1960 in US national laboratories. The Hermes test reactor is designed to use TRISO fuel pebbles, which will be produced at the New Mexico lab's Low Enriched Fuel Fabrication Facility (LEFFF) under an agreement between Los Alamos National Laboratory and Kairos Power. The LEFFF will host several fuel manufacturing processes being developed by Kairos Power at its facility in Albuquerque, New Mexico.

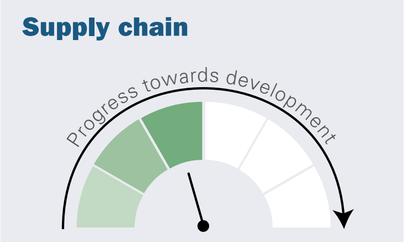
SEALER-55

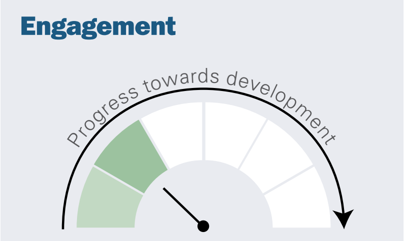


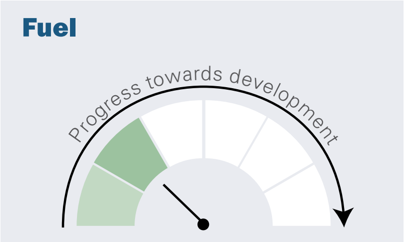
★ Active in multiple jurisdictions or countries.

Design organisation	Leadcold Reactors
Thermal Power (MWth)	140
Outlet Temperature (°C)	432
Spectrum (thermal/fast)	Fast
Fuel type	Uranium nitride
Fuel (LEU/HALEU/HEU)	HALEU









Assessment of SEALER-55's progress to deployment

Licensing

Leadcold Reactors applied for Phase 1 of the Canadian Safety Nuclear Commission's Pre-Licensing Vendor Design Review (VDR) process in January 2017. The VDR assessment is currently on hold at the request of Leadcold Reactors.

Siting

Leadcold Reactors has formed a joint venture with Uniper to advance the SEALER reactor concept at the Oskarshamn Nuclear Power Plant, which is owned by Oskarshamnsverkets Kraftgrupp OKG in Sweden. The development of the SEALER reactor is planned as an iterative process, starting with the construction of an electrically heated prototype at the Oskarshamn site by 2024, to be followed by the deployment of the nuclear demonstration reactor at the same site by 2030.

Financing

There are multiple funding announcements related to advancing aspects of Leadcold Reactors' SEALER SMR project at the Oskarshamn plant site. This includes more than SEK 99 million (USD 11.5 million) from the Swedish Energy Agency, a SEK 25 million (USD 2.9 million) investment by Norrsken, and a SEK 1.7 million (USD 0.2 million) award through Eurostars. Leadcold Reactors also has an agreement with the utility NewClearEnergy, where a percentage of electricity sales will be used to directly support the design and safety analysis of SEALER. Through Phase 1 of the UK Government's Advanced Modular Reactor Feasibility and Development project, Leadcold Reactors was also awarded a contract to produce a feasibility study for the Sealer-55 design.

Supply chain

Through a research programme focused on lead-cooled SMR technology, the Sustainable Nuclear Energy Research In Sweden (SUNRISE) centre was established which includes participants from the KTH Royal Institute of Technology, Uppsala University, Luleå University of Technology, and other industrial and societal partners. The SUNRISE project aims to design a research demonstration reactor for the SEALER-55 concept at the Oskarshamn site by 2030, and enable the commercialisation of new SEALER-55 reactors in Sweden. Leadcold Reactors has formed a joint venture with Uniper, which aims to construct an electrically heated prototype to advance the SEALER-55 reactor concept.

Engagement

KTH professor and founder of Leadcold Reactors, Janne Wallenius, received the KTH Innovation Award 2022, which recognises work on solutions to humanity's greatest challenges.

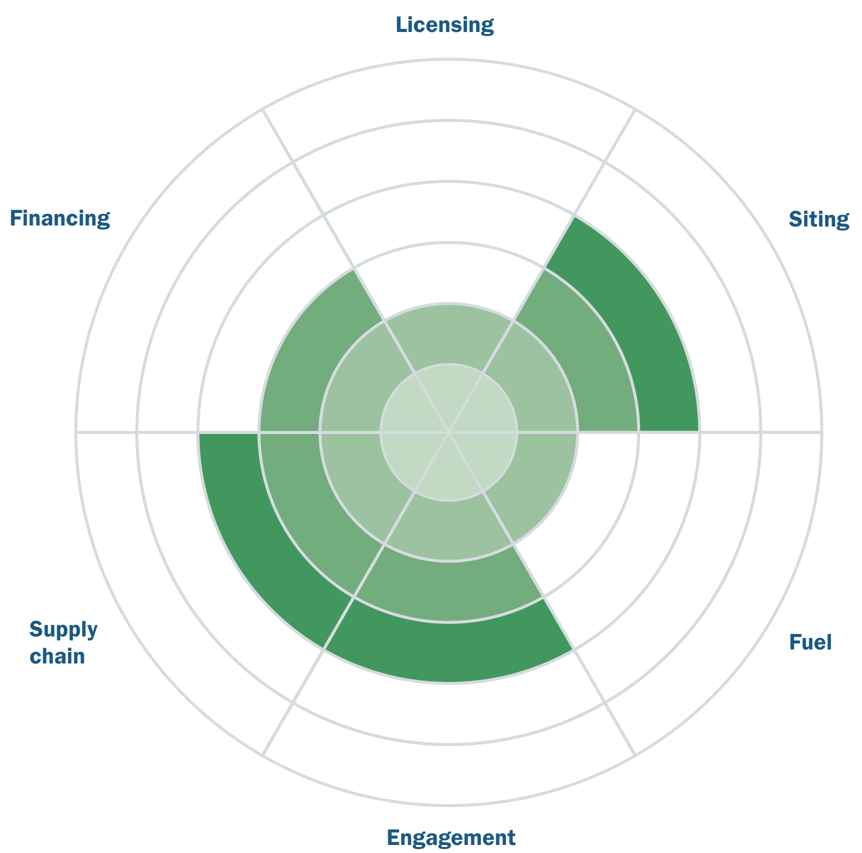
Fuel

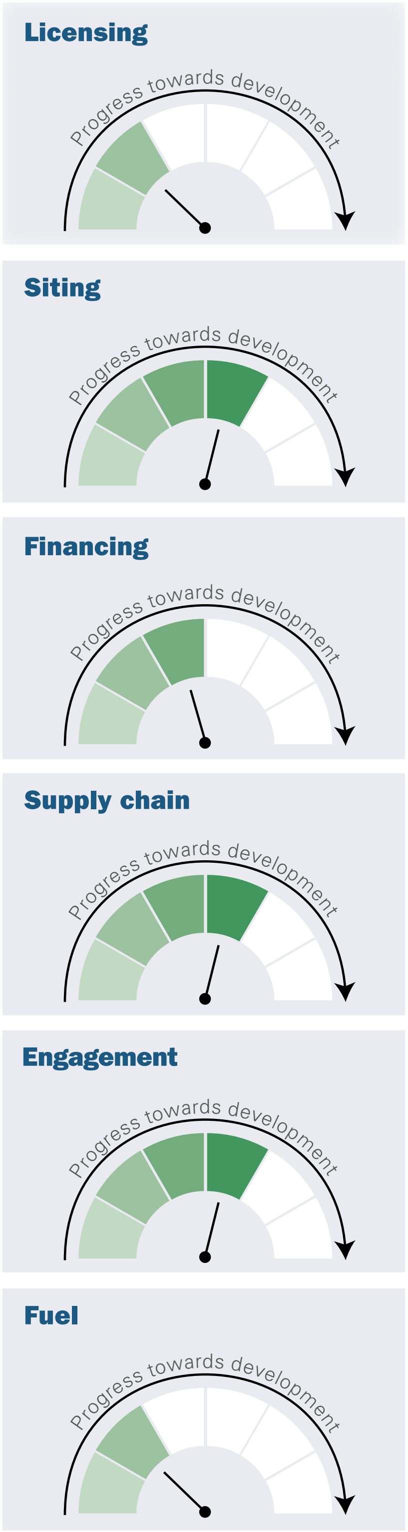
HALEU is a technically proven fuel type; however, there is presently no commercial supply from OECD countries.

Leadcold Reactors is engaged with KTH Royal Institute of Technology on studies related to the lab-scale production of fuel. This includes the fabrication of uranium nitride samples suitable for irradiation testing in a laboratory setting.

Note: The exchange rate applied is the currency relevant average for the year 2021. In this case, the price of SEK 8.577 equals the price of USD 1.000.

Stable Salt Reactor - Wasteburner





☆ Active in multiple jurisdictions or countries.

Design organisation	Moltex Energy
Thermal Power (MWth)	750
Outlet Temperature (°C)	590
Spectrum (thermal/fast)	Fast
Fuel type	Molten salt fuel
Fuel (LEU/HALEU/HEU)	LEU

Assessment of SSR-W's progress to deployment

Licensing

The Stable Salt Reactor - Wasteburner (SSR-W) design from Moltex Energy has been engaged in pre-licensing activities with the Canadian Nuclear Safety Commission (CNSC) since 2017. Phase 1 of CNSC's pre-licensing Vendor Design Review (VDR) was completed with Moltex Energy submitting 50 documents in eight work packages to cover 19 technical review focus areas. The design is currently proceeding in Phase 2 of the VDR.

Siting

Moltex Energy has a Memorandum of Understanding (MOU) with New Brunswick Power (NB Power) to evaluate the construction of its first SSR-W at the Point Lepreau Nuclear Power Plant site. Moltex Energy expects to have both its spent fuel recovery system and reactor in operation by the early 2030s. The company is also supporting NB Power with site evaluation and preparation activities.

Financing

Moltex Energy has obtained funding from multiple public and private sources. Public grants have been received from the US Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E), the Canadian government, the Ontario Power Group's Centre for Canadian Nuclear Sustainability and the UK's government Advanced Reactor Initiative. Multi-million investments have been secured from the engineering company IDOM and from a crowdfunding process via the Shadow Foundr platform.

Supply chain

In the Canadian 2022 Provincial Strategic Plan for the Deployment of Small Modular Reactors, the Government of New Brunswick set out its objective to advance supply chain readiness for SMRs, including Moltex Energy, in collaboration with Canadian Manufacturers and Exporters and Opportunities New Brunswick. In April 2022, Moltex Energy announced a partnership with SNC-Lavalin to support the licensing and construction of the first SSR-W in New Brunswick. IDOM, which has invested in Moltex's SSR-W technology, is also providing engineering support in various technical areas.

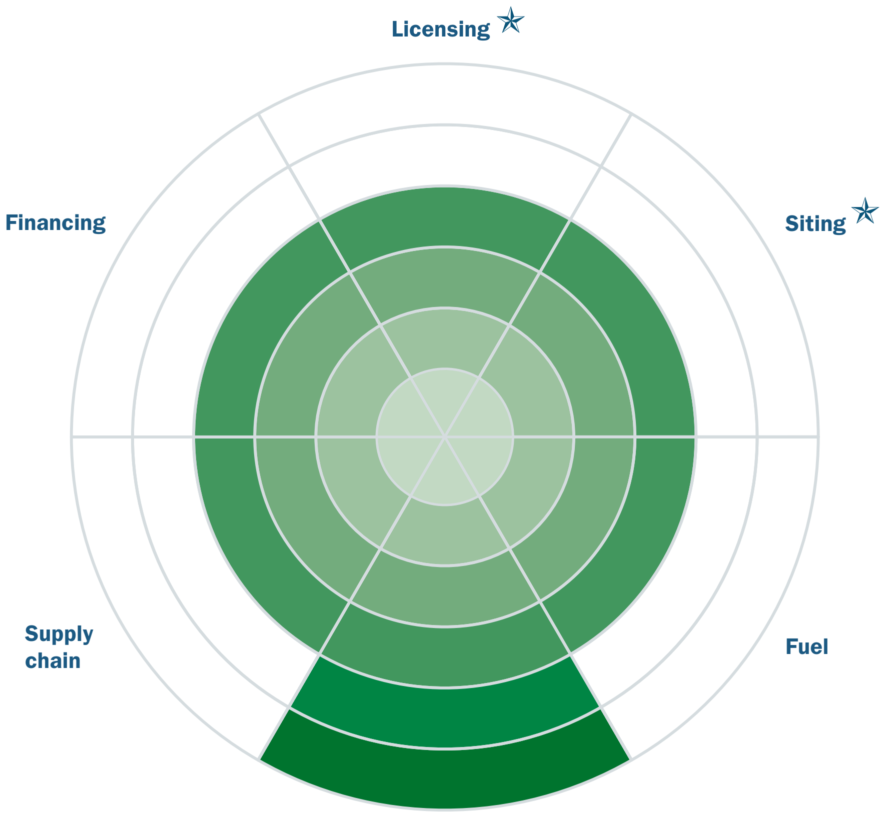
Engagement

Moltex Energy has received endorsements from provincial and federal governments in Canada for the development of its SSR-W technology. Moltex Energy has also entered into a partnership with North Shore Mi'kmaq District Council and has advanced collaborations with the First Nations Power Authority to deepen Indigenous engagement on nuclear energy broadly and then SMR technology specifically. The Centre for Nuclear Energy Research (CNER) at the University of New Brunswick (UNB) is also engaged with Moltex Energy on SMR research and talent development.

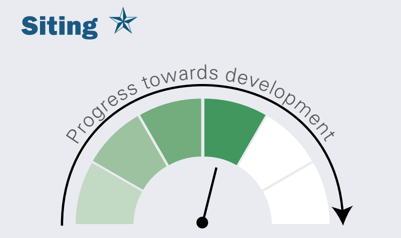
Fuel

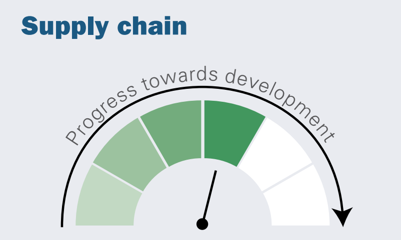
UNB and Canadian National Laboratories (CNL) are supporting SSR-W fuel development through CNL's Canadian Nuclear Research Initiative. Ontario Power Group has invested CAD 1 million to support the demonstration of the technical viability of using spent Canada Deuterium Uranium (CANDU) reactor fuel in the Moltex Energy SSR-W.

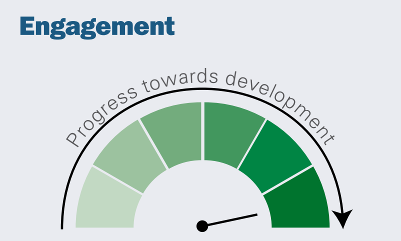
VOYGR

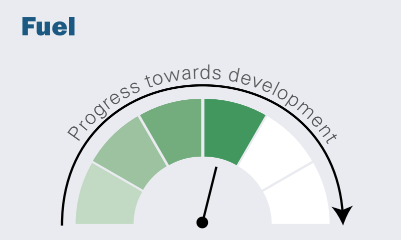


★ Active in multiple jurisdictions or countries.









Design organisation	NuScale Power
Thermal Power (MWth)	250
Outlet Temperature (°C)	321
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of VOYGR's progress to deployment

Licensing ★

The VOYGR design was approved by the US Nuclear Regulatory Commission (NRC) in 2020. NuScale Power is also conducting pre-licensing activities in additional jurisdictions, including Ukraine, Canada, Romania and Poland.

Siting ★

The VOYGR design was selected by Utah Associated Municipal Power Systems (UAMPS) for construction at the US Department of Energy (DOE) Idaho National Laboratory site. NuScale Power also has a memorandum of understanding (MOU) with Nuclearelectrica to conduct licensing and permitting activities related to the deployment of VOYGR at a site in Doicesti, Romania. NuScale Power has also signed a contract with RoPower Nuclear S.A., which will include activities related to defining the site for VOYGR at the Doicesti Power Station site in Romania.

Financing

In 2013, the US Department of Energy (DOE) announced that NuScale Power could receive up to USD 226 million in matching funds to support design development and obtain the US NRC design certification. In 2020, the DOE approved a multi-year cost-share award of USD 1.355 B to Carbon Free Power Project, LLC (CFPP, LLC) for the development and construction of a NuScale Power nuclear power plant at the Idaho National Laboratory site. In 2021, the US Trade and Development Agency (USTDA) announced a USD 1.2 million grant to Nuclearelectrica to identify and evaluate potential sites. NuScale Power has been able to secure an additional US federal grant and private investment from Nucor for the VOYGR project in 2022.

Supply chain

NuScale Power has made progress in securing suppliers – including agreements and contracts with Framatome, Ultra Electronics, Sarens, Samsung, Doosan Enerbility, PaR, Concurrent Technologies Corp, and Nucor-, testing, engineering and review capabilities, engineering and review assistance – including agreements and contracts with SIET, U.S. Reactor Forging Consortium, Oregon State University, Sargent and Lundy, Enercon, and BWXT –, and deployment assistance including agreements and MOUs with ČEZ, Kazakhstan Nuclear Power Plant, KGHM, Energoatom, Nuclearelectrica, Dairyland Power Cooperative in the US, Samsung, Doosan & GS Energy, and Ultra Electronics (global). Additionally, Fluor & CFPP are the joint Engineering, Procurement and Construction companies for NuScale Power in the United States.

Engagement

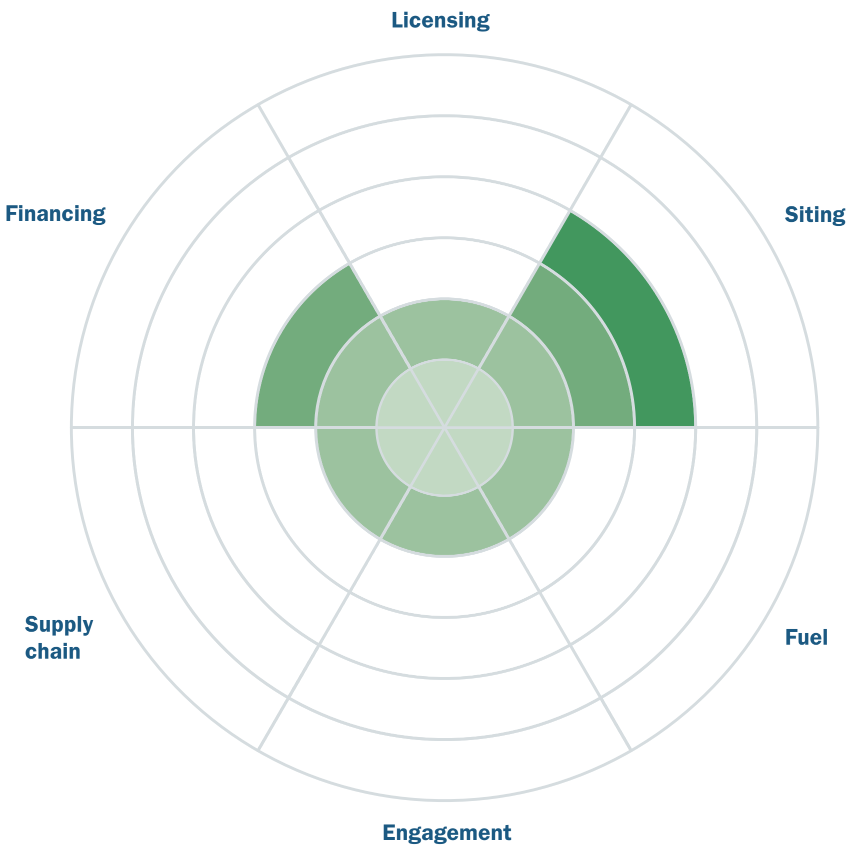
NuScale Power engages with universities in the US, and opened four 'NuScale Energy Exploration (E2) Centers' for students to learn about SMR technology, with plans to establish an E2 Center at University Politehnica, Romania. NuScale Power engages with communities by signing on to the Equal by 30 campaign, committing to eliminate gender inequity in the workforce, and having town halls for open discussion. NuScale Power engaged entities about potential deployment – e.g. an MOU with Dairyland Power Cooperative, an MoU with KGHM and PBE to explore the deployment as a repowering or repurposing solution, an MOU with Associated Electric Cooperative to explore deployment – and launched the Western Initiative for Nuclear, multi-western state collaboration to study the technology's demonstration and deployment.

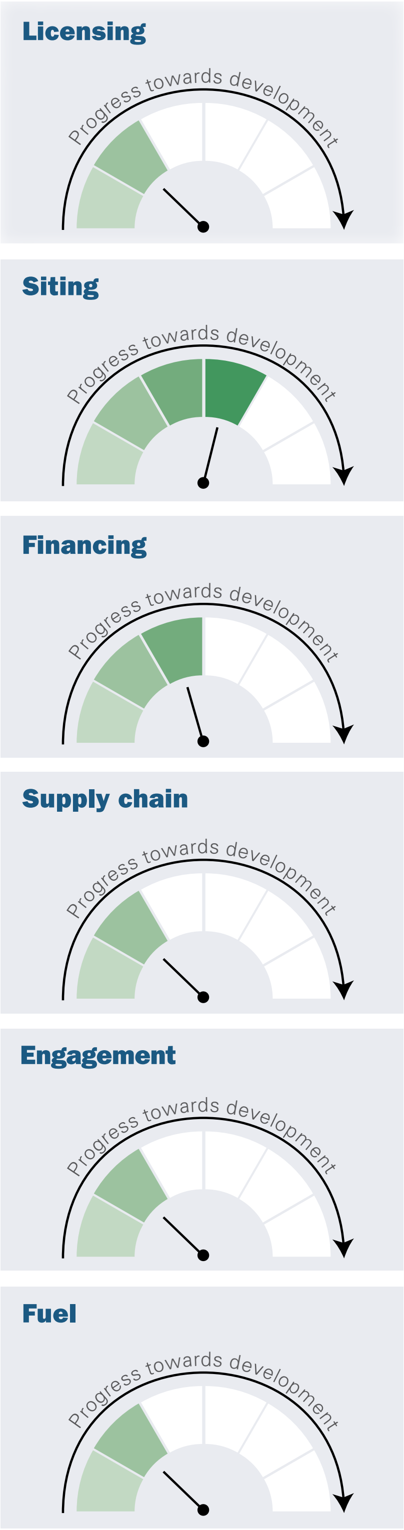
Fuel

NuScale Power fuel is similar to fuel used in operating commercial nuclear plants and will not require further development.

In 2015, NuScale Power and Areva signed a contract to manufacture the fuel assemblies for the initial core and reloads.

Aurora





★ Active in multiple jurisdictions or countries.

Design organisation	OKLO
Thermal Power (MWth)	4
Outlet Temperature (°C)	500
Spectrum (thermal/fast)	Fast
Fuel type	Metallic U-Zr alloy
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of Aurora's progress to deployment

Licensing

OKLO's Aurora reactor design is engaged in pre-licensing activities with the US Nuclear Regulatory Commission (NRC).

In 2022, OKLO submitted a Licensing Project Plan (LPP) to the US NRC to prepare for its Combined License Application (COLA).

Siting

OKLO has received a permit from the US Department of Energy (DOE) to build a First-of-a-Kind Aurora reactor at the Idaho National Laboratory. The company still needs to meet insurance, permitting and other requirements before construction can begin and will need to return the site to its original condition at the end of the project.

Financing

OKLO has benefited from more than five sources of funding, including cost-share awards from the US DOE Advanced Research Projects Agency – Energy (ARPA-E) programmes and the Technology Commercialization Fund.

Supply chain

OKLO was granted vouchers through the Gateway for Accelerated Innovation in Nuclear (GAIN) programme to access some US national laboratory capabilities at no cost. The company has also signed an agreement with Argonne National Laboratory to work towards commercialisation of advanced fuel recycling technology.

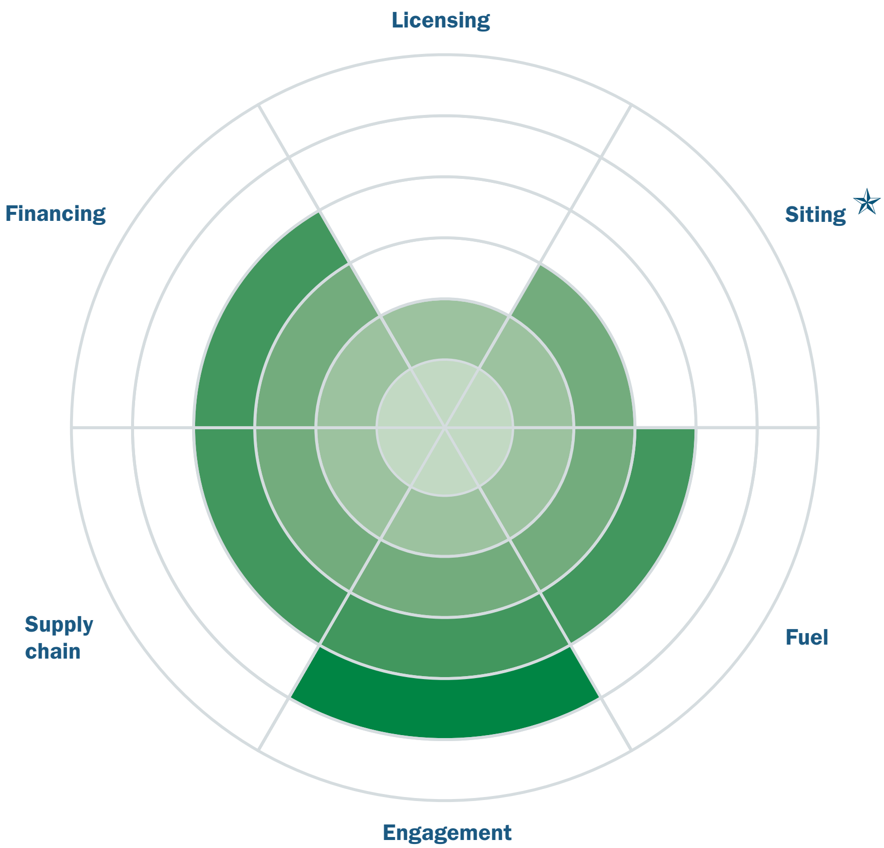
Engagement

OKLO has signed a 20-year commercial partnership with Compass Mining to power Bitcoin mining machines.

Fuel

HALEU is a technically proven fuel type; however, there is presently no commercial supply from OECD countries. OKLO fabricated and demonstrated prototypes of its metallic fuel with the Idaho National Laboratory in 2019. In 2021, the company signed a non-binding letter of intent with Centrus to co-operate in the deployment of a HALEU facility.

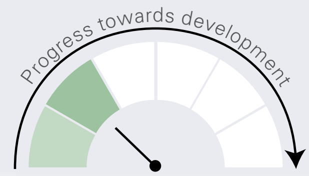
Rolls-Royce SMR



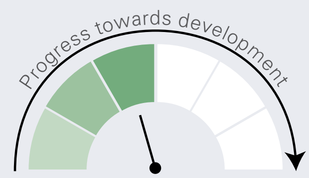
✭ Active in multiple jurisdictions or countries.

Design organisation	Rolls-Royce SMR Ltd
Thermal Power (MWth)	1 358
Outlet Temperature (°C)	325
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Licensing



Siting ✭



Financing

Supply chain

Engagement

Fuel

Assessment of Rolls-Royce SMR's progress to deployment

Licensing

The design certification application for the Rolls-Royce SMR has been submitted to the UK Office for Nuclear Regulation (ONR) for review, as the design has entered Step 1 of the ONR Generic Design Assessment (GDA) process.

Siting ✭

The UK Nuclear Decommissioning Authority (NDA) is exploring opportunities to use NDA land to support the UK government's energy security strategy, including by possibly siting a Rolls-Royce SMR on NDA land. Rolls-Royce SMR Ltd has shortlisted four potential sites owned by the NDA, including sites at Wylfa and Trawsfynydd, which have been identified to the UK ONR as options through the GDA. The Rolls-Royce SMR was also selected as the preferred technology by the Solway Community Power Company, which intends to deploy an SMR in West Cumbria, UK. Fermi Energy has shortlisted the Rolls-Royce SMR through a targeted call for tenders related to the potential deployment of an SMR in Estonia, with the final technology decision expected in 2023.

Financing

Rolls-Royce SMR has attracted more than GBP 500 million (USD 688 million) in combined public and private sector funding to support its development and deployment. The UK Government has supported the Rolls-Royce SMR, including with GBP 210 million (USD 289 million) in funding through the UK Research and Innovation funding. Private sector financing has been supplied by equity investments by partners in the Rolls-Royce SMR Ltd business. Specifically, Rolls-Royce Group, BNF Resources, Exelon Generation, and the Qatar Investment Authority have raised nearly GBP 300 million (USD 413 million) in combined funding for the Rolls-Royce SMR.

Supply chain

Rolls-Royce SMR Ltd aims to develop and own factories to build the SMR modules in order to maintain control of its supply chain, and to establish themselves as a turnkey engineering, manufacturing, and assembly supplier for the entire Rolls-Royce SMR power plant. Rolls-Royce SMR Ltd is currently working to select a suitable site for their first factory that will be used to build SMR modules. Rolls-Royce SMR Ltd has several notable agreements in place for products and services relevant to the development of the Rolls-Royce SMR. SNC-Lavalin's UK team is supporting work related to advancing the design and delivery aspects of the SMR. They also have contracts in place for specific materials, including a GBP 3.7 million (USD 5.1 million) contract with Sheffield Forgemasters.

Engagement

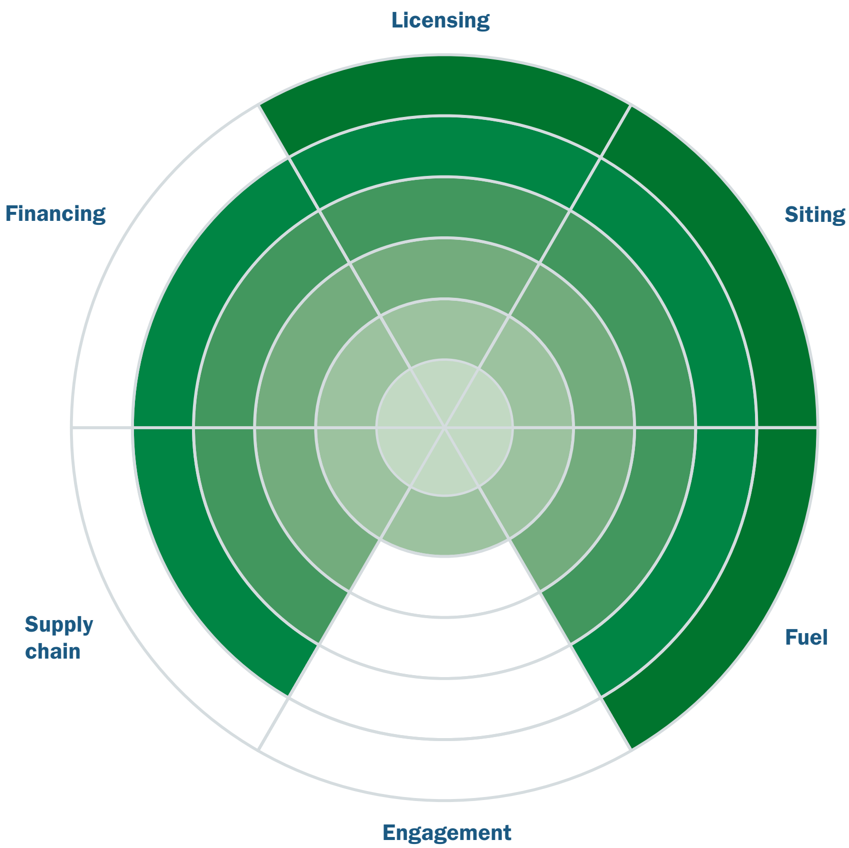
Rolls-Royce SMR Ltd is engaging with partners in the UK to build relationships in support of deploying the Rolls-Royce SMR, and opened their headquarters in Manchester. They have received notable endorsements from officials in the UK Government for the development of this SMR, and from the Greater Manchester Investment Authority. Rolls-Royce SMR Ltd is also working with stakeholders in local jurisdictions to explore sites to establish a factory to build SMR modules. Rolls-Royce SMR Ltd is working with relevant stakeholders to explore potential deployment of the Rolls-Royce SMR. Specifically, there are Memoranda of Understandings in place for this purpose with ČEZ in the Czech Republic, ULC-Energy in the Netherlands, Fermi Energia in Estonia, EUAS International ICC in Turkey, and the Jordan Atomic Energy Commission in Jordan.

Fuel

The Rolls-Royce SMR utilises fuel that is the current industry standard for water-cooled reactor technologies that are similar in design. Given this, there are no barriers expected in the fuel supply chain for this SMR.

Note: The exchange rate applied is the currency relevant average for the year 2021. In this case, the price of GBP 0.727 equals the price of USD 1.000.

KLT-40S



★ Active in multiple jurisdictions or countries.

Design organisation	Rosatom
Thermal Power (MWth)	150
Outlet Temperature (°C)	316
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	HALEU

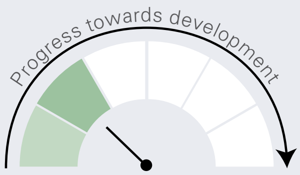
Licensing

Siting

Financing

Supply chain

Engagement



Fuel

Assessment of KLT-40S's progress to deployment

Licensing

The *Akademik Lomonosov* floating nuclear power plant powered by two KLT-40S units entered commercial operation in May 2020. Rostekhnadzor issued in 2019 a 10-year licence to Rosenergoatom to operate the *Akademik Lomonosov* until 2029.

Siting

The *Akademik Lomonosov* is currently docked in the city of Pevek, where it provides electricity and heat to the isolated grid of the Chaun-Bilibino energy center of Chukotka. The Chukotka Autonomous District administration announced the siting studies to host future floating nuclear power plants back in 2010.

Financing

The *Akademik Lomonosov* has been financed by the Committee of the Russian Federation Budget RF (17%) and JSC) Energoatom Concern (83%).

Supply chain

Substantial supply chain capabilities have been developed for the KLT-40S, as it builds on the Russian KLT-40M technology which is currently used to power ice-breakers. Several organisations have contributed to the construction of the *Akademik Lomonosov* floating nuclear power plant and its KLT-40S reactor units: Rosenergoatom as owner and operator; Afrikantov OKB Mechanical Engineering as chief designer and package supplier; Kurchatov Institute as scientific supervisor of the reactor design; TsKB "Iceberg" as general designer; Krylov Shipbuilding Research Institute as scientific supervisor; Baltiysky Zavod as builder of the floating nuclear power plant; Atomenergo as the designer of coastal and hydraulic engineering facilities; and Kalouzhsky Turbine Plant as the general designer and supplier of the turbine set.

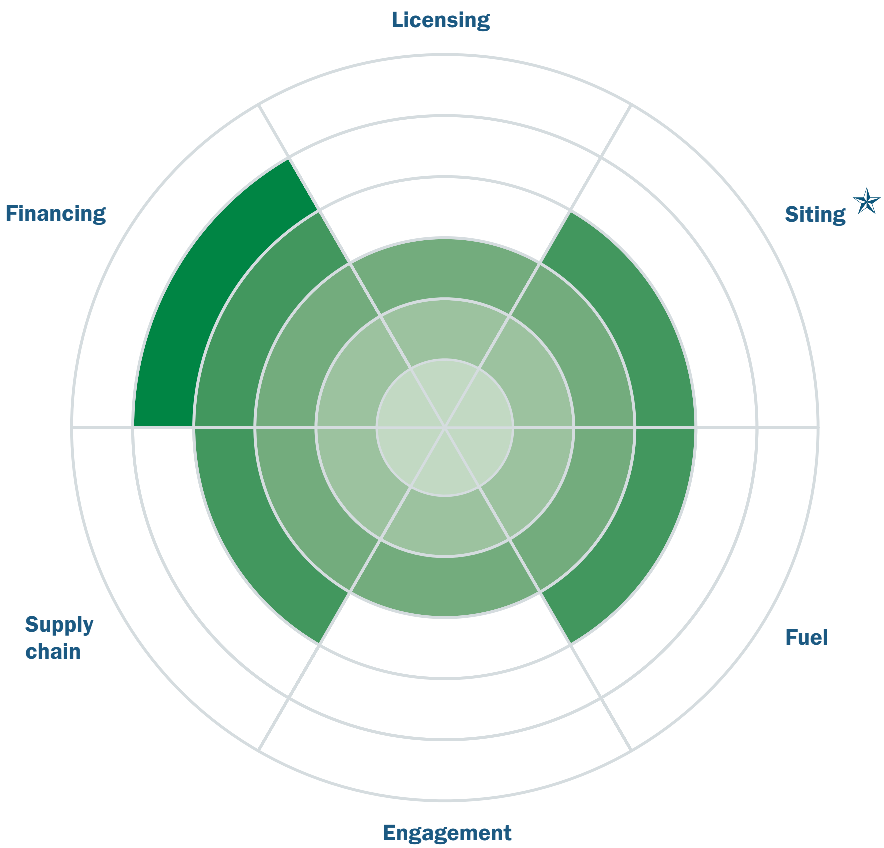
Engagement

Public hearings were led by Rosenergoatom at Pevek.

Fuel

The KLT-40S design is based on the existing KLT-40M technology which is currently used to power ice-breakers, and therefore relies on well-established fuel supply chains. In particular, the fuel for the *Akademik Lomonosov* was produced by Mashinostroitelny Zavod (MSZ), a subsidiary of the Russian fuel manufacturer TVEL.

RITM-200N



★ Active in multiple jurisdictions or countries.

Design organisation	Rosatom
Thermal Power (MWth)	190
Outlet Temperature (°C)	321
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of RITM-200N's progress to deployment

Licensing

The RITM-200N SMR by Rosatom, Russia's State Atomic Energy Corporation, is a land-based SMR in the RITM-200 series. Six RITM-200 units are already licensed and in operation on dual-draft ice-breakers - two on the Arktika icebreaker ship, two on Sibir, and two on Ural. Licensing for the land-based RITM-200N will benefit from past-precedence from the licensing and operation of the RITM-200 SMRs on ice-breakers. A licence to construct the RITM-200N in the Ust-Yansky District of the Republic of Sakha (Yakutia) in northern Russia is presently under consideration.

Siting ☆

In 2019, the Republic of Sakha and Rosatom signed an agreement of intent to build the first land-based a RITM-200N SMR in Yakutia. In 2020, the two parties reached a formal agreement to proceed with the construction.

Financing

In 2021, the Russian government approved a project cost of RUB 506 billion (USD 6.9 billion) for new nuclear technologies by 2030, including the construction of the land-based RITM-200N in Yakutia. In 2022, the Russian government announced that the government would invest RUB 100 billion (USD 1.4 billion) in new nuclear technologies, including RITM-200N projects. Rosatom has also secured an off-take agreement for up to 50 MW as well as access to the Far Eastern Concession, a major Russian state investment mechanism, for the Yakutia project. In addition, Rosatom has an agreement to provide power to the Public Joint Stock Company (PJSC) Seligdar, a Russian mining company, from the land-based RITM-200N project for gold mining operations in Yakutia.

Supply chain

Substantial supply chain capabilities for the land-based RITM-200N SMR have been developed with the construction of several RITM-200 units for ice-breakers. OKBM Afrikantov JSC, an engineering subsidiary of Rosatom, acts as a designer and a single-source manufacturer for RITM-200N units. For the RITM-200N in Yakutia, Rusatom Overseas is taking an expanded role, acting as developer and builder. Rosenergoatom will be the operator of the RITM-200N units.

Engagement

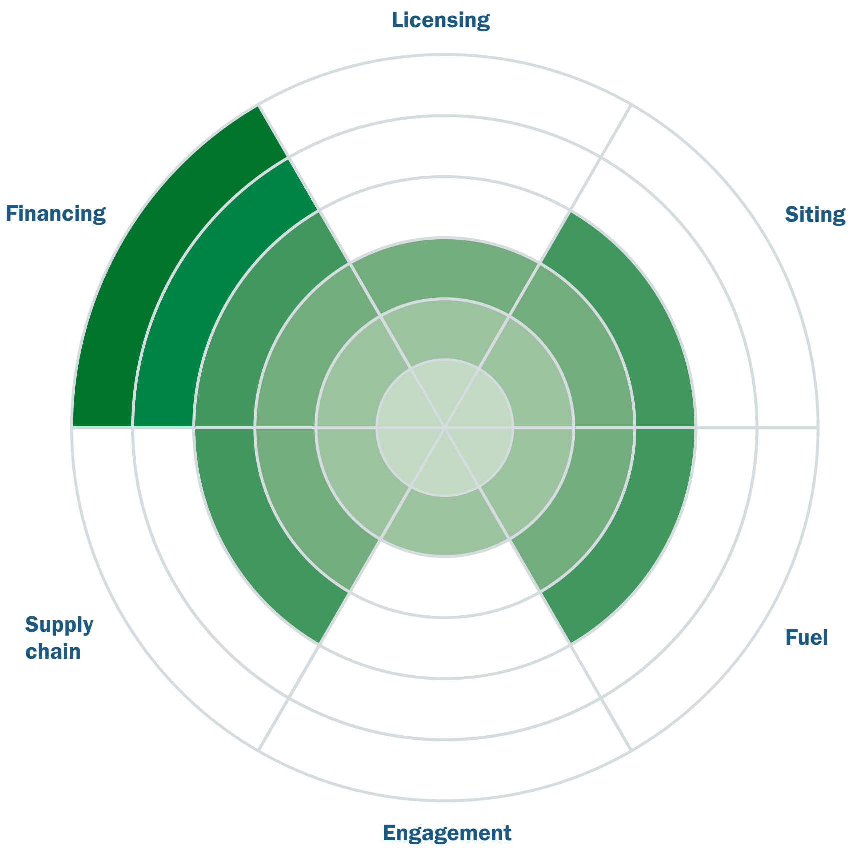
In 2021, public hearings were held in Yakutia for the land-based RITM-200N project. The Ministry for the Development of the Russian Far East has also established a working group to oversee the implementation of the project, with representatives from: Rusatom Overseas; the Ministry of Economic Development; the Ministry of Energy; and Joint Stock Company VEB Infrastructure. Additionally, Rosatom has signed a memorandum of co-operation with the Kyrgyzstan Republic on the construction of RITM-200N reactors in Kyrgyzstan.

Fuel

The land-based RITM-200N shares aspects of the same fuel supply chain with the 200 design, which is already operational on the Arktika, Sibir, and Ural ice-breakers. Regarding the RITM-200N fuel design, Elemash Machine-building plant, a fabrication facility of Russian fuel manufacturer TVEL, produced an experimental nuclear fuel assembly for the land-based RITM-200N to be constructed in Yakutia. Elemash has announced that they will start fabrication of the first fuel assemblies in 2025, with the intent to produce the core for 2026.

Note: The exchange rate applied is the currency relevant average for the year 2021 given. In this case, the price of RUB 73.654 equals the price of USD 1.000.

RITM-200S



★ Active in multiple jurisdictions or countries.

Design organisation	Rosatom
Thermal Power (MWth)	198
Outlet Temperature (°C)	318
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of RITM-200S's progress to deployment

Licensing

The RITM-200S SMR by Rosatom, Russia's State Atomic Energy Corporation, is a marine-based SMR in the RITM-200 series. Six RITM-200 units are already licensed and in operation on dual-draft ice-breakers - two on the Arktika icebreaker ship, two on Sibir, and two on Ural. Licensing for the marine-based RITM-200S will benefit from past-precedence from the licensing and operation of the RITM-200 SMRs on ice-breakers. A licence to construct the RITM-200S for deployment in Cape Nagleynyn in north-eastern Russia is presently under consideration.

Siting

In 2021, the Russian government concluded a competitive selection process to supply heat and power to the Baimskaya copper mine facility, in Cape Nagleynyn. The top two options were: a floating liquefied natural gas power plant; and a proposal by Rosatom to deploy at least six marine-based RITM-200S units. The Russian government selected the marine-based RITM-200S option, with the first unit expected to be deployed by 2027. FSUE Atomflot, Rosatom's owner and operator of floating nuclear power units, and GDK Baimskaya, the operator of a mine owned by Kaz Minerals (one of the largest copper producers in Kazakhstan), signed a preliminary agreement for FSUE Atomflot to supply power to GDK Baimskaya with marine-based RITM-200S SMRs.

Financing

In 2021, the Russian government approved a project cost of RUB 506 billion (USD 6.9 billion) for new nuclear technologies by 2030, including the construction of the marine-based RITM-200S in Cape Nagleynyn. In 2022, the Russian government announced that the government would invest RUB 100 billion (USD 1.4 billion) in new nuclear technologies, including multiple RITM-200S projects. Rosatom has signed an agreement with GDK Baimskaya for a long-term take-or-pay contract as part of the Cape Nagleynyn floating nuclear power plant project.

Supply chain

Substantial supply chain capabilities for the marine-based RITM-200S SMR have been developed with the construction of several RITM-200 units for ice-breakers. Atomenergomash, a machinery construction division of Rosatom, and OKBM Afrikantov JSC, an engineering subsidiary of Rosatom, started construction of equipment for the RITM-200S in 2022. In 2021, Rosatom signed an agreement for China to provide at least one hull for the marine-based RITM-200S in Cape Nagleynyn. A keel-laying ceremony was held at Wison Heavy Industries in Nantong, China, in August 2022.

Engagement

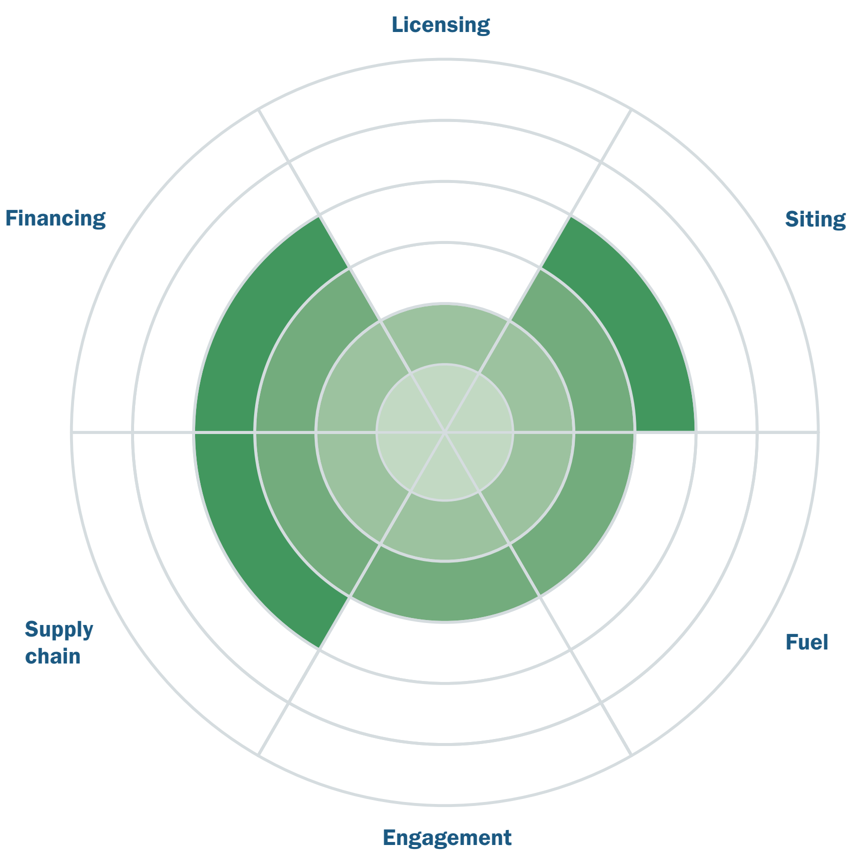
The local district administration of Cape Nagleynyn announced the start of public consultations for the marine-based RITM-200S floating nuclear power plant project in 2022.

Fuel

The marine-based RITM-200S shares aspects of the same fuel supply chain with the RITM-200 design, which is already operational on the Arktika, Sibir, and Ural ice-breakers. Regarding the RITM-200S fuel design, the fuel elements were developed by specialists of the Bochvar Research Institute of Inorganic Materials, part of the Russian fuel manufacturer TVEL. In December 2022, Rosatom finalised the technical design of the core of the RITM-200S reactor.

Note: The exchange rate applied is the currency relevant average for year 2021 given. In this case, the price of RUB 73.654 equals the price of USD 1.000.

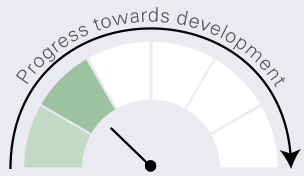
Natrium



☆ Active in multiple jurisdictions or countries.

Design organisation	TerraPower
Thermal Power (MWth)	840
Outlet Temperature (°C)	500
Spectrum (thermal/fast)	Fast
Fuel type	Metallic U-Zr alloy
Fuel (LEU/HALEU/HEU)	HALEU

Licensing

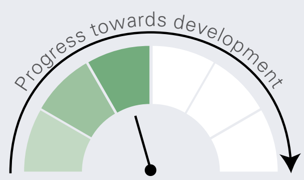


Siting

Financing

Supply chain

Engagement



Fuel

Assessment of Natrium's progress to deployment

Licensing

Natrium technology is undergoing pre-licensing activities with the US Nuclear Regulatory Commission. Several white papers and topical reports have been submitted to support its safety case and regulatory feedback has been received for some of them. The remaining reports are still under review.

Siting

PacificCorp has chosen Natrium technology to replace the retiring coal-fired Naughton Power Plant in Kemmerer, Wyoming. The company anticipates that early construction activities will begin in 2024.

Financing

TerraPower was selected as one of the two awardees of the US Department of Energy Advanced Reactor Demonstration Program (ARDP) in October 2020 and received USD 80 million in initial funding. The ARDP currently authorised USD 1.23 billion across seven years for the Natrium nuclear reactor demonstration. The Infrastructure Investment and Job Act (signed into law in November 2021) officially appropriates funding for the rest of the programme terms for the selected awardees. TerraPower has also secured over USD 1 billion in funding for Natrium through one of the largest private capital raises in the advanced nuclear industry.

Supply chain

Natrium is expanding its supply chain with various strategic partnerships involving: engineering, procurement and construction companies, such as Betchel; academia, including North Carolina State, Oregon State and the University of Wisconsin; as well as Idaho and Argonne National Laboratories. Under a partnership agreement with TerraPower, Energy Northwest has agreed to provide licensing and operating experience to support the development of the Natrium.

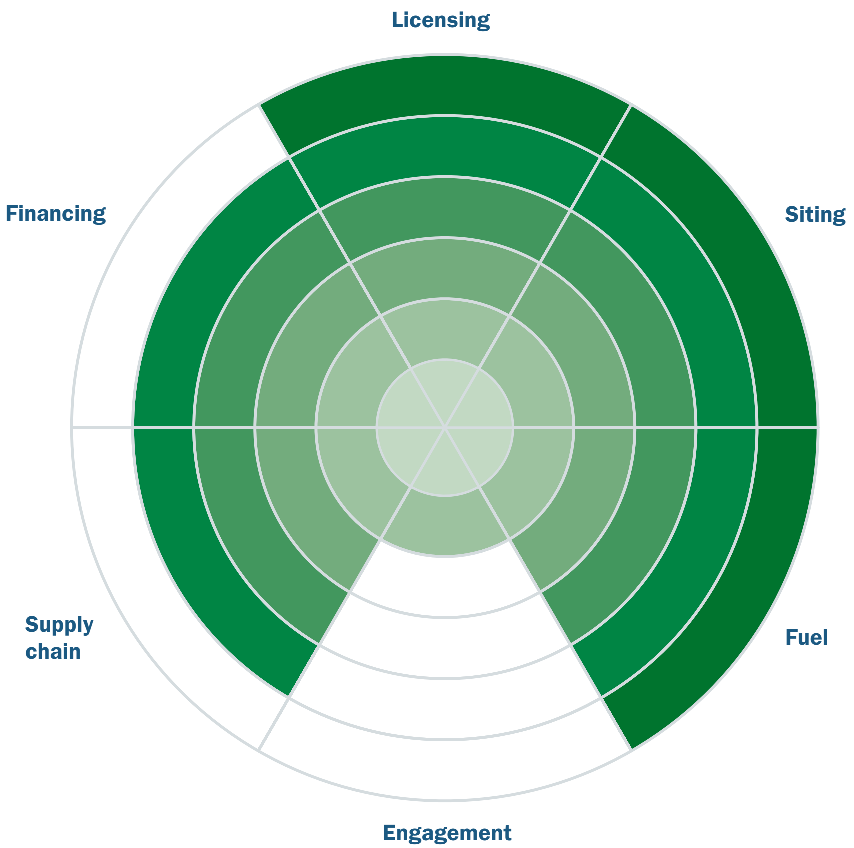
Engagement

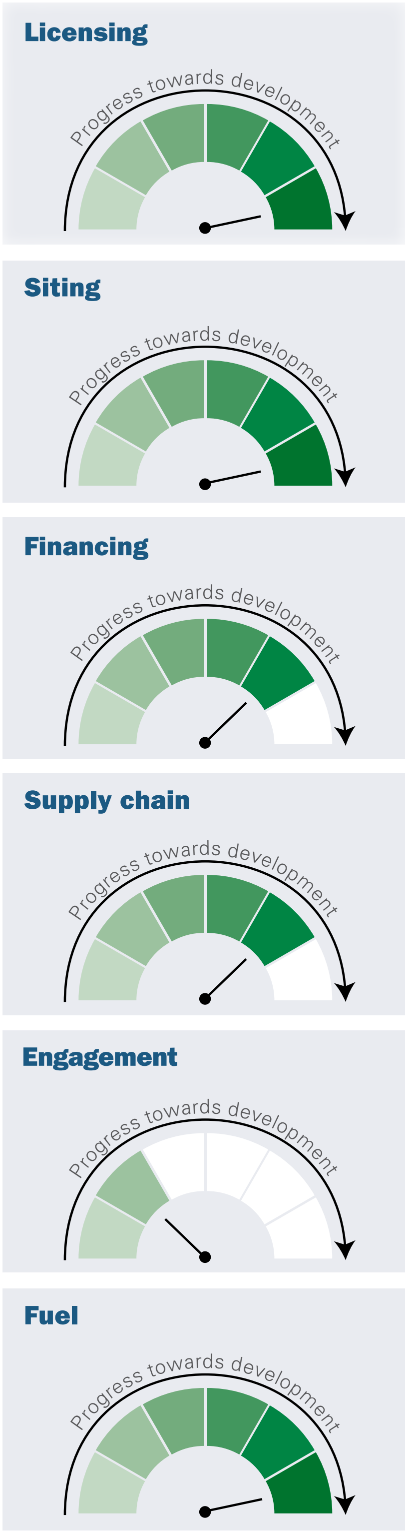
TerraPower has formed an advisory board comprising representatives from around ten US utilities. The company has also signed memoranda of understandings with the Japan Atomic Energy Agency (JAEA), Mitsubishi Heavy Industries and Mitsubishi fast breeder reactor (FBR) Systems, and South Korea SK Group to collaborate on the development of fast reactor technology. Additionally, TerraPower has received endorsements from the Wyoming Governor Mark Gordon, Wyoming President of the Senate Dan Dockstader and Bill Thek, the Mayor of Kemmerer, Wyoming.

Fuel

HALEU is a technically proven fuel type; however, there is presently no commercial supply from OECD countries. Global Nuclear Fuel-Americas (GNF-A) and TerraPower have announced a binding agreement to build a Natrium fuel fabrication facility at the site of GNF-A's existing plant near Wilmington, North Carolina.

HTR-PM





★ Active in multiple jurisdictions or countries.

Design organisation	INET
Thermal Power (MWth)	500
Outlet Temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO pebble
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of HTR-PM's progress to deployment

Licensing

The HTR-PM reactor is fully licensed. It is operating and connected to the electrical grid.

Siting

The HTR-PM is connected to the electrical grid as Shidaowan Nuclear Power Plant in Shandong province.

Financing

The First-of-a-Kind (FOAK) HTR-PM is operating and has been fully financed.

Supply chain

The HTR-PM is owned by a consortium composed of China Huanend, China Nuclear Engineering Corporation and Tsinghua University's Institute of Nuclear and New Energy Technology. China National Nuclear Corporation (CNNC) collaborated with the consortium to provide Engineering, Procurement and Construction (EPC) services, to manufacture fuel elements and for the construction. Up to 93.4% of the equipment was manufactured domestically.

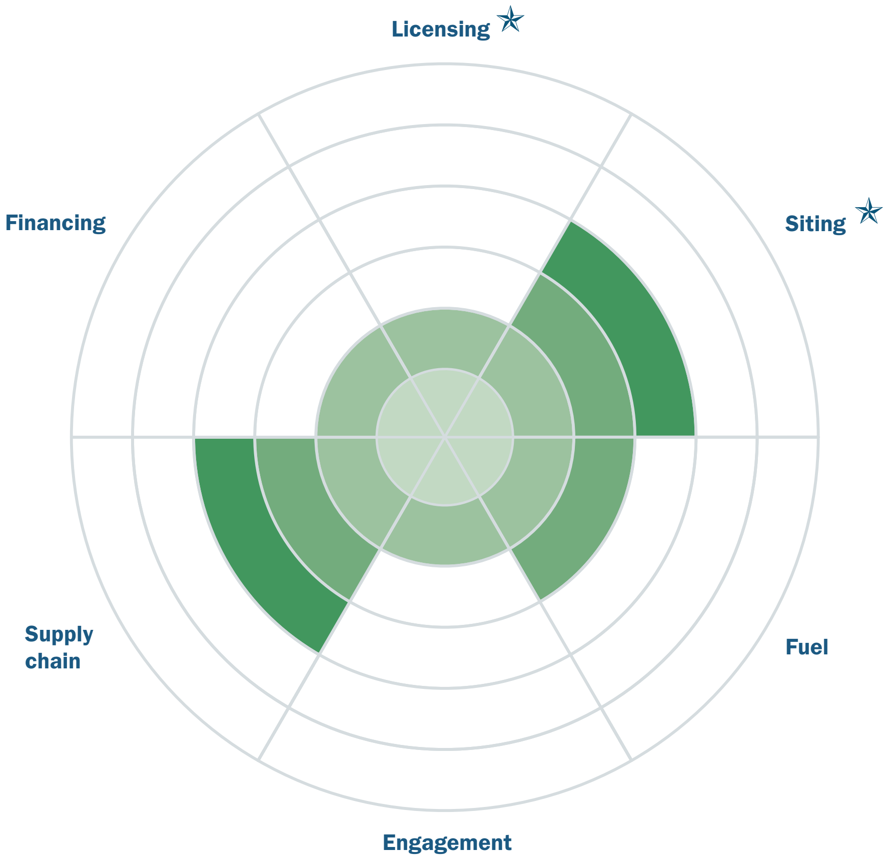
Engagement

The HTR-PM project is owned by a consortium that includes Tsinghua University's Institute of Nuclear and New Energy Technology.

Fuel

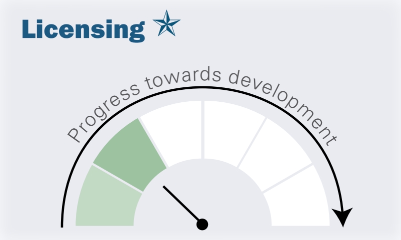
HTR-PM fuel is licensed for operation.

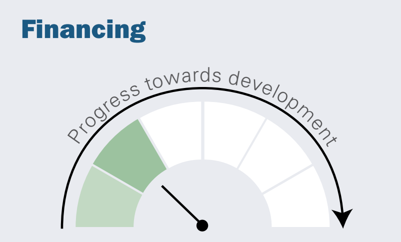
MMR

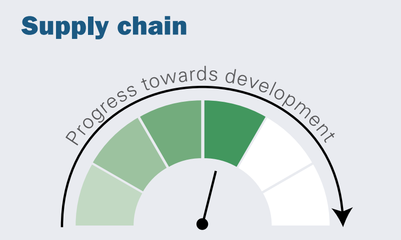


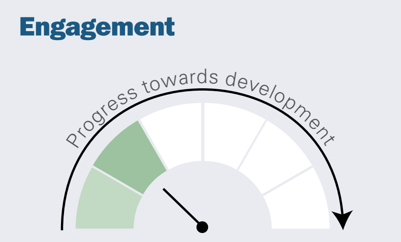
Active in multiple jurisdictions or countries.

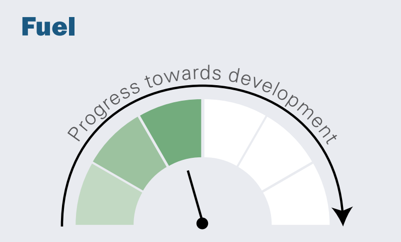
Design organisation	Ultra Safe Nuclear
Thermal Power (MWth)	15
Outlet Temperature (°C)	630
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU











Assessment of MMR's progress to deployment

Licensing ★

USNC has completed Phase 1 of the Canadian Safety Nuclear Commission's (CNSC) Pre-Licensing Vendor Design Review (VDR) process for its MMR, and the Phase 2 assessment is currently underway. Global First Power (GFP), a joint venture between USNC and Ontario Power Generation (OPG), has submitted an application to CNSC for a license to prepare the site at Canadian Nuclear Labs for construction of the MMR. In the United States, USNC is collaborating with the University of Illinois to submit a regulatory engagement plan to the US Nuclear Regulatory Commission (NRC), as well as whitepapers justifying regulatory compliance.

Siting ★

In Canada, Canadian Nuclear Labs has signed a project host agreement with GFP to co-operate on the deployment of the USNC MMR at Chalk River, Ontario, Canada. GFP and USNC have also signed a memorandum of understanding (MOU) with McMaster University in Ontario Canada to examine the feasibility of deploying the USNC MMR on the McMaster Campus. In the United States, a Letter of Intent has been submitted to the NRC to submit an application for a construction permit to deploy the MMR reactor at the University of Illinois Urbana-Champaign. Copper Valley Electric Association is also working with USNC to study the feasibility of deploying a MMR in Alaska, United States.

Financing

The MMR technology has received a financial award through the UK Government's Advanced Modular Reactor Research, Development and Demonstration programme to develop a modified design that is suited to industry needs in the UK. USNC has also attracted investment from Hyundai Engineering, who agreed to invest in USNC for the exclusive rights to engineering, procurement and construction business related to the MMR technology. The MMR at Chalk River in Canada is pursuing deployment through a joint venture between USNC and OPG, where OPG is a provincial Crown corporation supported and wholly owned by the government of Ontario.

Supply chain

Hyundai Engineering has exclusive rights for work related engineering, procurement and construction (EPC) for the MMR technology through an equity investment in USNC. USNC has secured contracts for specific services and materials in support of the MMR technology. USNC is also progressing advanced manufacturing techniques, such as 3D printing of reactor components. Through a joint venture with Ontario Power Generation, Global First Power will own and operate the MMR at the Chalk River Laboratories site in Canada.

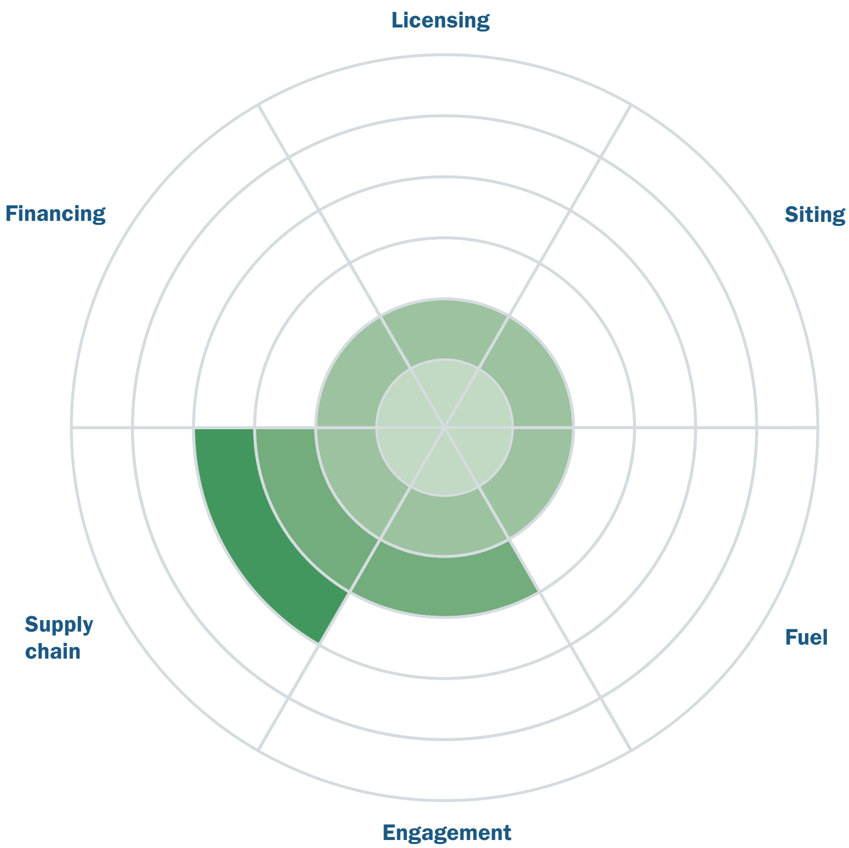
Engagement

USNC has established an advisory board to support the deployment of the MMR technology in Canada, which includes partners from industry, communities, and government – including advisors from CNSC, Canadian banks, EPCs, Atomic Energy of Canada Ltd. (AECL), CanArctic Inuit Networks – with a range of expertise. Through the Advanced Modular Reactor Research, Development and Demonstration programme in the United Kingdom, Energy Minister Greg Hands acknowledged the potential of the USNC MMR technology to support domestic priorities in the country.

Fuel

USNC announced the opening of its Pilot Fuel Manufacturing facility in Oak Ridge to produce the first fuel for testing and qualification for use in MMR. They also opened a facility in Salt Lake City to support fuel development for the MMR. USNC is also engaged in laboratory-scale production of fuel through a collaboration with Canadian Nuclear Laboratories through the Canadian Nuclear Research Initiative, as well as performance and safety analysis with work through the Nuclear Research & Consultancy Group from the Netherlands. In the United States, the University of Illinois announced that it will source MMR fuel from a US Department of Energy's existing Research Reactor Infrastructure Program, which makes fuel available for research reactors.

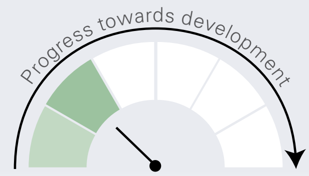
U-Battery



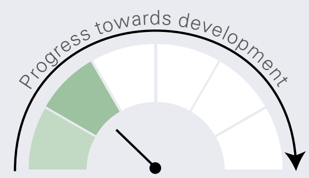
★ Active in multiple jurisdictions or countries.

Design organisation	Urenco
Thermal Power (MWth)	10
Outlet Temperature (°C)	710
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

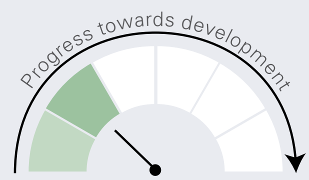
Licensing



Siting

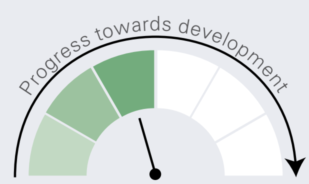


Financing

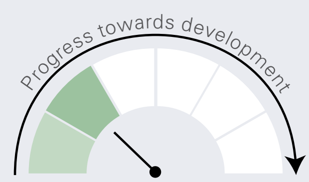


Supply chain

Engagement



Fuel



Assessment of U-Battery's progress to deployment

Licensing

U-Battery is involved in pre-licensing activities in Canada and the United Kingdom (UK). In the United Kingdom, pre-licensing involves all SMR designs involved in the first phase of the Advanced Modular Reactor (AMR) Feasibility & Development (F&D) project. In this context, the Office of Nuclear Regulation (ONR) developed regulatory criteria to advise the Department for Business, Energy & Industrial Strategy (BEIS) on the ability of the U-Battery to meet UK regulatory requirements in the future. In Canada, U-Battery has established a service agreement with the Canadian Nuclear Safety Commission (CNSC) to conduct pre-licensing activities, under the CNSC's Vendor Design Review.

Siting

U-Battery is participating in an "Invitation to Site" an SMR as a demonstration unit at a site owned by Atomic Energy of Canada Limited (AECL) and operated by Canadian Nuclear Laboratories (CNL). U-Battery has completed the pre-qualification phase, which is the first of four stages that would eventually result in a technology being selected for deployment at a CNL-operated facility.

Financing

U-Battery received around GBP 11 million (USD 15 million) in financial support from the UK Government through the AMR Research, Development and Demonstration (RD&D) programme and the AMR F&D project.

Supply chain

U-Battery reactor was originally designed by the Universities of Manchester (UK) and Delft (Netherlands). It is developed by a consortium that includes Urenco, a leading supplier of nuclear fuel worldwide, Kinetrics, and Jacobs. The consortium is supported by the UK National Nuclear Laboratory, Cavendish Nuclear, Rolls-Royce, Costain and BWXT. Urenco also signed a MOU with Bruce power to assess the feasibility of U-Battery potential deployment across Canada and the Japan Atomic Energy Agency (JAEA) for joint work on High Temperature Gas Reactor (HTGR) nuclear design. U-Battery collaborates with several foreign national laboratories, such as the Polish National Centre for Nuclear Research, the Canadian Nuclear Laboratories and JAEA to further assess U-Battery development in those countries.

Engagement

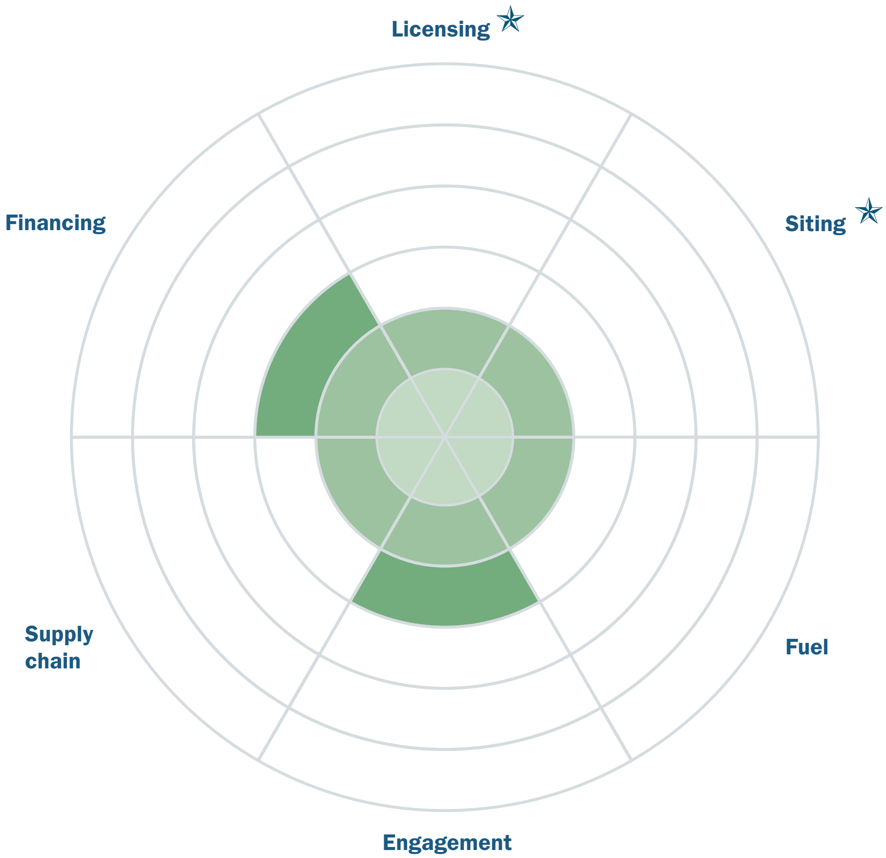
In 2022, U-Battery Development Ltd. Constructed a mock-up for stakeholders from government, academia, trade bodies, federations and industry to see, touch and walk around at Cavendish's Whetstone site in Leicestershire.

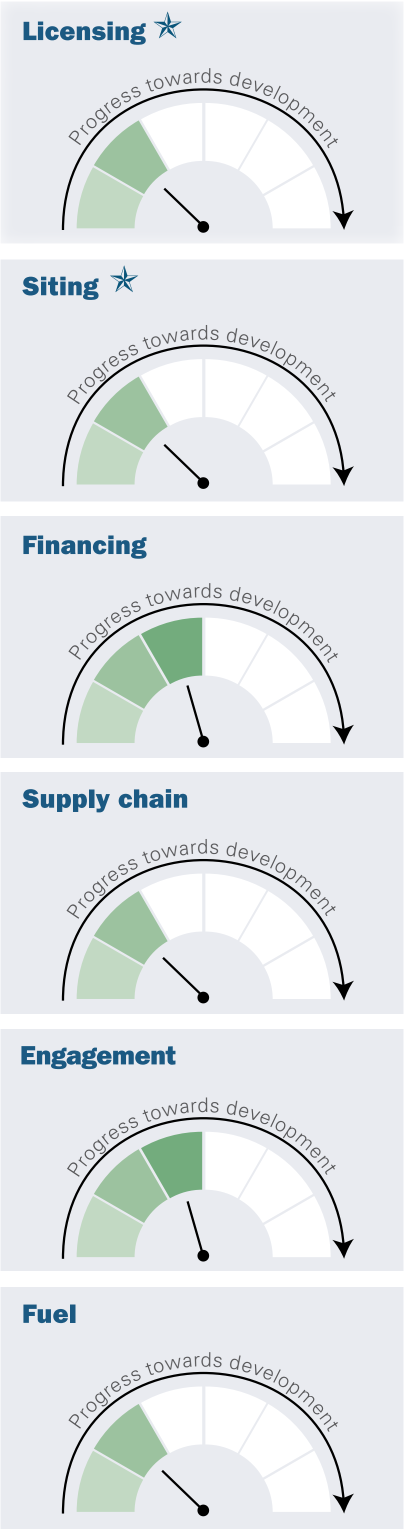
Fuel

Urenco, a leading nuclear fuel supplier worldwide, is a key member of the U-Battery consortium. No additional public announcements have been made on U-Battery fuel supply chain development.

Note: The exchange rate applied is the currency relevant average for the year 2021. In this case, the price of GBP 0.727 equals the price of USD 1.000.

eVinci





★ Active in multiple jurisdictions or countries.

Design organisation	Westinghouse Electric Company
Thermal Power (MWth)	13
Outlet Temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of eVinci's progress to deployment

Licensing ✯

Westinghouse Electric Company is engaged in pre-licensing activities for its eVinci with both the US Nuclear Regulatory Commission (NRC) and the Canadian Nuclear Safety Commission (CNSC).

Siting ✯

Westinghouse Electric Company has Memoranda of Understandings (MOU) with Pennsylvania State University for discussions on deployment in University Park, United States, and an MOU with the Canadian Saskatchewan Research Council for a project for deployment in Saskatchewan, Canada, that would include development and testing of energy use applications.

Financing

Westinghouse Electric Company has secured numerous cost-share awards from the US Department of Energy (DOE) as well as an investment from the Canadian federal government, with totals exceeding USD 100 million. Funding from the US DOE includes awards from the Industry Opportunities for Advanced Nuclear Technology Development programme, the Advanced Research Project Agency – Energy, the Advanced Research Development Program (ARDP) Energy Risk Reduction project and the Modeling Enhanced Innovations Trailblazing Nuclear Energy Reinvigoration programme. The investment from the Government of Canada was granted through Canada's Strategic Innovation Fund by the Department of Innovation, Science and Economic Development.

Supply chain

Westinghouse Electric Company is advancing collaborations with Idaho National Laboratory and Southern Company Services on many activities including the reactor's interface with the grid and remote monitoring, and qualifying its fuel.

Engagement

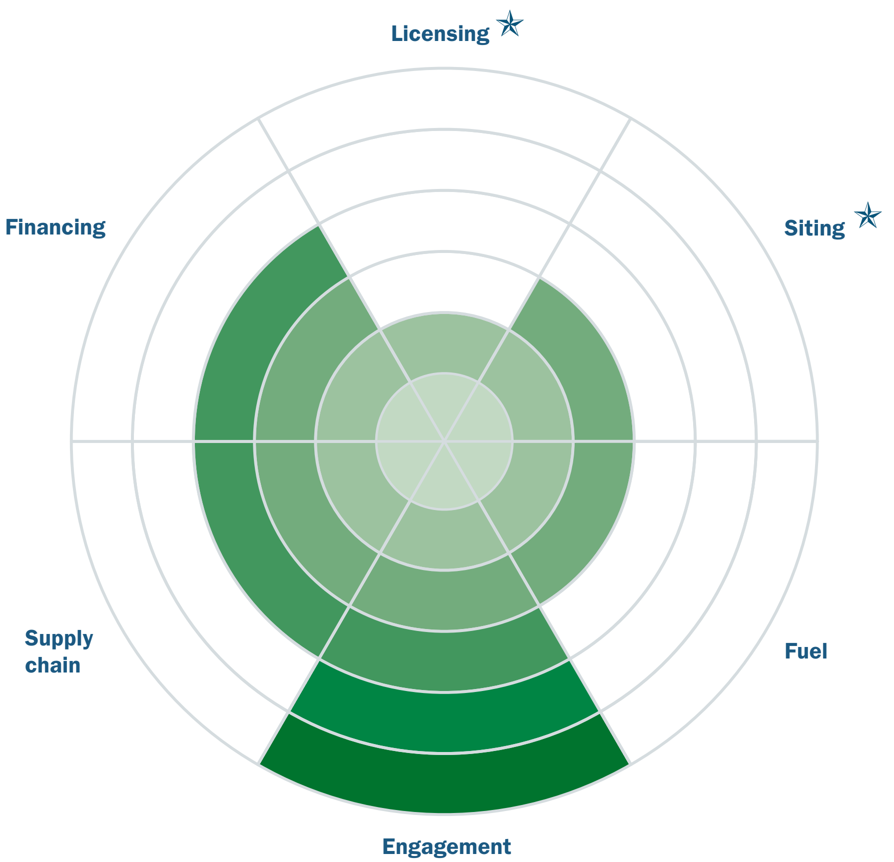
Westinghouse Electric Company signed an MOU with Pennsylvania State University to partner on research efforts focused on exploring and applying nuclear engineering and science innovations to societal needs which includes discussing the use of deploying eVinci in a safe and sustainable way. Westinghouse Electric Company has also signed MOUs with Bruce Power to pursue applications of Westinghouse Electric Company's eVinci within Canada and with Saskatchewan Research Council to advance the eVinci in Saskatchewan.

Fuel

HALEU is a technically proven fuel type; however, there is presently no commercial supply from OECD countries. Additionally, TRISO fuel, or TRi-structural ISOtropic fuel, has been tested since 1960 in US national laboratories.

Westinghouse Electric Company is collaborating with Urenco on a Pre-Front End Engineering Design study on TRISO fuel.

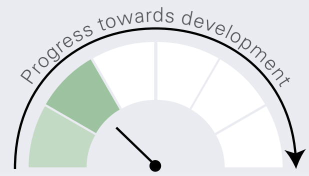
Xe-100



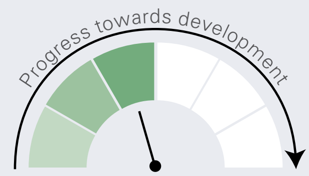
★ Active in multiple jurisdictions or countries.

Design organisation	X-energy
Thermal Power (MWth)	200
Outlet Temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO-X pebble
Fuel (LEU/HALEU/HEU)	HALEU

Licensing ★



Siting ★



Financing

Supply chain

Engagement

Fuel

Assessment of Xe-100's progress to deployment

Licensing ✯

The Xe-100 reactor is undergoing pre-licensing review by both the US Nuclear Regulatory Commission (NRC) and the Canadian Nuclear Safety Commission (CNSC). Additionally, the NRC and the CNSC have agreed to co-ordinate their reviews.

Siting ✯

Xe-100 is shortlisted by Energy Northwest for their nuclear-licensed site in Richland in Washington. X-energy is also partnered with the Maryland Energy Association to investigate repowering their Maryland coal site, and with Dow Chemical to investigate supplying heat and power to one of their industrial plants. Xe-100 has also been selected as the SMR of choice for further assessment of potential development by Grant County Public Utility District (PUD).

Financing

X-energy was selected as one of the two awardees of the US DOE Advanced Reactor Demonstration Program (ARDP) in October 2020 and received USD 80 million in initial funding. The ARDP currently authorised USD 1.23 billion across seven years for X-energy nuclear reactor demonstration. The Infrastructure Investment and Job Act (signed into law in November 2021) officially appropriates funding for the rest of the programme terms for the selected awardees. X-energy has also received slightly less than USD 6 million under the Advanced Research Projects Agency- Energy (ARPA-E) framework for its digital twin project that ends in April 2023. X-energy secured an equity stake deal with Dow Chemical in August 2022.

Supply chain

X-energy selected Zachry Group, Day & Zimmerman and Burns & McDonnell as constructors and contracted Doosan to perform design studies. They have agreements with Ontario Power Generation (OPG), Southern Nuclear, Cavendish Nuclear and Kinectrics to explore Xe-100 deployment. X-energy also has agreements with Amsted Graphite to supply nuclear graphite and with SIMSA to explore supply chain development in Saskatchewan.

Engagement

In Canada, X-energy signed Memoranda of Understanding (MOU) with First Nations Power Authority (FNPA), Millwright Regional Council of Ontario, Building Trades of Alberta. In the United States, X-energy signed MOUs with Energy Northwest and the Grant County PUD. X-energy also has an MOU with the Jordan Atomic Energy Commission. These MOUs cover different activities, from increasing public awareness for the Xe-100, to collaborating and sharing resources for siting, building and operating the Xe-100 reactor at an existing Energy Northwest site near Richland, USA. X-energy is also collaborating with OPG, Dow Chemical, Maryland Energy Administration and Frostburg State University to study the potential for supplying heat and power to an industrial plant and to investigate retrofitting a fossil fuel site.

Fuel

HALEU is a technically proven fuel type; however, there is presently no commercial supply from OECD countries. TRISO fuel, or TRi-structural ISOtropic fuel, has been tested since 1960 in US national laboratories. The Xe-100 reactor is designed to use TRISO-X Pebble fuel. X-energy is collaborating with partners – MIT, Sargent & Lundy, Centrus and others – to design, produce and license TRISO-X Pebble fuel. In 2022, X-energy selected Horizon Center Industrial Park in Oak Ridge as the site for its TRISO-X Fuel Fabrication Facility (TF3), which is scheduled for commissioning and start-up in 2025. The NRC is currently reviewing an Xe-100 topical report on TRISO-X Pebble Fuel Qualification Methodology.

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The NEA Small Modular Reactor Dashboard

All low-carbon solutions will be required to achieve the world's net zero targets. Nuclear energy has a role to play in meeting this need. A wave of innovation in small modular reactors (SMRs) is advancing quickly with the potential to help decarbonise hard-to-abate sectors. Progress is real and is positioned to accelerate pathways to net zero. SMRs could replace coal on-grid, fossil fuel cogeneration of heat and power for heavy industry, diesel at off-grid mines, as well as producing hydrogen and synthetic fuels.

Looking beyond technical feasibility, The NEA SMR Dashboard defines new criteria for assessing real progress in six additional dimensions of readiness: licensing, siting, financing, supply chain, engagement, and fuel. This first edition tracks the progress of 21 SMRs around the world.

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