The NEA Small Modular Reactor Dashboard: Second Edition

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Nuclear Technology Development and Economics

The NEA Small Modular Reactor Dashboard: Second Edition

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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 Small Modular Reactor Dashboard*

When completing the assessments for the *NEA SMR Dashboard: Second Edition*, 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-edition2-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 made 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 detailed in Annex 1 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

This decade has proved to be a vital juncture in the history of commercial nuclear energy. In the face of the imperative in most countries to drive carbon emissions to net zero by mid-century, many are turning to new nuclear power capacity as an important component of their energy futures. These decisions are spurred by global concerns about energy security and the growing need to provide reliable, cost-effective energy to power needs such as the data centres growing around the world and carbon-free industrial processes. Added to these requirements are needs of emerging economies in Africa, the Middle East, Asia and elsewhere to supply energy for economic development and growth for rapidly expanding populations. The energy challenge will be one of the defining characteristics of this era.

Fortunately, just as these needs have reached the forefront of government leaders, innovation in the nuclear sector is coming to fruition. Technological advancements that have been confined to academia and laboratories, novel concepts from start-ups and entrepreneurs and new thinking from traditional vendors are converging to provide new approaches to harness fission energy to serve markets and needs that would have been scarcely considered even a decade prior.

This second edition of the *NEA Small Modular Reactor (SMR) Dashboard* provides a snapshot of this critical moment in the evolution of nuclear energy. SMRs – which include light water technologies, Generation IV nuclear energy systems and microreactors – provide policymakers and the private sector with vital new tools to help achieve climate and energy security objectives by providing a versatile and scalable solution to meet the growing demand economy-wide for power generation and industrial heat production.

Progress since the publication of the inaugural volume of the *NEA SMR Dashboard* has been rapid and is accelerating, with multiple projects moving from conceptual design, licensing and siting to breaking ground on construction. There are already SMRs deployed and operating in the People's Republic of China, the Russian Federation as well as one test reactor in Japan. The past year witnessed, among other developments, the licensing of the first non-water-cooled reactor design in the United States to be approved for construction in 50 years, the selection of new sites to power heavy industry applications, the start of civil works for SMR projects in Canada and the United States, and widespread progress in other enabling areas such as financing, engagement and fuel.

This second edition of the *NEA SMR Dashboard* also offers new insight into the emerging commercial structure of the SMR industry. While experience from other industries suggests that only a limited subset of SMR designs will survive through to deployment, the *NEA SMR Dashboard* outlines the benefits of having such a diversity of designs under development. It may create opportunities to consolidate global supply chains, foster standardisation and improve the economic case for SMR deployment. The advanced materials and engineering solutions under development carry further benefits for industrial uses and applications beyond the nuclear sector.

This edition of the *NEA SMR Dashboard* also captures setbacks for multiple SMR developers, reminding decision makers in the public and private sectors of remaining challenges, particularly for SMR licensing, economic competitiveness and fuel. Waste management considerations are also critical for the successful deployment of SMRs and will be further assessed in future editions of the *NEA SMR Dashboard*.

The challenges to deploying many of these new nuclear technologies in time for the needs that face the world are not insignificant. But the opportunities and benefits to their success is vast. There is a clear need for continued and expanding government-to-government, regulator-to-regulator, public-private and business-to-business co-operation. The *NEA SMR Dashboard* highlights where gaps persist and, hopefully, spark greater efforts to close those that remain.

William D. Magwood, IV
NEA Director-General

Acknowledgements

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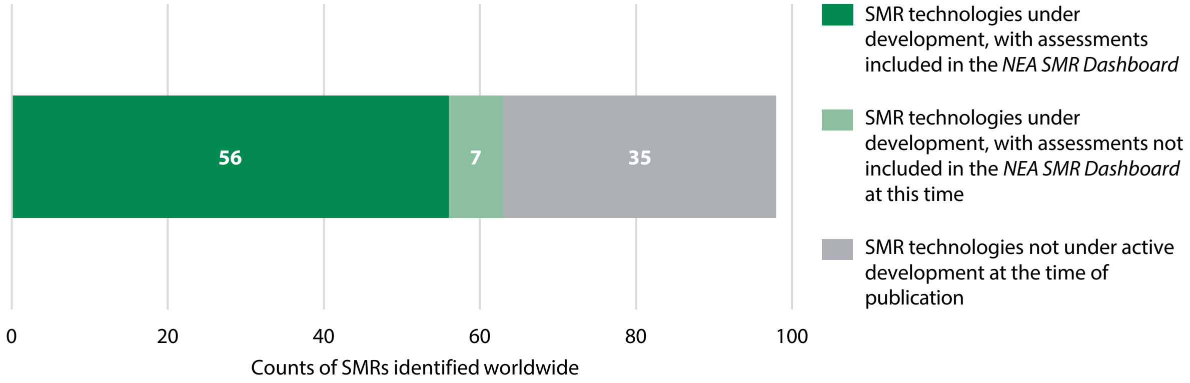
Executive summary

Small modular reactors (SMRs) are technologies capable of harnessing the energy from nuclear fission reactions to produce heat and electricity with power outputs typically smaller than 300 MWe, with some as small as 1-10 MWe. SMRs are designed for modular manufacturing, factory production, portability and scalability. They also come in a variety of configurations and temperature ranges to create heat that can be used directly, or to generate electricity to decarbonise hard-to-abate sectors. The combination of these innovations presents additional potential benefits in terms of safety, operational and deployment flexibility, economics, as well as potentially spent fuel and waste management.

The second edition of the *NEA SMR Dashboard* provides a comprehensive assessment of the progress made by SMR designers and companies worldwide. Looking beyond technical feasibility, the *NEA SMR Dashboard* assesses progress towards first-of-a-kind commercial deployment across six dimensions: licensing, siting, financing, supply chain, engagement and fuel. The *NEA SMR Dashboard* reveals substantial progress towards SMR deployment and commercialisation in NEA and non-NEA member countries, with a subset of designs in more advanced stages of commercialisation and deployment.

The first edition of the *NEA SMR Dashboard* tracked the progress of 42 SMRs worldwide and was published in two volumes. Volume I of the *NEA SMR Dashboard* was launched during the US Nuclear Regulatory Commission's (NRC) 36th Regulatory Information Conference on 13 March 2023. Volume II was published in July 2023 during the 14th Clean Energy Ministerial in Goa, India, on 19 July 2023.

Figure 1. **Count of SMRs identified worldwide**



For this second edition of the *NEA SMR Dashboard*, the NEA's comprehensive global review identified 98 SMR technologies around the world. Fifty-six SMRs are included in this complete edition of the *NEA SMR Dashboard*; these are the SMRs for which the requisite publicly available information was assessable and for which the relevant designers were willing to participate. The other 42 include approximately 7 that are under development but requested not to be included in the *SMR Dashboard* at this time but may be included in the future; the remainder include SMR technologies that are not under active development, may be without human or financial resources, or have been cancelled or paused indefinitely. The assessments in this edition of the *SMR Dashboard* are based on progress up to a cutoff date of 10 November 2023.

SMRs are part of nuclear energy's contribution to net zero energy systems by 2050 and beyond

In a special report published in 2018, the IPCC (2018) considered 90 pathways consistent with a 1.5°C scenario, i.e. pathways with emission reductions sufficient to limit average global warming to less than 1.5°C. NEA analysis found that, on average, these 90 pathways require nuclear energy to triple and to reach 1 160 gigawatts of electricity by 2050 (NEA, 2022). In 2022, the NEA concluded that this target could be achieved through a combination of the long-term operation of existing plants, large-scale new builds and SMRs. The significance of nuclear energy in pathways to net zero was emphasised at the 28th Conference of the Parties (COP28) in Dubai on 2 December 2023 when over 20 countries referenced NEA analysis and committed to tripling nuclear energy capacity by 2050, recognising the critical role of nuclear energy in achieving global net zero greenhouse gas emissions and keeping within reach the goal of limiting the temperature rise to 1.5°C.

SMRs are expected to have an increasingly important role to play in nuclear energy's contribution to net zero targets and may simultaneously contribute to alleviating energy poverty and promoting economic development and prosperity. There are already SMRs deployed and operating in China and Russia, as well as one test reactor in Japan. Other first-of-a-kind SMRs are expected to be built this decade, followed by accelerated deployment around the world during the 2030s, particularly as a source of reliable, low-carbon power generation and heat for hard-to-abate sectors. This includes notably the use of SMRs for on-grid baseload power to replace coal-fired generation, though market demand for SMRs continues to grow for other applications as well. The most promising include off-grid heat and power to replace diesel generators in remote regions for mining operations, fossil-fuel replacement for district heating and high temperature heat to replace fossil fuel cogeneration in heavy industries. Other applications include replacing fossil fuels in cogeneration for ammonia and potash production for the fertiliser industry; hydrogen production for synthetic fuels and clean steel production; as well as marine propulsion to replace heavy-fuel oil for merchant shipping.

SMRs are driving innovation in the nuclear sector

The sector is witnessing significant innovation internationally. This includes SMRs at various stages of development, from fundamental research on new concepts to commercial deployment and operation. The 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. It also includes SMRs in a variety of configurations – with land-based, multi-module, marine-based and transportable designs. These innovations incorporate new materials, a range of coolants and, in a number of cases, innovative fuels. This is in turn expected to lead to the deployment of a range of SMRs of different sizes, with a range of outlet temperatures, and new attributes.

The *NEA SMR Dashboard* as a tool to track progress

The *NEA SMR Dashboard* provides authoritative assessments of the progress of SMRs globally, highlighting substantial developments towards first-of-a-kind deployment in a rapidly evolving field. While the technical features of the different SMR technologies may be well understood, gaps remain in understanding the speed with which they are approaching widespread commercialisation. Clear insight into the early deployment phase of SMRs is critical for building confidence in the technology and identifying potential challenges that may necessitate targeted policy action. The *NEA SMR Dashboard* addresses this need by looking beyond the technology readiness level to assess progress across six additional enabling conditions based on objective criteria:

- **Licensing**: The criteria for assessing progress in licensing closely follow international licensing norms, including pre-licensing interactions with regulators, design approval, construction and the issuance of operating licences. A bonus is given to SMRs with licensing activities in multiple jurisdictions at any level.
- **Siting**: The criteria for assessing progress in siting reflects decisions by site owners and considers licensing readiness of sites for SMR construction. A bonus is given to SMR technologies making progress at multiple sites at any level.
- **Financing**: The criteria for the financing assessments reflect both public announcements from reactor designers and financing reports from publicly available sources.

- **Supply chain**: The criteria for assessing progress in supply chain readiness consider increasing levels of commitment reflected in memoranda of understanding, binding contracts, and formal partnerships, joint ventures or consortia with suppliers or engineering, procurement and construction companies.
- **Engagement**: The criteria for engagement reflect the number of engagements with people and communities associated with the SMR project, evidenced by memoranda of understanding, endorsements, town hall meetings or benefit-sharing agreements.
- **Fuel**: The criteria for assessing progress on fuel are based on progress towards the commercial supply of qualified fuel. Once a licensed and operating fuel fabrication facility exists for 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 licence to operate the reactor with the specific fuel.

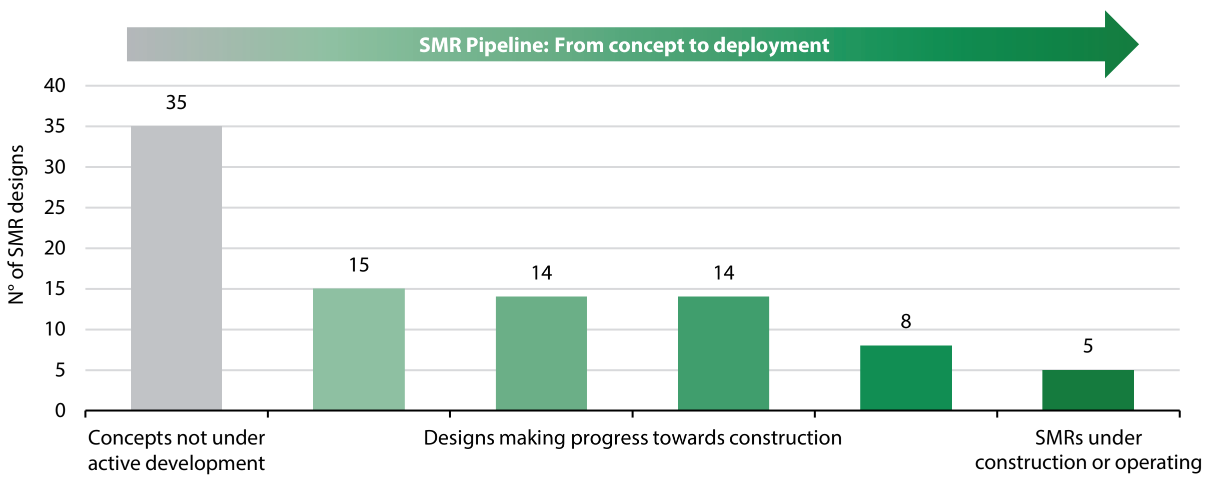
The *NEA SMR Dashboard* also includes information about each SMR design such as technology concept, configuration, outlet temperature, size and fuel type, including requirements for enrichment.

The *NEA SMR Dashboard* uses information exclusively from verifiable public sources. The assessments also benefit from consultations with SMR designers to provide further information subject to independent verification. The assessments take into account the latest developments for each SMR design.

Key insights into SMR deployment progress

The *NEA SMR Dashboard* gathers an extensive amount of data from publicly available sources, enabling insights into critical factors for commercial deployment as well as emerging market trends. The wide variety of SMR technologies reflects a dynamic and innovative ecosystem. Several SMRs are making tangible progress towards first-of-a-kind deployment.

Figure 2. **SMR pipeline: Progress from concept towards first commercial deployment**



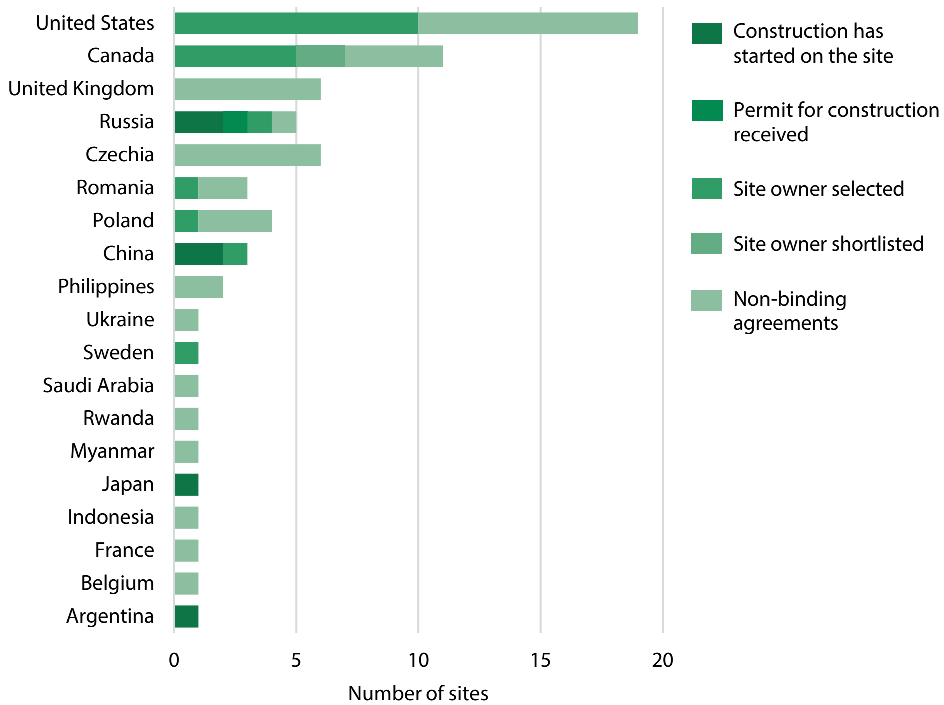
The *NEA SMR Dashboard* provides the most comprehensive assessment to date of the progress towards SMR commercialisation, identifying designs that are making tangible progress and those that are in earlier stages of development (Figure 2). The *NEA SMR Dashboard* finds that a few designs are already operating, and there is a robust pipeline of SMRs making progress towards first-of-a-kind deployment. A few SMRs are presently conceptual, though some of these may accelerate their progress towards first-of-a-kind deployment in the coming years. The breadth of designs may create opportunities to consolidate global supply chains, increase standardisation and improve the economics of SMRs for commercialisation.

Progress by region

Initial findings show that Russia and China are leading on first-of-a-kind deployment, but rapid and real progress is underway in North America and Europe. To date, there are already SMRs deployed and operating in Russia and China as well as one test reactor in Japan. SMRs are under construction in Russia, China and Argentina. Three additional SMR designs have received regulatory approval: VOYGR by NuScale in the United States, SMART by KAERI in Korea and Hermes by Kairos Power in the United States. North America and Europe are home to the headquarters of many SMR designers. The United States is home to the largest number of SMR design organisations, with nearly 35% of the field.

The *NEA SMR Dashboard* also reveals significant progress on siting, with SMRs operating and/or under construction in Russia, China, Japan and Argentina, and a large number of earlier stage siting discussions and negotiations advancing in North America and Europe.

Figure 3. **Siting progress by country**



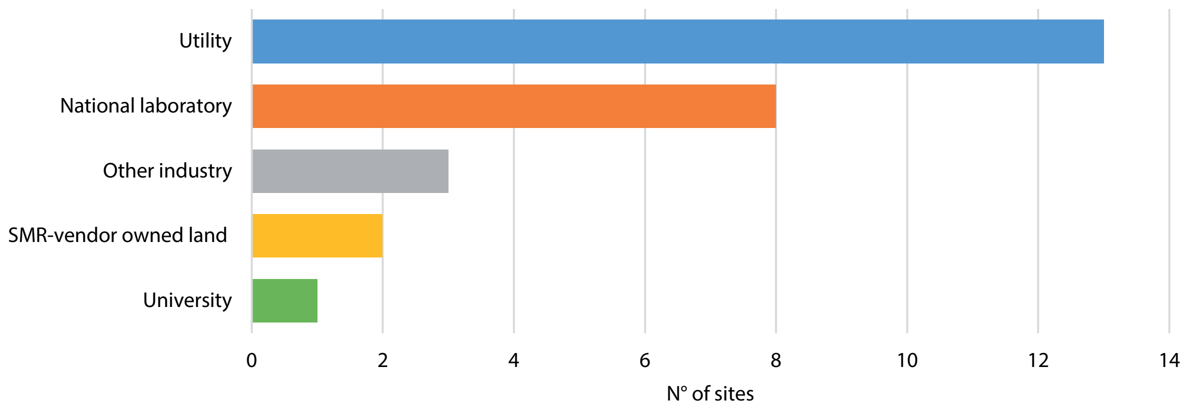
Different markets, financing strategies and business models are emerging

Different markets, financing strategies and business models are emerging (Figure 4). A number of SMR projects are located on government-owned land, particularly at national laboratories. This underscores governmental support for the initial demonstration projects. Utilities have also selected several designs for on-grid applications, notably existing nuclear or coal sites, which present opportunities to leverage existing infrastructures while securing reliable low-carbon generation and local economic benefits. Additionally, an increasing number of site owners are from industrial sectors, such as mining and chemicals, which confirms the growing recognition of the potential of SMRs in hard-to-abate industrial sectors.

To a large extent, SMR developers rely on public-private partnerships to bring their projects to fruition. Private finance plays a sizeable role, with public efforts devoted primarily to supporting research and development activities and to de-risking first-of-a-kind demonstration plans. Within private financing, venture capital also plays a role, particularly for SMR designs at lower technology readiness levels.

Some vendors are enhancing their financing frameworks by securing power-purchase agreements with industrial players to address price uncertainty. While off-take agreements can facilitate project financing by mitigating electricity price uncertainty, they do not address the construction risks, which can be significant, especially for first-of-a-kind SMR projects. Addressing these risks may require the use of cost- and risk-sharing approaches between the governments and the private sector, or the formation of industrial consortia to distribute risks among multiple stakeholders and across a larger number of projects.

Figure 4. **Types of site owners for SMRs selected for deployment, under construction or already operating**

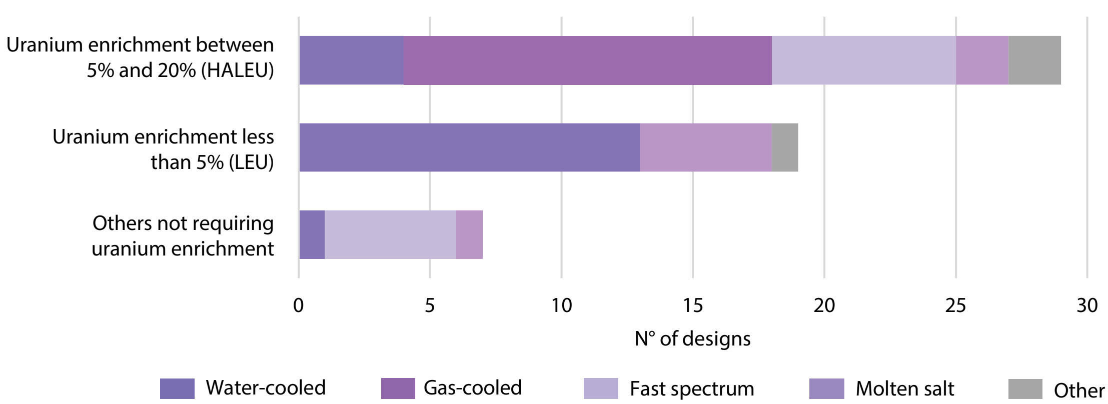


Note: This chart only considers projects where the site owner has selected an SMR technology or SMRs are already under construction or operating. SMRs can be active in multiple projects with different site owners.

Fuel qualification and commercial availability is critical

Over 50% of the designs evaluated for the *NEA SMR Dashboard* plan to use high-assay low-enriched uranium (HALEU), with enrichment levels between 5% and 20%. Most of the SMRs planning to use HALEU are novel concepts that are either gas-cooled, fast-spectrum or molten salt (Figure 5). HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. This shortfall could potentially delay the deployment of some SMRs. Some developers have announced delays in their project timelines due to HALEU unavailability.

Figure 5. **SMR uranium enrichment requirements**



Note: XAMR from NAAREA is not included in this chart since its fuel information was not disclosed.

Focus on first deployment – the paradigm shift to fleet deployment has yet to start

The *NEA SMR Dashboard* finds that, to date, there are no indications of any SMR design being engaged in serial construction. This trend may be explained by the current market uncertainties surrounding SMRs but also the necessity for successful first-of-a-kind projects as a critical step on the path to shifting the paradigm to fleet deployment.

One strategy to navigate market uncertainties and catalyse a robust order book for SMRs may involve forming industrial consortia among first movers aiming at deploying a given design. Such industrial consortia may help share development risks, achieve economies of multiples in the production of systems and components, and expedite the licensing process across jurisdictions.

Waste management

Waste management represents an additional enabling condition critical to the success of SMR deployments. Some advanced SMR designs are being developed together with innovative strategies for the back end of the nuclear fuel cycle, where fuel could potentially be reused. These reactors have the potential to reduce the quantity of high-level waste to be managed by deep geological repositories and the uranium resource requirements for the front end of the nuclear fuel cycle. At the time of publication of this edition, there was insufficient available information from verifiable public sources to assess the progress of SMRs in terms of waste management planning and readiness for end-of-life cycle management. Work on future editions of the *NEA SMR Dashboard* is expected to include the development of a methodology and criteria for assessing progress in this area.

Box 1. **Waste Integration for Small and Advanced Reactor Designs (WISARD)**

The innovative features of advanced reactors (ARs) and SMRs which enable their promised benefits have an inherent effect on their spent fuel characteristics and waste streams. New fuel, moderator, or coolant materials lead to waste with different chemical, physical, and radioactive characteristics; the irradiation behaviour of these materials throughout the plant lifecycle must be considered; and changing the size of the reactor may change the volume and type of waste produced. There are also potential issues with used fuel transportation due to higher burn-ups or end-of-cycle reactivity, higher decay heat, and different fuel sizes for cask storage. Whatever the design, it is clear that the waste from the next generation of nuclear power plants will have some significant differences to that currently processed in national waste management programmes. These differences must be understood, evaluated, and anticipated to provide a long-term, sustainable waste management solution.

The NEA Joint Project on *Waste Integration for Small and Advanced Reactor Designs (WISARD)* aims to take advantage of the present unique window of opportunity to integrate waste management from the beginning of the SMR and AR design life cycle. Early consideration of the logistics and constraints of future waste streams will allow waste management concerns to be actively considered when taking decisions on technology deployment and fuel cycle options. Some issues may be identified and 'designed away' in this process, while the awareness and understanding of others will improve preparation for future disposal efforts. Another advantage of starting to consider waste management early on is the opportunity to co-ordinate with the multiple stakeholders involved in bringing a new reactor design to completion. While large Light Water Reactors (LWRs) are a mature, well-understood technology, SMRs and ARs represent a diverse field with an active start-up culture and close collaboration with both academia and independent research organisations worldwide. With such a wide range of potential stakeholders, care must be taken to involve all parties in the waste management process to minimise disconnects between the design, operation, and decommissioning phases. The dedicated NEA WISARD platform will facilitate the collaboration and understanding between stakeholders throughout the plant life cycle, which will be the key to building a successful, sustainable programme.

Future updates to the *NEA SMR Dashboard*

The NEA will continue to update the *NEA SMR Dashboard* to track progress in these technologies around the world. In 2024, the NEA will begin the development of a digital platform that will enable continuous data collection and more frequent updates to SMR assessments to provide near real-time evidence-based analysis to policymakers and other interested stakeholders.

Energy policy priorities: The role of nuclear energy and SMRs

Carbon emissions must peak within the next decade and reach net zero by 2050 according to the Intergovernmental Panel on Climate Change (IPCC) 1.5°C scenarios. Enabling countries to meet net zero objectives will require substantial investments in innovation and infrastructure for the large-scale deployment of non-emitting energy technologies. Electricity grids must be decarbonised; vehicle fleets must be electrified or transitioned to non-emitting fuels; and other hard-to-abate sectors must be transformed, including buildings, mining and industries such as the production of chemicals, iron, steel, and concrete, among others.

Nuclear energy already contributes significantly to avoiding carbon emissions as the largest source of low-carbon electricity in use by OECD countries, with significant potential to help nations around the world meet their commitments to reach a cleaner and more sustainable future. The role of nuclear energy in meeting these pathways was emphasised at the 28th Conference of the Parties (COP28) in Dubai on 2 December 2013 when the leaders of over 20 countries committed to tripling global installed nuclear capacity by 2050, recognising the critical role of nuclear energy in achieving global net zero greenhouse gas emissions and keeping within reach the goal of limiting the temperature rise to 1.5°C. This commitment builds on NEA analysis that concluded in 2022 that to meet climate goals consistent with a 1.5°C scenario, global installed nuclear capacity needs to triple to 1 160 gigawatts by 2050 (NEA, 2022).

Governments are now looking to turn the climate commitments into action while making efforts to ensure that their societies and industries have access to affordable, reliable energy. This makes nuclear energy attractive to governments as a baseload complement to renewable energy technologies, which are set to grow rapidly in all climate mitigation pathways, and as an off-ramp to dependence on suppliers of fossil fuels and exposure to their price volatility. In particular, nuclear energy enables variable renewables by supporting more affordable, secure and resilient energy supply with baseload generation.

Existing nuclear power plants displace 1.6 gigatonnes of carbon emissions annually and contribute to energy security

Nuclear energy supplies approximately 10% of the world's electricity from 412 nuclear power reactors in operation, providing 370 gigawatts of capacity. It is the largest source of non-emitting electricity generation in OECD countries and the second largest source worldwide after hydropower. 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). Nuclear power is also available on demand, providing grid services to the electricity system and fuel diversity with low and predictable operational costs. This significantly contributes to the system's overall stability and security. These characteristics are anticipated to become more critical as the proportion of variable renewable sources in the electricity system grows. They may also hedge against potentially increasingly volatile fossil fuel prices.

Pathways to net zero require global installed nuclear capacity to triple by 2050

In a special report published in 2018, the IPCC (2018) considered 90 pathways consistent with a 1.5°C scenario, i.e. pathways with emissions reductions sufficient to limit average global warming to less than 1.5°C. NEA analysis found that, on average, the 90 pathways for the 1.5°C scenario considered by the IPCC require nuclear energy to triple and to reach 1 160 gigawatts of electricity by 2050 (NEA, 2022).

This is an ambitious target for nuclear energy, but not beyond reach. It can be achieved through a combination of the long-term operation of nuclear power plants (LTO), large-scale new builds and the deployment of SMRs (as shown in Figure 6):

- **Long-term operation**: 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**: There is significant potential for large-scale nuclear new builds based on existing technologies to provide non-emitting electricity in existing and embarking nuclear power jurisdictions.
- **Small modular reactors**: 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.

Efforts to triple global installed nuclear capacity for net zero by 2050 will benefit from both power and non-power applications of nuclear energy, including industrial and district heating, and nuclear-produced hydrogen for synthetic fuels.

Box 2. **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.

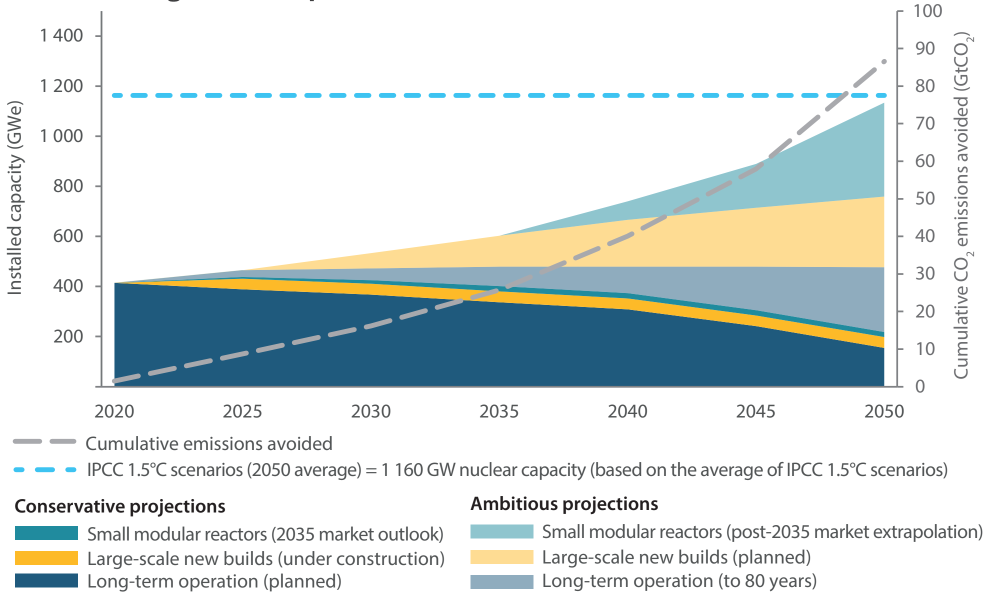
Modular

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.

Figure 6. **Full potential of nuclear contributions to net zero**



Source: NEA, 2022.

The full extent of nuclear energy's role in the pathways to net zero by 2050 can be seen by estimating its potential contribution to emissions reductions through clean power generation, the supply of industrial heat, and the production of clean hydrogen. As shown in Table 1, reaching the target of 1 160 gigawatts of electrical capacity from nuclear energy would avoid 87 gigatonnes of cumulative emissions between 2020 and 2050, preserving 20% of the world's carbon budget consistent with a 1.5°C scenario (NEA, 2022).

Table 1. **Projected contributions of nuclear energy to cumulative emissions reductions (2020-2050)**

Cumulative emissions avoided from…*	*…electricity*	*…heat*	*…hydrogen*	**Totals**
…long-term operation	38.3	6.7	4.3	49.2
…new builds of large Generation III reactors	16.2	4.2	2.4	22.8
…small modular reactors (SMRs)	9.7	3.6	1.8	15.1
Totals	**64.1**	**14.5**	**8.5**	**87.1**

* All cumulative emissions from 2020 to 2050 are shown in gigatonnes of carbon dioxide ($GtCO_2$).

Source: NEA, 2022.

Addressing the challenges faced by nuclear energy

While nuclear energy has the potential to contribute much more to global climate change mitigation efforts, challenges remain. The above estimates are not forecasts but represent what could be achieved with timely enabling policy decisions. Challenges to realising the contribution of nuclear energy to achieving net zero carbon emissions by 2050 include:

- **Delivering nuclear projects on time and on budget**. Some recent first-of-a-kind large nuclear projects have experienced time and cost overruns, which have led to new nuclear projects being perceived as costly and risky investments. These projects have also suffered from the loss of industrial capability after a long hiatus without construction. However, these recent projects have contributed to rebuilding industrial capability and supply chains, providing valuable learnings. With timely new constructions that leverage these learnings and benefit from committed order books of multiple projects that foster standardisation, costs can be reduced significantly and delivery predictability improved (NEA, 2020b; DOE, 2023b).
- **Unlocking access to significant amounts of capital at competitive rates**. Realising the contribution of nuclear energy to achieving net zero by 2050 will require unlocking access to significant amounts of capital at competitive rates. The sector's ability to demonstrate that nuclear projects can be delivered on time and on budget will be key to attracting affordable capital. Governments can also play a role to help attract capital at competitive rates.
- **Ensuring a healthy and resilient supply chain**. While the nuclear industry benefits from international nuclear supply chains built up over 70 years, new nuclear technologies in the energy transition such as SMRs will require changes, for example to manage high-assay low-enriched uranium (HALEU) fuel with transport containers, and to use factory production instead of on-site construction. Countries will benefit from working together through government-to-government, business-to-business and public-private co-operations to reduce supply chain redundancies and improve cost competitiveness to reach efficiencies of scale for the new industry.
- **Building and maintaining public confidence**. Building trust is central to public confidence and requires sustained investments in open and transparent engagements, in addition to effective science communication. Effective public engagement strategies emphasise transparency, open dialogue and education, aiming to engage the citizenry on the role of nuclear power in achieving climate targets in a secure and affordable manner, as well as advancements in nuclear technology, safety measures, and waste disposal solutions. Revisiting best practices in public engagement will likely be required to accelerate current projects and deliver new ones.
- **Ensuring a skilled workforce**. Although recent nuclear new builds have contributed to revitalising international supply chains, a new wave of projects will require a strong industrial foundation and quality workforce. Governments and industry will need to find the right balance between reliance on domestic investments in critical skills and infrastructure, and efficiencies from forming strategic partnerships internationally. Workforce preparedness to sustain the tripling or more of global installed nuclear capacity for net zero by 2050 will require both back-to-basics and creative solutions to strengthen networks for nuclear education.

Both recent and historical experience show that under the right policy frameworks and with a robust programmatic approach, nuclear energy is a low-carbon solution with rapid delivery times. This was the case historically for countries such as France and jurisdictions such as Ontario in Canada, which decarbonised their electricity mixes in less than two decades with nuclear energy and hydropower. Today, countries with established nuclear programmes such as China and Korea have demonstrated construction lead times of 5-6 years or less for large-scale reactor designs. Newcomer countries, such as the United Arab Emirates with the Barakah project, have also demonstrated the ability to deliver new nuclear energy projects on a timeline and cost consistent with the speed required to reach 1 160 gigawatts of global installed nuclear capacity by 2050 (NEA, 2022).

The role of SMRs in pathways to net zero

SMRs will have an essential and increasingly important role to play supporting decarbonisation targets. The NEA estimates that by 2050 SMRs could reach 375 gigawatts of installed capacity in an ambitious case (NEA, 2022). 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 renewables face limitations.

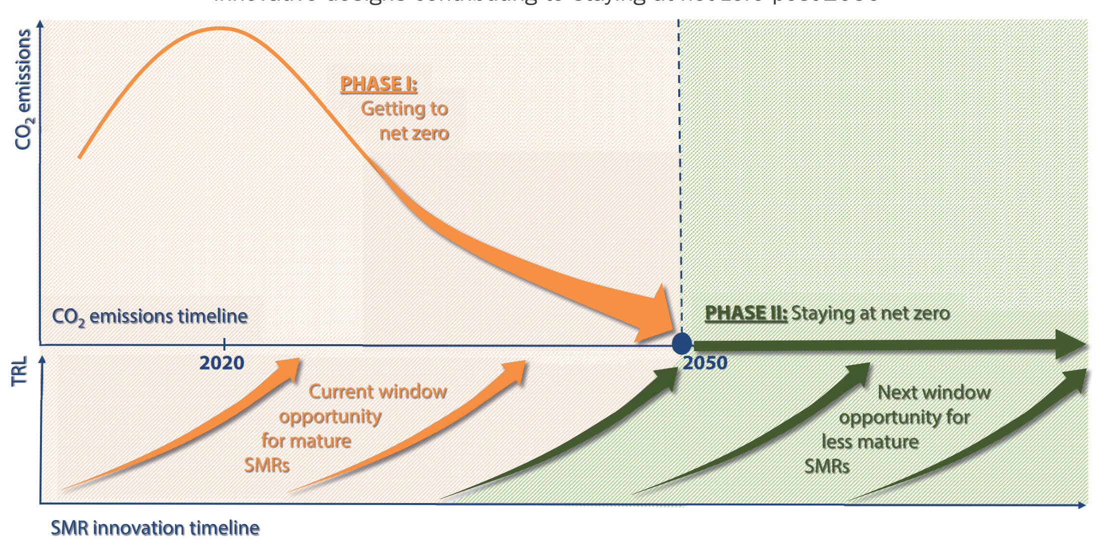
The SMR technology pipeline reflects a range of technology readiness levels. Some SMR technologies are already demonstrated (at lab and commercial scales), while others are still in research and development (R&D). Timelines for deployment vary, with some designs expected to be demonstrated and commercialised before 2030 and others to follow later in the 2030s. Importantly, this 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 7):

- **Phase 1**: SMRs and advanced reactors with high levels of 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 readiness could be deployed at scale from the 2040s to supply electricity, heat and hydrogen, and could contribute to long-term sustainability with advanced nuclear fuel cycles.

In light of project lead times, policy support today is necessary for SMRs with high and low levels of readiness to be deployed within their respective windows of opportunity.

Figure 7. **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

Safety

SMR designs build on lessons learnt from over 70 years of experience in the nuclear energy sector to enhance safety and improve operational flexibility. Many SMR designs include inherent safety features.

SMRs also leverage design features that have the potential to bring safety-related advantages such as:

- Smaller reactor cores with smaller quantities of nuclear material;
- The use of accident-tolerant fuels and advanced fuels that can maintain their structural integrity even at higher temperatures; and
- Operation at lower pressures and the use of passive safety systems that do not require external sources of electricity or human intervention to maintain safety.

The implementation of such design features could help reach safety objectives while reducing the reliance on human intervention and operational measures, enabling design simplifications and cost reductions.

The benefits of lower quantities of nuclear material in the reactor cores combined with passive safety features may also lead to smaller off-site emergency planning zones (EPZ). This may facilitate plant siting and potentially reduce grid requirements for on-grid SMRs.

The new technical features of SMRs present both opportunities and challenges in terms of safety. While they potentially offer significant safety enhancements, the novelty and diversity of SMR designs mark a significant departure from established regulatory experience. Additional work will be required to demonstrate the safety of innovative designs. Implementing performance-based and objective-oriented regulations is one approach to improving the licensing process for new reactor designs and could create opportunities for enhanced international regulatory co-operation. Additionally, using SMRs in industries other than power generation will likely require more co-operation between nuclear safety authorities and other industry regulators.

Flexibility

The Clean Energy Ministerial NICE Future Flexible Nuclear Energy for Clean Energy Systems campaign 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 utilising both traditional and advanced nuclear power plants and integrated systems" (NREL, 2020). More generally, the flexibility of SMRs also includes deployment flexibility and diversity of products such as combined heat and electricity production. The operational, deployment and product flexibility offered by SMRs is summarised in Table 2.

Operational flexibility

In general, SMRs are designed to integrate into energy systems, offering much-needed flexibility to enable high shares of variable renewable energy while maintaining security of electricity supply.

In hybrid systems, SMRs could potentially switch between electricity and heat generation, further bolstering operational flexibility. Such operational flexibility could be achieved with lower capacities and in more decentralised configurations, potentially enhancing the resilience of remote applications and micro-grids.

Deployment flexibility

SMRs offer a wide range of deployment configurations, with some designs using a multi-module approach for scalability and adaptability to diverse and evolving demands. Some SMRs with smaller emergency planning zones may be well suited to more densely populated areas and industrial clusters, while very small – or "micro" – SMRs may be deployed on remote or off-grid sites. SMRs can be deployed on grid where gigawatt-scale nuclear power plants would either exceed electricity demand requirements or grid capacity.

The compact size and simplicity of some SMRs also enable the use of new delivery models to improve constructability. Moreover, the smaller scale of SMRs may facilitate the adoption of advanced manufacturing techniques that have the potential to reduce manufacturing time by increasing speed, reducing the number of welds and eliminating handling requirements.

Product flexibility

SMRs can deliver low-carbon electricity and heat on demand, and in some cases can be designed to produce medical radioisotopes. Such flexibility is particularly advantageous as it enables SMRs to address various market needs.

Table 2. **Flexibility attributes and potential benefits of SMRs**

Attribute	Sub-Attribute	Benefits
Operational flexibility	Manoeuvrability	Load following
	Compatibility with hybrid energy system and polygeneration	Economic operation with increasing penetration of intermittent generation, alternative missions
	Diversified fuel use	Economics and security of supply
	Island operation	System resiliency, remote power, micro-grid, emergency power applications.
Deployment flexibility	Scalability	Ability to deploy at the scale needed
	Siting	Ability to deploy where needed
	Constructability	Ability to deploy on schedule and budget
Product flexibility	Electricity	Reliable, dispatchable power supply
	Process heat	Reliable, dispatchable process heat
	Radioisotopes	Unique or high demand isotopes supply

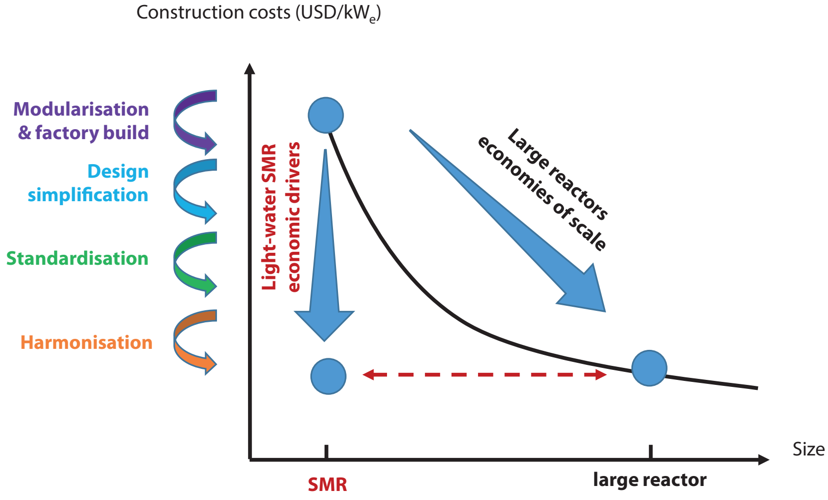
Source: Sadhankar, 2019.

Costs, competitiveness and economic benefits

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 multiples (or serial construction). 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).

By comparing SMR cost estimates with other alternatives, it is possible to assess the relative competitiveness of SMRs at the plant level. 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 dollars per megawatt hour. Similarly, for on-grid coal replacement, SMRs are expected to become increasingly competitive compared to fossil-based generation as carbon pricing and other limitations increase as governments seek to meet ambitious climate goals.

Figure 8. **Key economic drivers to compensate for diseconomies of scale**



Source: NEA (2021b).

SMR competitiveness should also benefit from several design features that can improve financial conditions. For instance, SMR projects will be smaller, offering a more affordable upfront proposition compared to large reactor projects. These attributes should appeal to a broader class of investors and financiers.

The economic viability of SMRs hinges on the existence of a sufficiently large market for a single design, which would drive learning curves and enable economies of multiples. After the completion of the first SMR projects, deployment should shift towards a product-based approach, with supply chains aiming for higher levels of consolidation and standardisation. This shift will be essential to harness the full potential of economies of multiples and increase SMR competitiveness.

Capital costs will be a crucial factor in the decision-making process for investors in SMRs. While the features mentioned above have proven successful in other industries, they need to be demonstrated for SMRs. The first projects will be critical in reducing capital costs and schedule uncertainties, and in catalysing investor trust. Concurrently, potentially rising fossil fuel costs, carbon pricing and stringent environmental regulations may continue to enhance the relative competitiveness of SMRs compared to fossil fuel-based alternatives.

While capital costs are a significant factor in final investment decisions, there are other factors that affect the value of the SMR option for end-users. Despite their potentially higher capital costs compared to other low-carbon alternatives, SMRs are being considered in integrated resource plans thanks to their dispatchability and reliability attributes (NEA, forthcoming). Furthermore, SMRs can extend the benefits of nuclear power to new communities, where their implementation could facilitate a just transition by eliminating air pollution and supporting quality jobs over extended periods.

Nuclear fuel and waste management

The successful deployment of SMR technologies also hinges on accounting for considerations related to the back end of the fuel cycle. The nuclear sector has been implementing proven solutions to manage nuclear fuel and nuclear waste for several decades (JRC, 2021). Scientific consensus exists at the international level that deep geological repositories are a safe and effective approach for the final disposal of high-level waste, which is supported by the progress made so far in several countries – with Finland, Sweden and France leading the way (NEA, 2020a).

Light water-based SMR technologies, as a general category, enjoy the benefits of familiarity. While there are some differences in configuration from traditional reactors, no major technical challenges are expected to planning for and implementing the disposal of used fuel from these technologies.

Innovation in SMR technologies, however, will require innovation in nuclear waste management and disposal solutions, building on the existing knowledge base. Some advanced SMR designs are being developed together with innovative strategies for the back end of the nuclear fuel cycle, where fuel could potentially be reused. These reactors have the potential to reduce the quantity of high-level waste to be managed by deep geological repositories and the uranium resource requirements for the front end of the nuclear fuel cycle.

Some SMRs propose novel fuel cycles that will produce new types of waste that will need to be characterised and planned for. Some SMR developers aiming to deploy novel fuel cycles have already begun efforts to characterise their waste streams and work with waste management organisations to prepare suitable plans for the effective management of these waste streams. At the time of publication, there was insufficient information available from verifiable public sources to assess the progress of SMRs in terms of waste management planning and readiness for end-of-life cycle management. As a result, at this early stage, consideration of preparation for used fuel from innovative SMRs is not included in the *NEA SMR Dashboard*; however, it is anticipated that future editions of the *NEA SMR Dashboard* will elaborate a methodology and criteria for assessing progress in this area when sufficient progress is completed and information more generally available to enable authoritative evaluations.

Box 3. **Safeguarding Small Modular Reactors: Meeting the non-proliferation obligations**

By Jeremy Whitlock, Senior Technical Advisor, Department of Safeguards, IAEA

The growing global interest in nuclear energy means that many new and advanced nuclear technologies may require International Atomic Energy Agency (IAEA) verification in the years ahead.

The IAEA works to enhance the contribution of nuclear energy to peace and prosperity around the world, while verifying that nuclear material in peaceful use is not diverted for use in nuclear weapons or other explosive devices.

To this end, the IAEA implements technical measures, known as 'safeguards', to verify that States are honouring their international nuclear non-proliferation obligations. This independent verification work allows the IAEA to play an indispensable role in helping to prevent the spread of nuclear weapons.

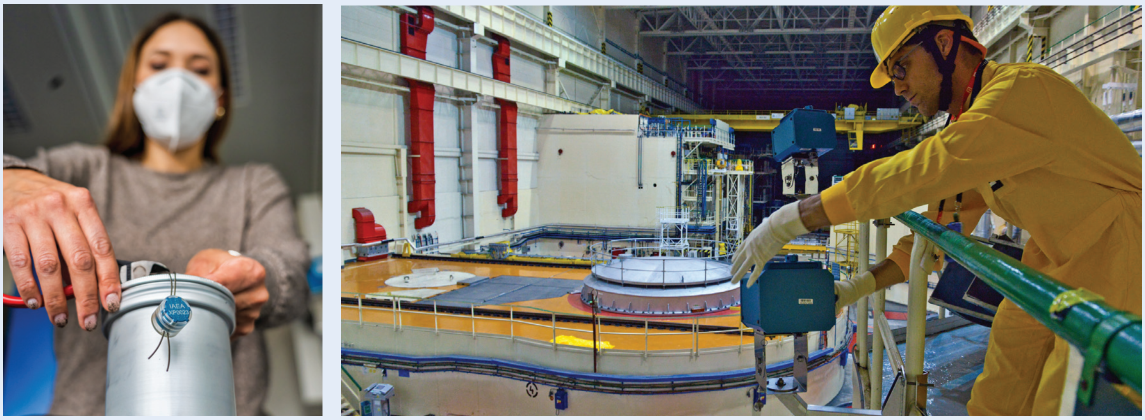
A great majority of the world's States have concluded comprehensive safeguards agreements (CSAs) with the IAEA pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). These agreements require the implementation of IAEA safeguards on all nuclear material in peaceful nuclear activities within, or under the jurisdiction or control of, the State.

As the latest innovations and technologies continue to present new possibilities, experience has shown that it is desirable to design nuclear facilities with safeguards in mind from the start. A concept known as safeguards by design (SBD) takes this into account by recognising safeguards considerations during the planning phase; prior to embarking on the construction or modification of a nuclear facility. SBD is a voluntary activity that does not replace or alter any existing safeguards obligation of a State.

The aim of SBD is to facilitate the development of verification methods that minimise the impact on both the operator and the State, while maximising the effectiveness and efficiency of IAEA safeguards activities.

For example, by planning for expected verification activities in advance, facilities can be designed to minimise inspectors' potential exposure to radiation, accommodate IAEA seals, surveillance systems and other safeguards equipment without retrofitting, facilitate access to safeguards equipment for maintenance, ensure the possibility of on-site remote data transmission (where permitted), and in general avoid safeguards-related activities that may disrupt a facility's normal operation. Furthermore, early planning can incorporate flexibility into the facility's infrastructure that may make it easier to adapt to future technological innovations, benefiting both the operator and the IAEA.

To prove effective, SBD requires that facility designers have a detailed understanding of safeguards requirements. Therefore, one of the key goals of the IAEA in implementing SBD is to raise awareness about such requirements among industry participants, nuclear regulators, and the R&D community.



Left: An IAEA safeguards inspector applies a Field Verifiable Passive Seal (FVPS) to a container (IAEA); Right: An IAEA safeguards inspector performs maintenance on a surveillance camera at a power reactor (IAEA).

Published by the IAEA starting in 2013, an eight-part guidance series reflects the application of SBD to all aspects of the nuclear fuel cycle, from initial planning and design, through construction, operation, spent fuel management, decommissioning, and radwaste management. The series provides advice for decision makers, designers, equipment providers and prospective purchasers, while also considering the economic, operational, safety, and security factors related to the design of a nuclear facility.

SBD for future SMRs

Small modular reactors (SMRs) present an emerging opportunity for the application of SBD. The novel reactor designs, fuel-cycle processes, and supply arrangements presented by SMRs mean that considering safeguards early in the design process will be a win-win for the State and the IAEA alike.

SMRs offer significant potential for nuclear energy expansion thanks to their shorter construction timelines, greater adaptability, and inherent safety features. It is important that safeguards provisions be considered throughout the development of these new reactors (and related fuel-cycle facilities), thereby avoiding the need to make incremental changes once construction is already completed. This is particularly important where innovative technologies are involved, as these may require the development of new safeguards processes and technologies, requiring both time and resources from the State and the IAEA.

To address this need, the IAEA is engaged in SBD discussions through its Member State Support Programmes (MSSPs). MSSPs allow for an open exchange of design information between interested countries, reactor designers, and the IAEA. The IAEA also engages stakeholders through other channels, such as the SMR Regulators' Forum, which brings together nuclear safety and security experts to discuss challenges and share experiences related to the regulation of SMRs.

Additionally, in 2021 the IAEA established the 'Platform on SMRs and their Applications' in response to requests to address the challenges related to, and to facilitate the timely deployment of, SMRs. The Platform is a one-stop shop for the IAEA's full array of support and expertise on SMRs, from technology development and deployment to nuclear safety, security, and safeguards.

The IAEA's 'Nuclear Harmonization and Standardization Initiative' (NHSI) is a complementary initiative that aims to advance the harmonisation and standardisation of SMR design, construction, regulatory and industrial approaches. The initiative is comprised of two separate but complementary tracks – the NHSI Regulatory Track and the NHSI Industry Track – together addressing the goal of effective global deployment of safe and secure advanced nuclear reactors.

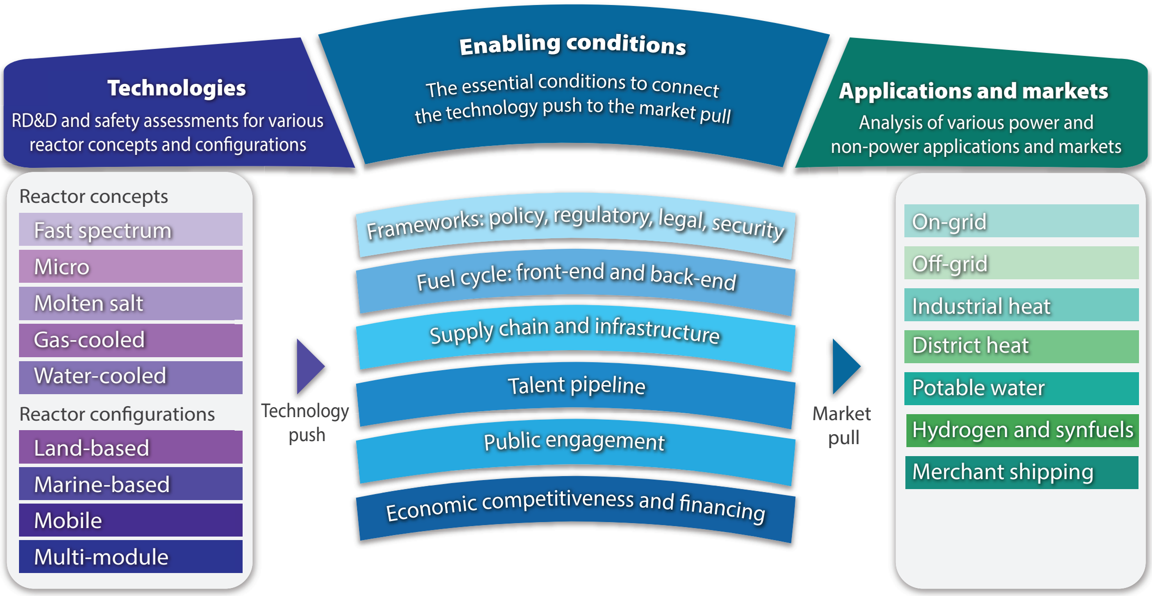
By engaging early in the discussion of safeguards requirements, facility designers and the IAEA can jointly work to ensure that effective and efficient implementation of IAEA safeguards. In turn, this collaboration will support the safe, secure, and timely deployment of SMRs and related nuclear fuel-cycle facilities.

For more information on Safeguards by Design and SMRs, contact the IAEA at SBD@iaea.org, or consult the IAEA's guidance documents at: www.iaea.org/topics/assistance-for-states/safeguards-by-design.

Conditions for successful deployment of SMRs

Beyond technical feasibility, there are several other necessary conditions for the success of SMRs. Figure 9 illustrates a comprehensive map of the SMR landscape, from research and development of various SMR technologies to deployment in real-world markets and applications. Several enabling conditions connect the technology push side of the landscape with the market pull for innovative nuclear technologies.

Figure 9. **Enabling conditions connecting SMR technology push to market pull**



Source: NEA, 2023a.

On the technologies side of the landscape, 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 shifts 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.

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. On-grid power generation to replace coal presents a key market around the world for SMRs and Generation IV reactors. 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.

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 of SMRs: From concept to first commercial deployment

The *NEA SMR Dashboard* considers factors beyond technology readiness levels 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 technology readiness levels. 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 the 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 to assess substantial progress towards first-of-a-kind 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.

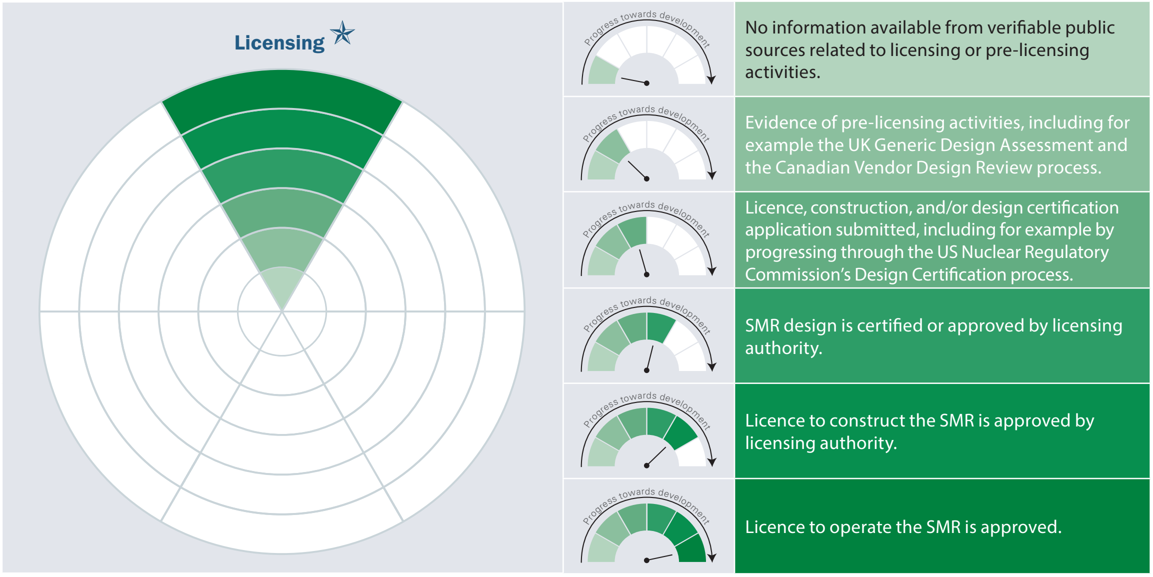
The six areas and progress criteria are described below. The criteria are also summarised in Table 11 in Annex 1.

Licensing

The licensing process is critical for any SMR to reach markets. 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 *NEA SMR Dashboard* progress criteria for licensing closely follow international licensing norms, including pre-licensing interactions with regulators, design approval, construction and the issuance of operating licences. A bonus is given to SMRs with licensing activities in multiple jurisdictions at any level.

Figure 10. **Tracking progress in licensing**



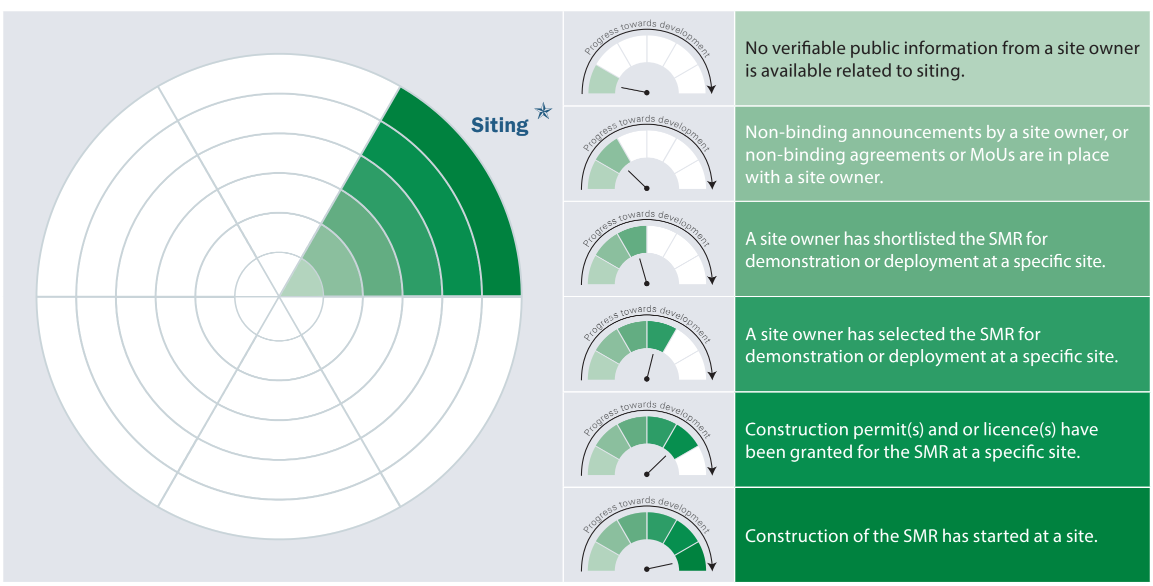
Note: The star indicates a bonus given to SMRs with licensing activities in multiple jurisdictions at any level.

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 designs 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 or deployed on the site. A bonus is given to SMR technologies making progress at multiple sites at any level.

Figure 11. **Tracking progress in siting**



Note: The star indicates a bonus given to SMRs making progress at multiple sites at any level.

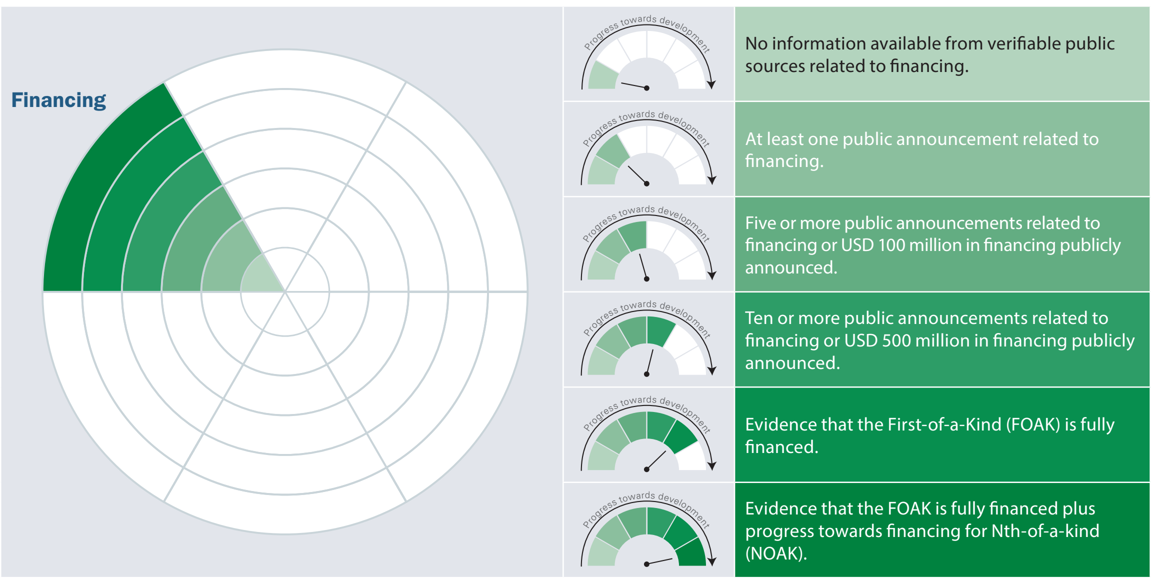
Financing

Securing financing is critical for any SMR technology to reach markets. 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, such as 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 progress: either there is 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.

Figure 12. **Tracking progress in financing**

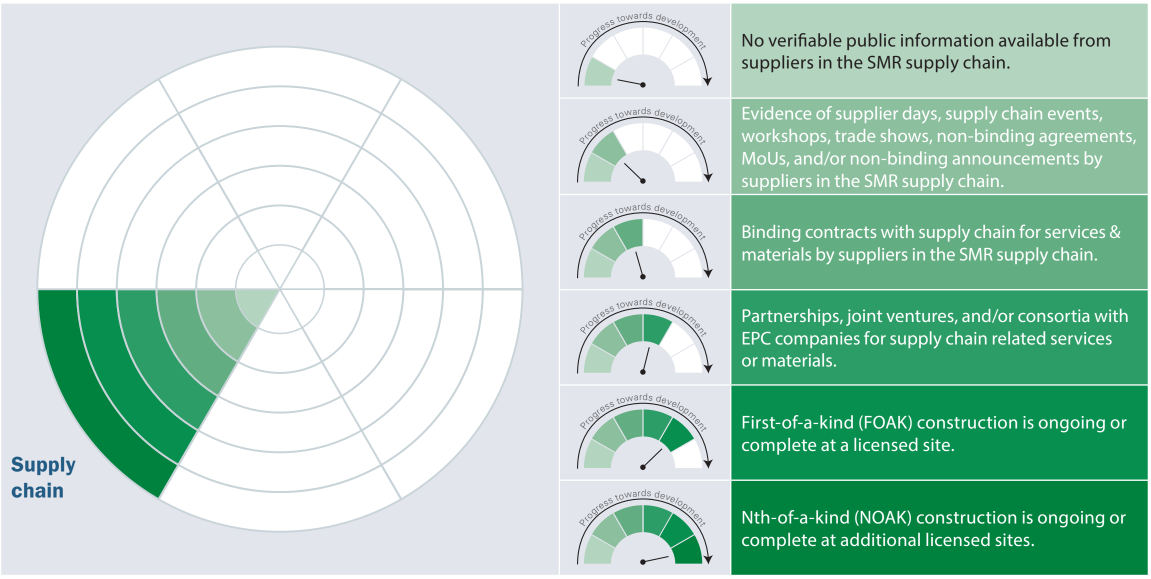


Supply chain

In most cases, a designer is not alone in developing an SMR, though 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, formal partnerships, joint ventures or consortia. A supply chain is considered 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" SMR.

Figure 13. **Tracking progress in supply chain readiness**

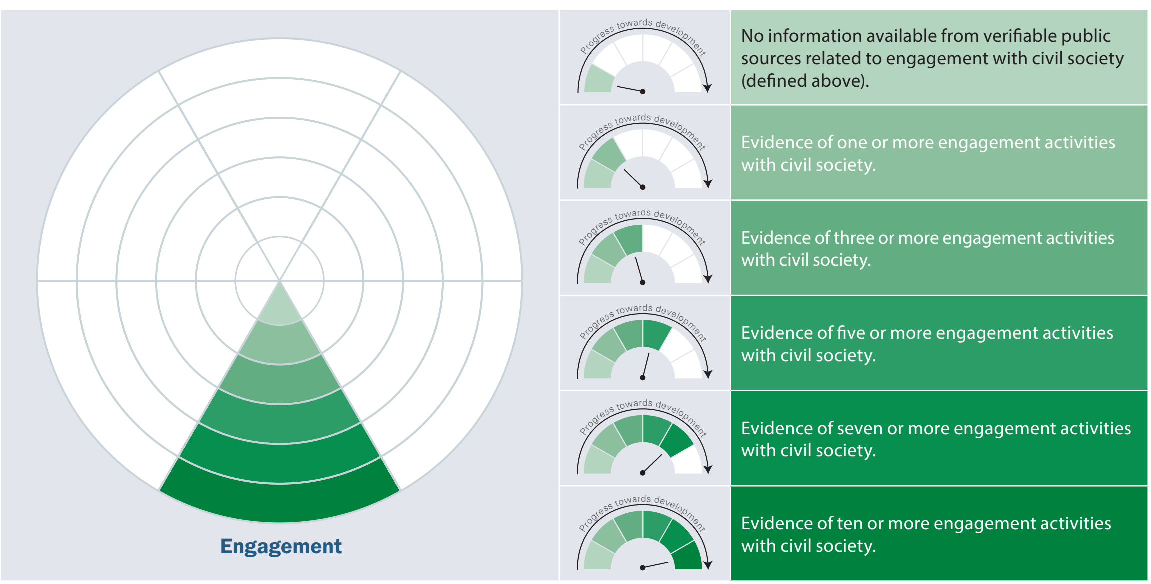


Engagement

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 people and communities associated with the SMR project. Engagement activities in mainstream, non-nuclear media through videos, podcasts or interviews will be considered as well as memoranda of understandings, endorsements, town hall meetings and benefit-sharing agreements 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.

Figure 14. **Tracking progress in engagement**

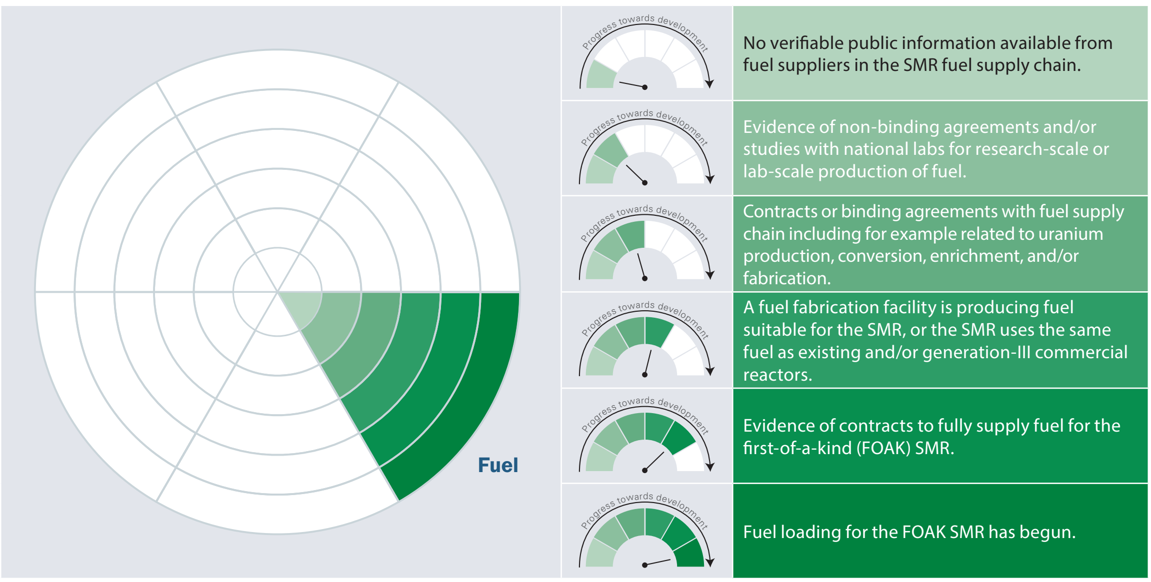


Fuel

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 use 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 are based on the progress made 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 licence to operate the reactor with the specific fuel.

Figure 15. **Tracking progress in fuel availability**



Key findings worldwide

Through preparation of the different editions so far of the *NEA SMR Dashboard*, an extensive amount of data and market intelligence has been gathered. As a result, the *NEA SMR Dashboard* is able to assess actual deployment progress and provide insights into the different factors enabling the commercialisation of SMRs. This section presents key learnings based on the data and assessments to date, along with recent policy developments and market trends. The assessments in this edition of the *NEA SMR Dashboard* are based on progress up to a cutoff date of 10 November 2023.

Global momentum for SMRs

SMR technology is gaining traction globally. This is the result not only of an increased interest from the private sector but also of a recognition at the policy level of the potential of SMRs to support deep decarbonisation.

There are total of 56 SMR designs under active development, including 18 by SMR design organisations headquartered in North America, 16 in Europe and 7 in Asia (Figure 16). Fifteen SMR design organisations are headquartered in the United States, seven in France, four in China, three in Canada two in Japan, and two in Russia.

Figure 16. **Locations of SMR designer headquarters by region**

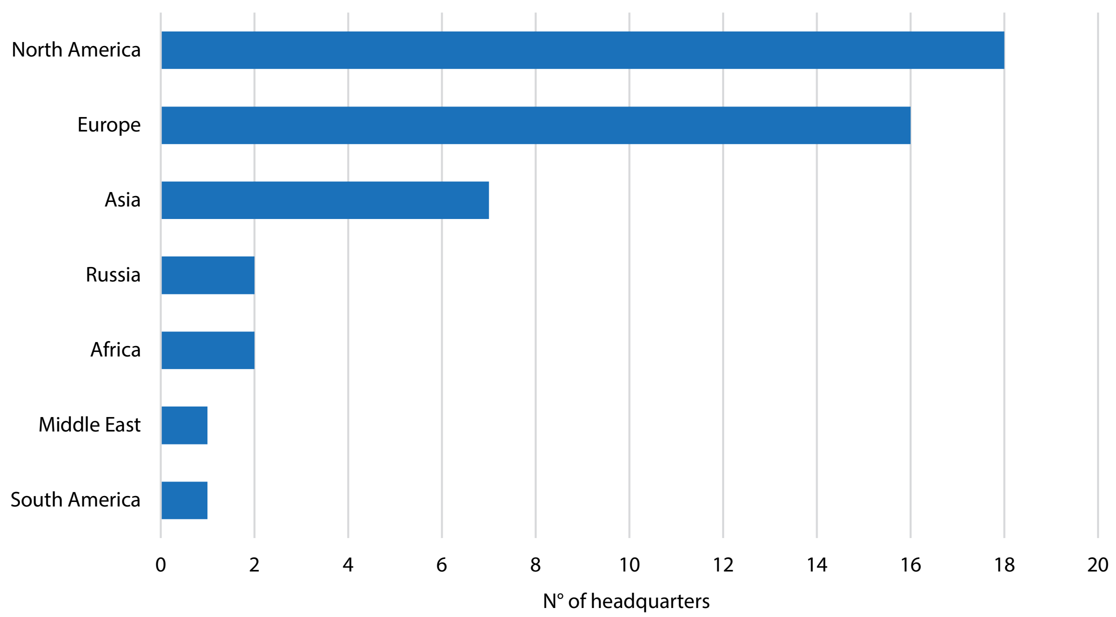
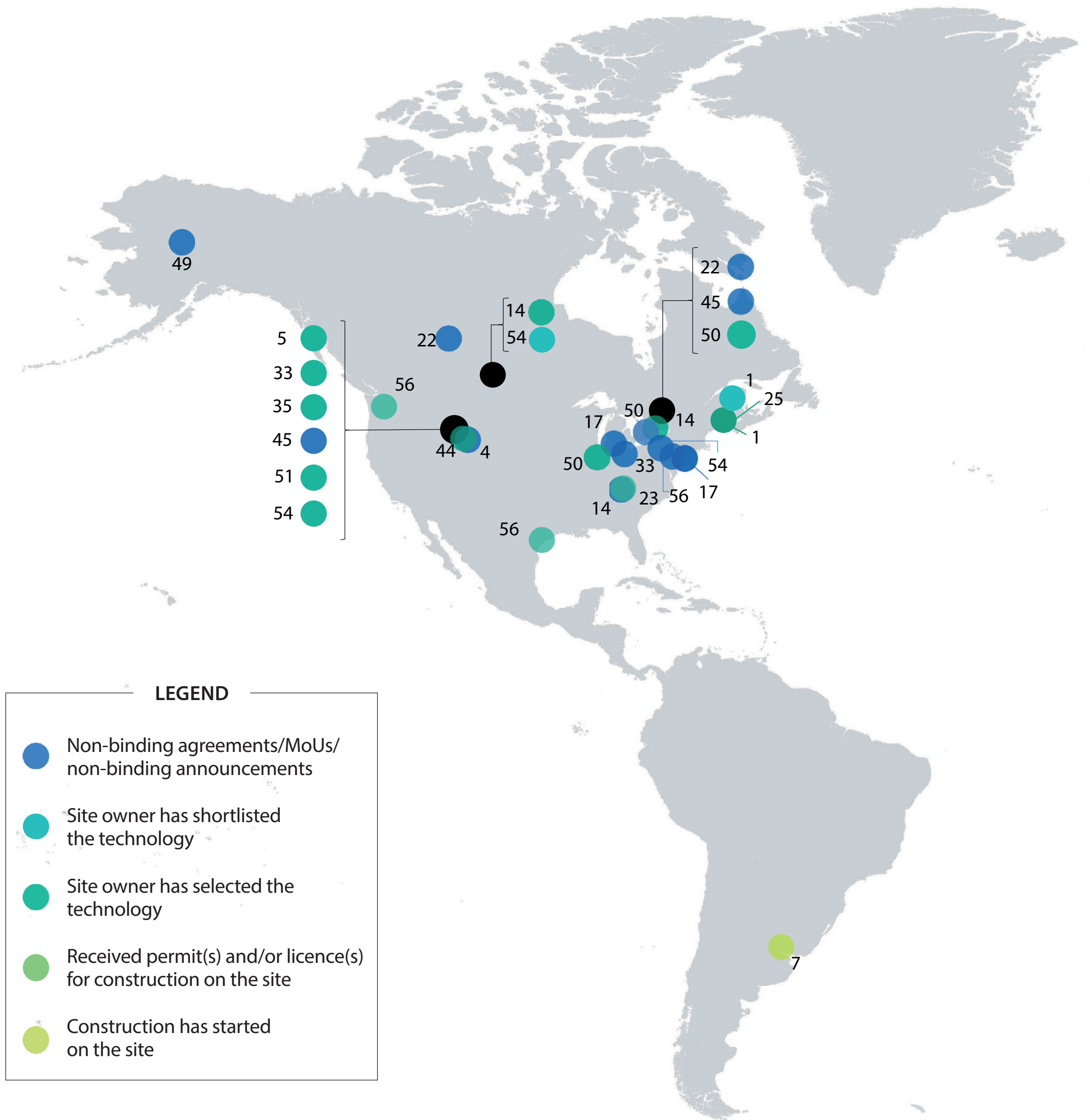
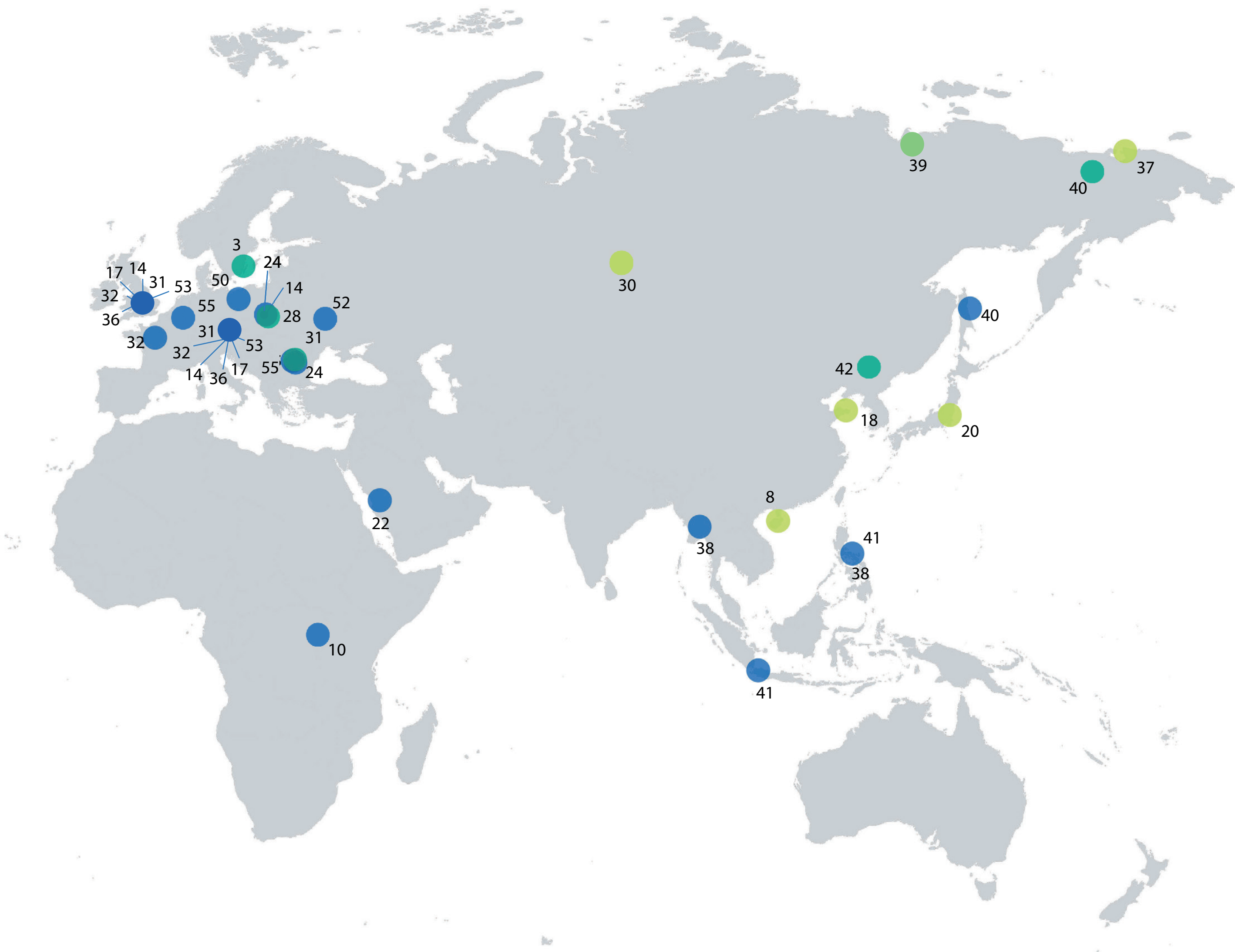


Figure 17 illustrates progress in siting SMRs for deployment around the world. Figure 18 displays the geographical breadth of this growing industry, showing the locations of SMR designer headquarters around the world.

Figure 17. **Global map of SMR sites**

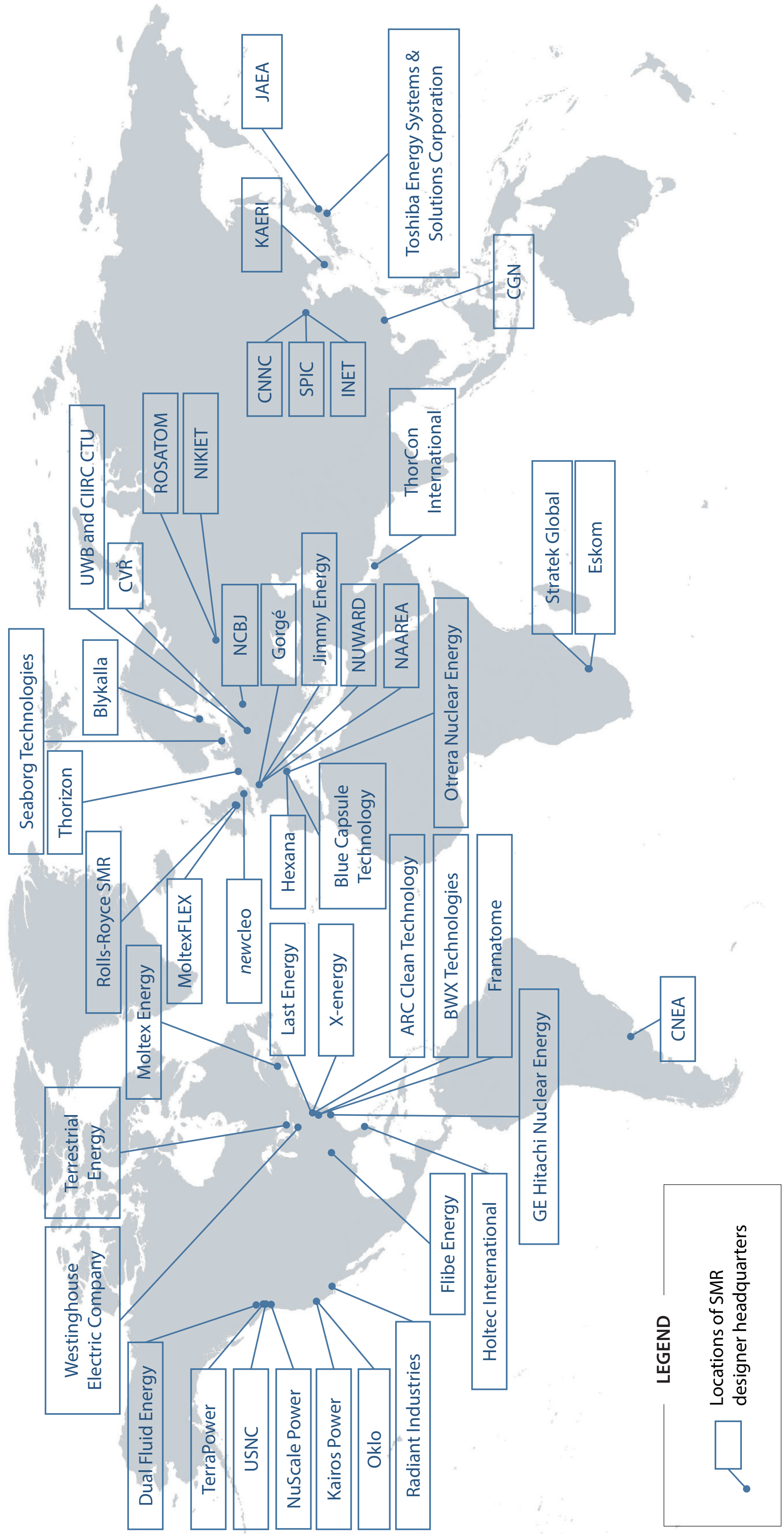


1	ARC-100	ARC Clean Technology
2	Blue Capsule	Blue Capsule Technology
3	SEALER-55	Blykalla
4	BANR	BWXT
5	Project Pele	BWXT
6	ACPR50S	CGN
7	CAREM	CNEA
8	ACP100	CNNC
9	Energy Well	CVŘ
10	DF300	Dual Fluid Energy
11	A-HTR-100	Eskom
12	LFTR	Flibe Energy
13	SC-HTGR	Framatome
14	BWRX-300	GE Hitachi Nuclear Energy
15	Calogena	Gorgé
16	HEXANA	Hexana
17	SMR-300	Holtec International
18	HTR-PM	INET
19	GTHTR300	JAEA
20	HTTR	JAEA
21	Jimmy SMR	Jimmy
22	SMART	KAERI
23	Hermes	Kairos Power
24	PWR-20	Last Energy
25	SSR-W	Moltex Energy
26	FLEX	MoltexFLEX
27	XAMR	NAAREA
28	HTGR-POLA	NCBJ



29	LFR-AS-200	*new*cleo	43	HTMR-100	Stratek Global
30	BREST-OD-300	NIKIET	44	Natrium Reactor Plant	TerraPower
31	VOYGR	NuScale Power	45	IMSR	Terrestrial Energy
32	NUWARD SMR	NUWARD	46	ThorCon 500	ThorCon International
33	Aurora Powerhouse	Oklo	47	Thorizon One	Thorizon
34	Otrera 300	Otrera Nuclear Energy	48	MoveluX	Toshiba Energy Systems & Solutions Corporation
35	Kaleidos	Radiant Industries	49	4S	Toshiba Energy Systems & Solutions Corporation
36	RR SMR	Rolls-Royce SMR	50	MMR	USNC
37	KLT-40S	ROSATOM	51	Pylon D1	USNC
38	RITM-200M	ROSATOM	52	TEPLATOR	UWB and CIIRC CTU
39	RITM-200N	ROSATOM	53	AP300™ SMR	Westinghouse Electric Company
40	RITM-200S	ROSATOM	54	eVinci microreactor	Westinghouse Electric Company
41	CMSR	Seaborg Technologies	55	Westinghouse LFR	Westinghouse Electric Company
42	HAPPY200	SPIC	56	Xe-100	X-energy

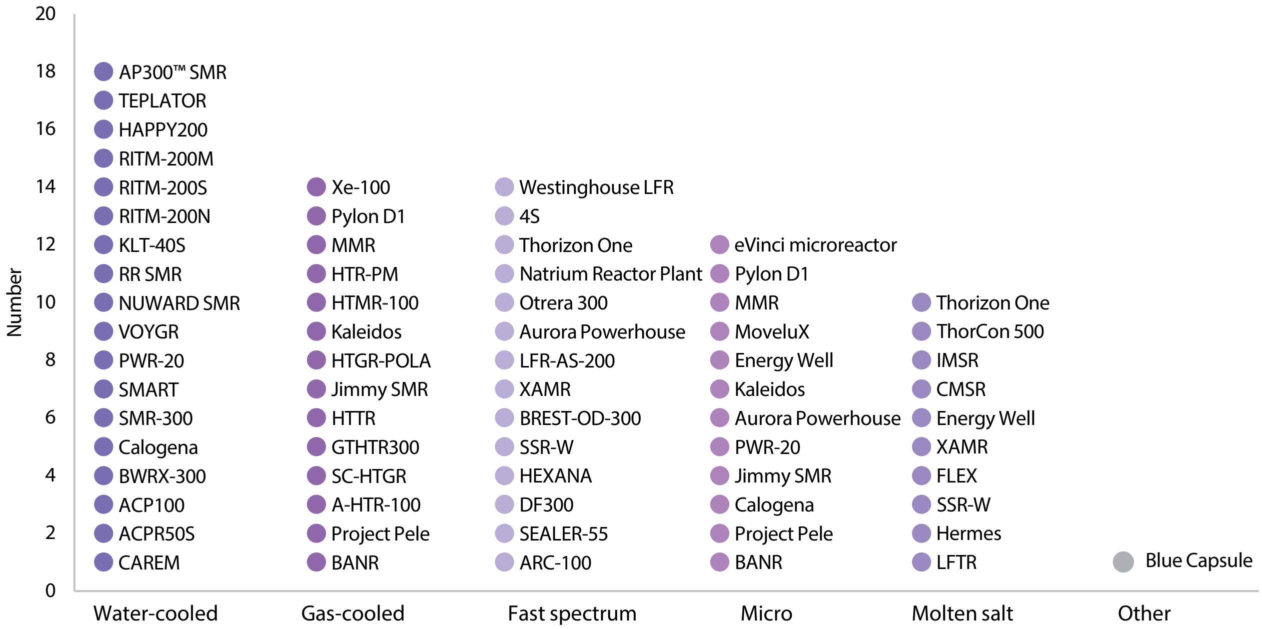
Figure 18. **Global map of SMR designer headquarters**



Different SMRs for different applications

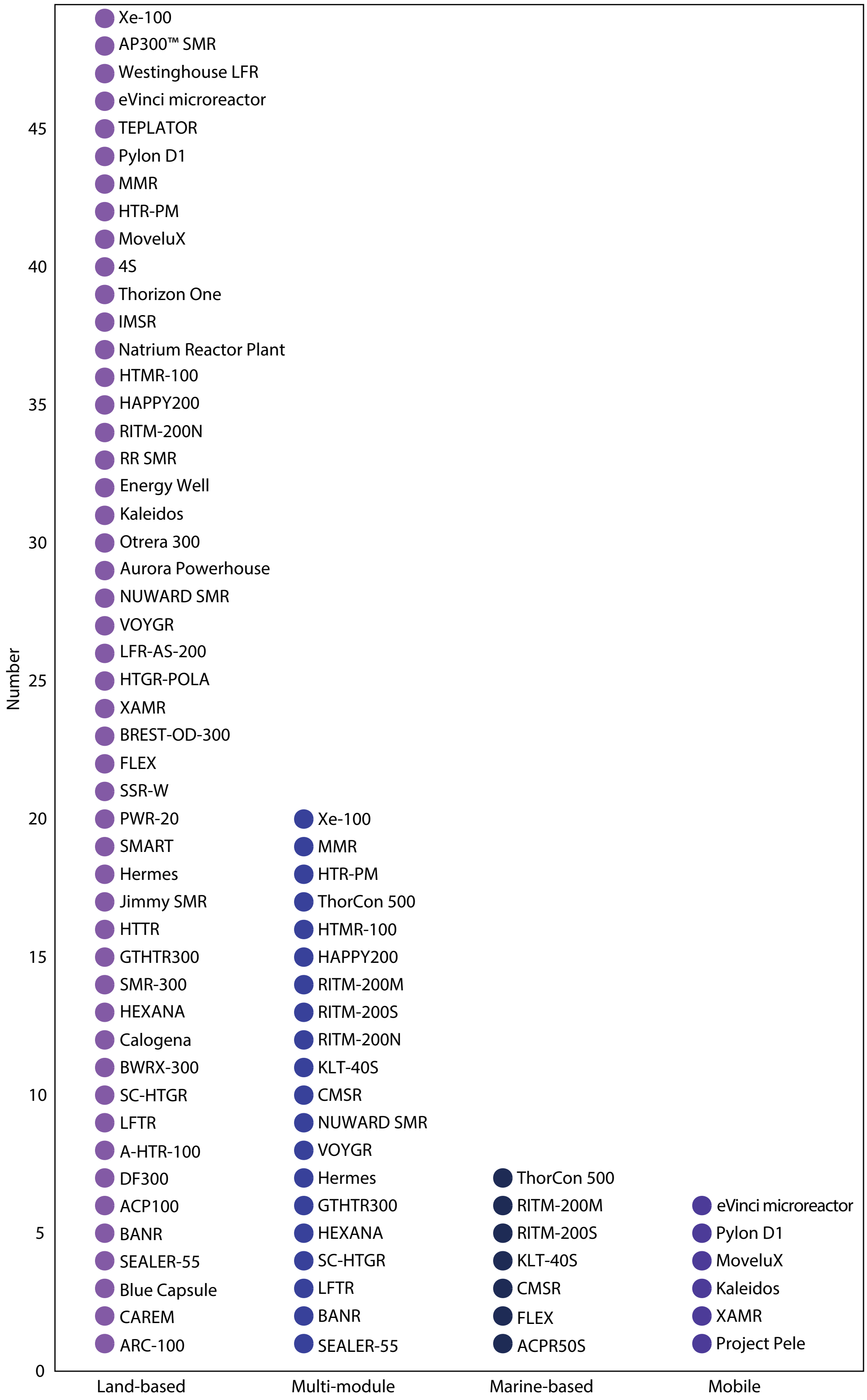
Different SMRs for different applications are under development around the world, including different reactor concepts (Figure 19) and configurations (Figure 20). The range of reactor concepts extends beyond traditional water- or gas-cooled designs to include fast spectrum, molten salt and even microreactors.

Figure 19. **Reactor concepts**



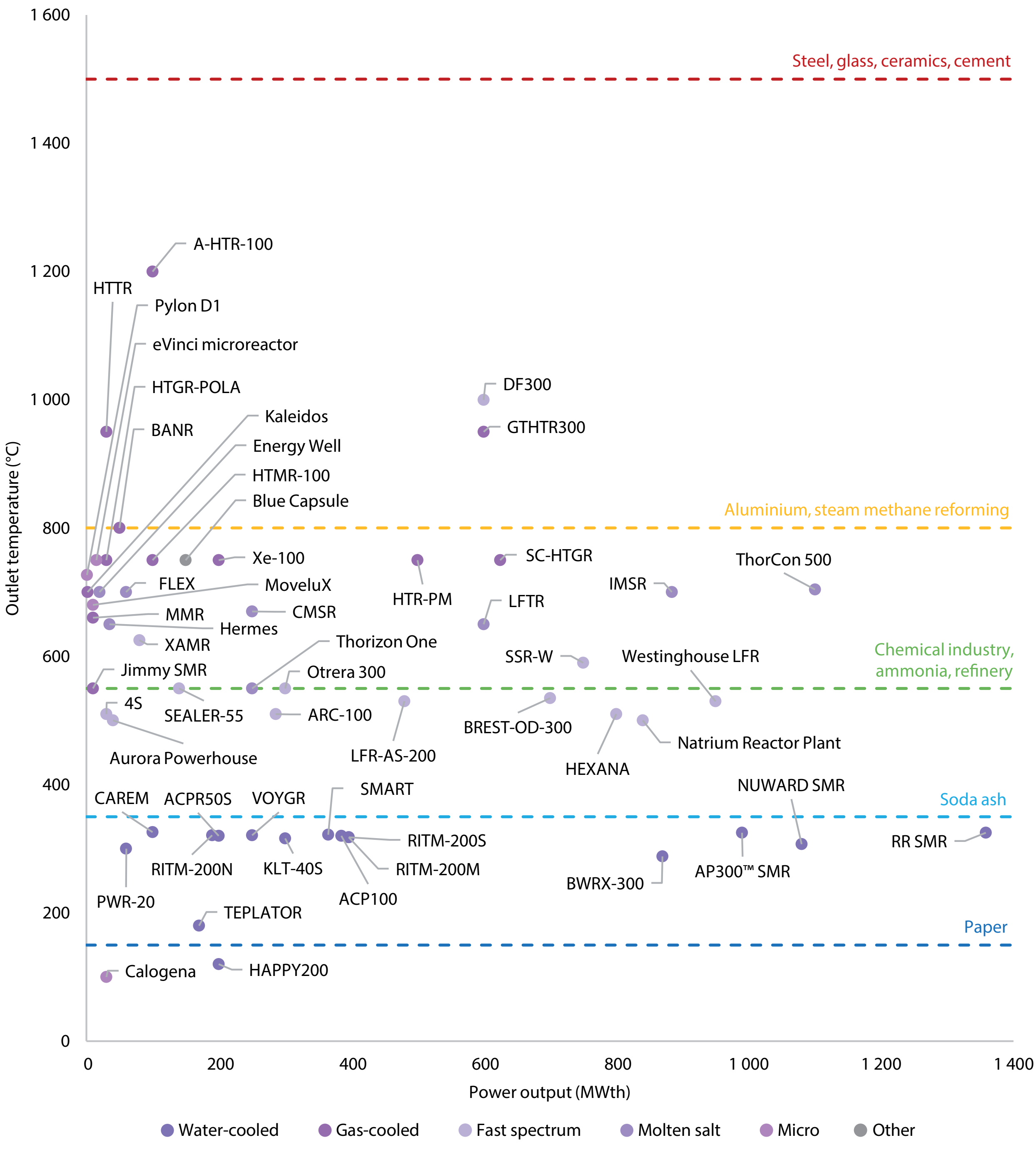
The configurations are no longer limited to being land-based, with some marine-based reactors now operating. Additional novel deployment pathways are also planned, including reactor systems consisting of multiple modules and mobile reactors designed for portability.

Figure 20. **Reactor configurations**



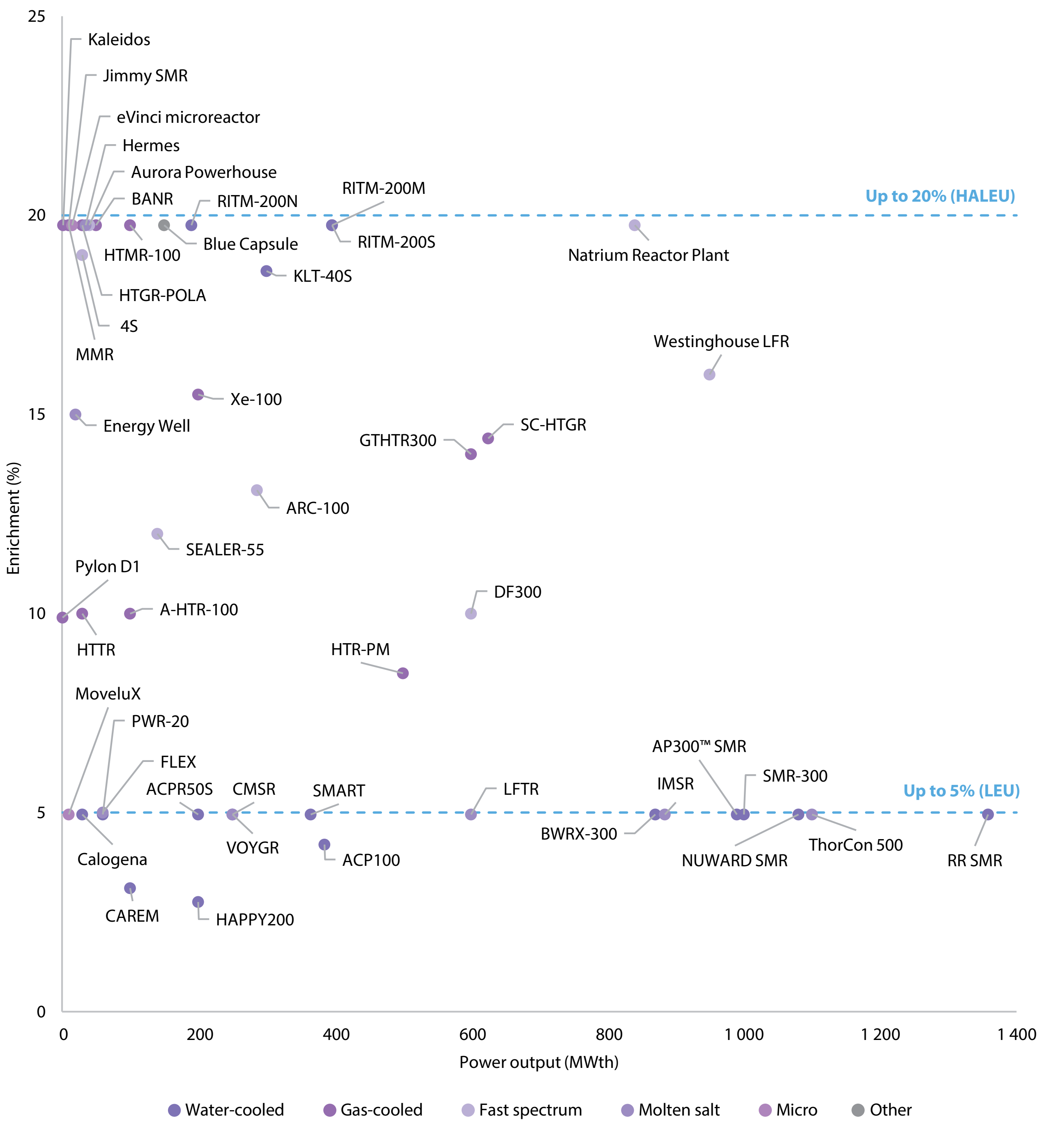
As a class of reactors, SMRs are defined by their smaller size, but there exists considerable variety within this class of reactors; they vary by power output, outlet temperature, technology and fuel cycle. A number of SMRs are based on existing commercially deployed light water technologies, while others 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 100°C to more than 850°C to meet the specific energy needs of hard-to-abate industrial sectors (Figure 21).

Figure 21. **SMRs: Range of sizes and temperatures for heat applications**



SMR designs currently under development also incorporate various fuel cycles, each associated with different types of fuels and levels of enrichment (as shown in Figure 22). The uranium enrichment levels range from 5% or less, similar to existing commercial light water reactors, up to 20% for some novel designs. These higher uranium enrichment levels will have a direct impact on the fuel supply chain, potentially necessitating new investments to meet these requirements.

Figure 22. **SMRs: Range of sizes and uranium enrichment requirements**



Previous figures have shown that SMR designs currently under development encompass a wide range of concepts, configurations, sizes, outlet temperatures and fuel cycles. These technical features broaden the traditional market of nuclear energy. For example, some SMR technologies may be particularly suitable for applications and hard-to-abate sectors such as heavy industry, mining and merchant shipping, where large-scale nuclear and variable renewables may encounter some limitations.

- **Coal replacement for on-grid power**: Coal power is still the largest source of electricity generation and emissions globally. However, the fleet of coal power plants in OECD countries is slated for retirement due to ageing assets, accelerated decarbonisation policies and dwindling competitiveness. Momentum is growing globally to transition a portion of the global coal fleet to nuclear power, with commitments from utilities in the United States and Central Europe. This presents a significant short-term market opportunity for deploying SMRs in support of climate action.

  Due to their size and flexible deployment attributes, SMRs are well-suited to replace coal power plants, many of which are smaller than 500 MWe. SMRs offer dispatchability, energy density and ability to reuse existing infrastructure. Capital costs will be the primary driver of SMR competitiveness. Beyond serial deployment, cost reductions are possible by reusing existing coal infrastructure. Meanwhile, potentially increasing fossil fuel costs, carbon pricing and stricter environmental regulations may improve the relative competitiveness of SMRs over fossil fuel alternatives. Additionally, SMRs can be part of a diversified technology portfolio that integrates nuclear power with renewables to minimise system costs and mitigate grid reliability risks. Coal-to-nuclear transitions also bring social benefits and support a just transition for local communities, offering opportunities to retrain and retain the existing coal workforce and to bring additional high-pay jobs during both construction and operation. The short-term market potential is significant, with demand reaching up to 380 GW by 2040, mainly driven by coal power plant retirements in the United States, Europe and Korea (NEA, forthcoming). The United States alone represents around 70% of this market.
- **Fossil fuel cogeneration replacement for industries**: As of 2022, heavy industries were responsible for around 25% of carbon emissions globally (IEA, 2023). Demand for heat is also significant and it is currently being met primarily by burning fossil fuels. Many SMR designs will operate over 250 degrees Celsius and could create the first real non-emitting alternative to fossil fuel cogeneration by offering combined heat and power solutions for industrial customers. To effectively unlock this market, it is crucial that the design of nuclear reactors is compatible with existing industrial processes. A majority of industrial applications use fossil-based on-site cogeneration plants that are replaceable by nuclear reactors, representing a “plug-in market” for SMRs. However, other applications require direct heating at high temperatures, often involving highly integrated and optimised systems, where incorporating a nuclear reactor could necessitate extensive reengineering and significant adaptations to existing processes. The oil sands, chemicals and ammonia sectors are part of the plug-in market opportunities that could be first movers for commercial deployment of SMRs for industry. Applications such as pulp and paper, oil refining and aluminium, in particular, have lower process compatibility and would require significant reengineering to accommodate SMRs (NEA, 2022).
- **Diesel replacement for off-grid mining**: Mining is a strategic sector in OECD countries, providing resources, supporting supply chains and economic growth, including in rural communities, and enabling the clean energy transition. The mining sector represents 2-3% of global carbon emissions, with demand expected to increase significantly in the coming years. Some mining companies are exploring the use of SMRs to support the decarbonisation of their activities. In North America, SMRs are being considered for large grid-connected mines at brownfield sites to support both mining and mineral processing activities. In Poland, efforts are moving forward to deploy SMRs for copper mining and processing. Off-grid mining offers the most promising near-term opportunities to decarbonise with SMRs at sites where energy costs are high and energy options limited. SMRs could replace diesel generators at these sites, which require on average 16 MWe of power to operate. The NEA (forthcoming) estimates that the market for SMRs for brownfield remote mining could reach more than 2 GWe, primarily concentrated in Australia, Canada, Chile, Indonesia, Russia, the United States and Sub-Saharan Africa. NEA analysis projects a growing need for remote mining due to increased demand for critical minerals, which are essential to technologies that are required for the clean energy transition. The NEA has found that 16% of critical mineral deposits globally are located more than 20 kilometres from an electricity grid, and that certain specific critical minerals – such as rare earth elements lithium, cobalt and copper – are more commonly found in these remote areas.

- **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 used for district heating in at least 11 countries (EPRI, 2022). While these examples are all large nuclear power plants, there is an opportunity for SMRs to provide district heating and, due to their smaller footprint, they may be better suited to some sites. According to a recent NEA survey, potential end users interested in adopting SMRs for district heating applications include university campuses, downtown urban centres, hospitals, government and military facilities, and airports.
- **Fossil fuel replacement for data centres**: The rapid development of artificial intelligence and other digital technologies is creating new and rapidly growing market demand for reliable electricity for data centres. Digital applications process vast amounts of data stored in servers within these centres. These facilities require continuous and reliable power and cooling for their servers and associated subsystems. To keep pace with the increasing demand for digital applications, there is a need for new data centres, potentially operating off-grid. As a source of low-carbon, baseload power capable of meeting small, off-grid power requirements, SMRs are being considered by companies like Microsoft as an option to power their operations (Microsoft, 2023).

Box 4. **Emerging markets for SMRs**

Data collected for the *NEA SMR Dashboard* reveal four potential and significant near-term markets for SMRs:

1. Coal replacement for on-grid power;
2. Fossil fuel cogeneration replacement for industries, including hydrogen production;
3. Diesel replacement for mining; and
4. Fossil fuel replacement for data centres.

Figure 23. **Examples of sites of near-term emerging markets for SMRs**

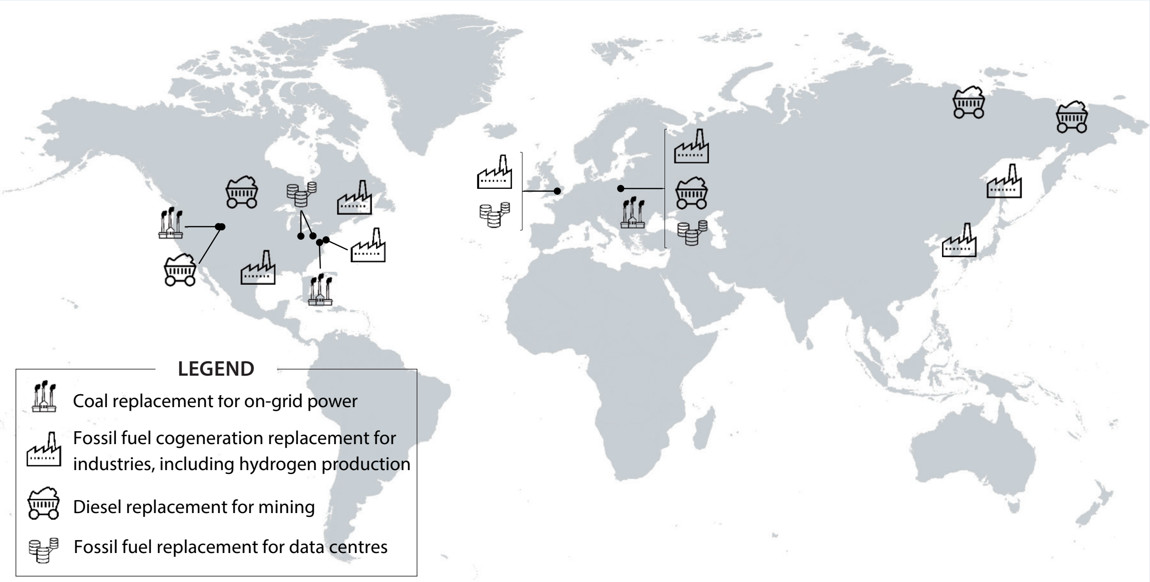
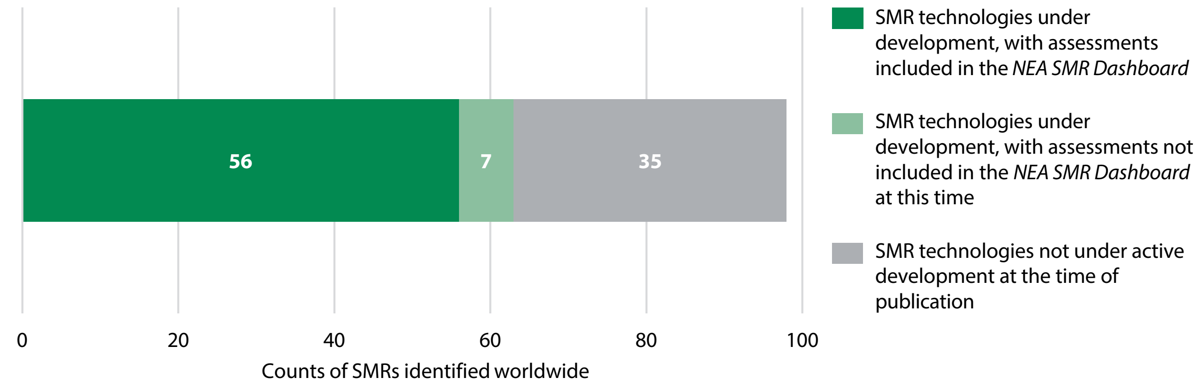


Table 3. **Examples of near-term demand for SMRs in emerging markets**

Coal replacement for on-grid power:
• PacifiCorp has chosen the Natrium technology to replace coal at its Kemmerer plant in Wyoming, United States, and is contemplating additional coal replacement projects using SMRs beyond 2035. • The Maryland Energy Administration is collaborating with X-energy to explore repowering a coal site in Maryland, United States. • In Romania, RoPower, a joint venture of Nuclearelectrica and Nova Power & Gas, is evaluating the NuScale VOYGR concept to replace coal at the Doicesti plant.
Fossil fuel cogeneration replacement for industries, including hydrogen production:
• Dow Chemical has selected X-energy's Xe-100 design for its facility in Seadrift, Texas, United States. • ORLEN Synthos Green Energy is exploring the BWRX-300 design for hydrogen production and decarbonising chemical activities in Poland. • Canada's Belledune Port Authority has shortlisted the ARC-100 to provide firm heat and power for industrial users at its Green Energy Hub in New Brunswick, Canada. • Holtec is a member of the Mid-Atlantic Clean Hydrogen Hub (MACH2), which includes Holtec's Oyster creek site in the United States, where Holtec is considering deploying its SMR-300. • Last Energy has signed power purchase agreements (PPAs) with industrial partners in the United Kingdom and Poland, including for hydrogen production capacity. • In Korea, GS Energy and the Uljin County signed a Memorandum of Understanding (MoU) to conduct feasibility studies of using NuScale VOYGR for hydrogen production. • Rolls-Royce SMR has a MoU as well as a Memorandum of Intent with the Polish industrial group Industria to develop plans towards deploying Rolls-Royce SMRs to decarbonise Industria's activities in Poland, including through the production of clean hydrogen. • Kommersant, a Russian news outlet, has reported that natural gas company Gazprom is considering RITM-200S units for the Kirinskoye and Yuzhno-Kirinskoye gas condensate fields in the Sakhalin region.
Diesel replacement for mining:
• In Russia, a floating RITM-200S reactor is being considered to supply heat and power to the Baimskaya copper mine and mineral processing facility in Cape Nagleynyn, Russia, by 2027 and ROSATOM has an agreement to provide power to Seligdar, a Russian mining company, using a land-based RITM-200N SMR for gold mining operations in Yakutia, Russia, by 2028. • In Poland, KGHM is exploring the construction of several NuScale VOYGR modules for its copper mining activities by 2029. • BWX Technologies has been contracted by the Wyoming Energy Authority to assess the feasibility of deploying BANR microreactors for the power needs of trona mining operations in Wyoming, United States. • GE Hitachi Nuclear Energy also has an agreement with the Saskatchewan Industrial and Mining Suppliers Association to engage with local suppliers on the potential deployment of the BWRX-300 in Saskatchewan, Canada.
Fossil fuel replacement for data centres
• In 2023, Standard Power announced plans to work with NuScale to deploy SMRs at two data centres in Ohio and Pennsylvania, United States. • Last Energy has also signed PPAs with industrial partners in the United Kingdom and Poland, including for a data centre.

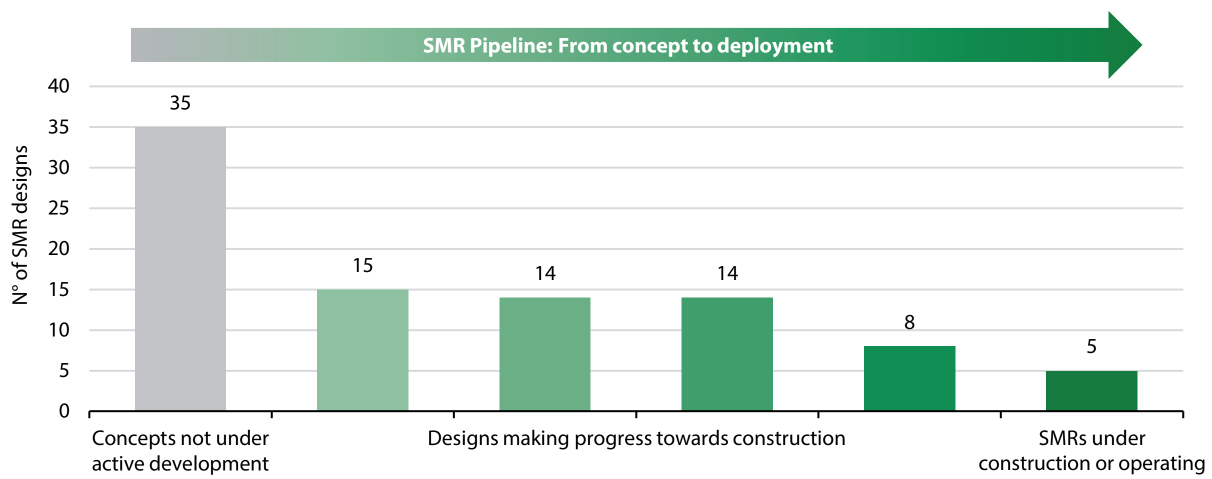
Overview of progress towards demonstration and commercialisation

Figure 24. **Count of SMRs identified worldwide**



For this second edition of the *NEA SMR Dashboard*, the NEA's comprehensive global review identified 98 SMR technologies around the world. Of those, 56 are included in this edition; these are the SMRs for which the requisite publicly available information was assessable and for which the relevant designers were willing to participate. The other 42 include approximately 7 that are under development but requested not to be included in the *NEA SMR Dashboard* at this time but may be included in the future; the others include SMR technologies that are not under active development, may be without human or financial resources, or have been cancelled or paused indefinitely.

Figure 25. **SMR pipeline: Progress from concept towards first commercial deployment**



The *NEA SMR Dashboard* provides the most comprehensive assessment to date of the progress towards SMR commercialisation, identifying designs that are making tangible progress and those that are in earlier stages of development (Figure 25). The *NEA SMR Dashboard* shows that three designs are already operating, and there is a robust pipeline of SMRs making progress towards first-of-a-kind deployment. A few SMRs are presently conceptual, though some of these may accelerate their progress towards first-of-a-kind deployment in the coming years. The breadth of designs may create opportunities to consolidate global supply chains, foster standardisation and improve the economics of SMRs for commercialisation.

The next sections present global trends and progress made in the areas of licensing, siting, financing, supply chain, engagement and fuel for SMRs.

Licensing

China and Russia are leading deployment

Figure 26 shows the pipeline of SMRs progressing through licensing around the world. For 23 SMR designs there is no information available from verifiable public sources related to licensing or pre-licensing activities. Twenty SMR designs are in the pre-licensing process, five have a licence application submitted, one SMR design has had its design approved, four have a licence to construction approved, and three are licensed to operate. More information is presented in Table 4.

Figure 26. **Licensing progress worldwide**

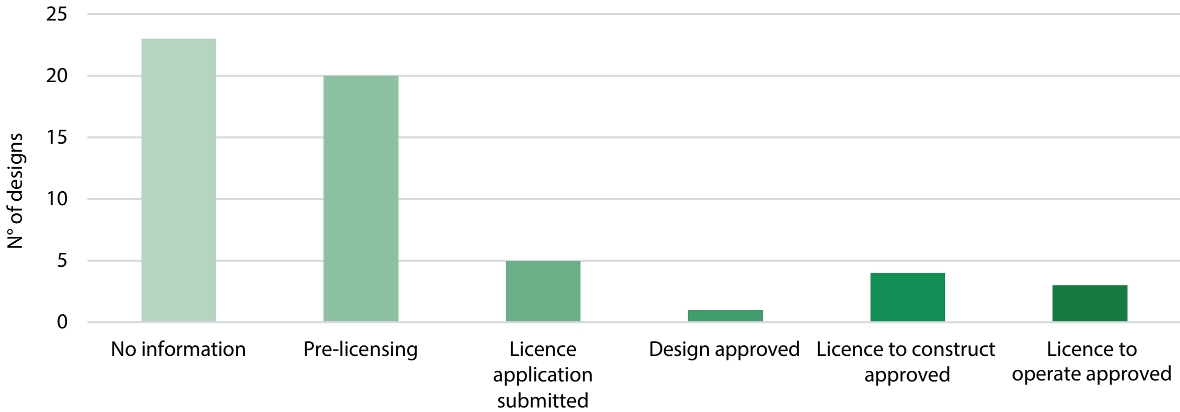
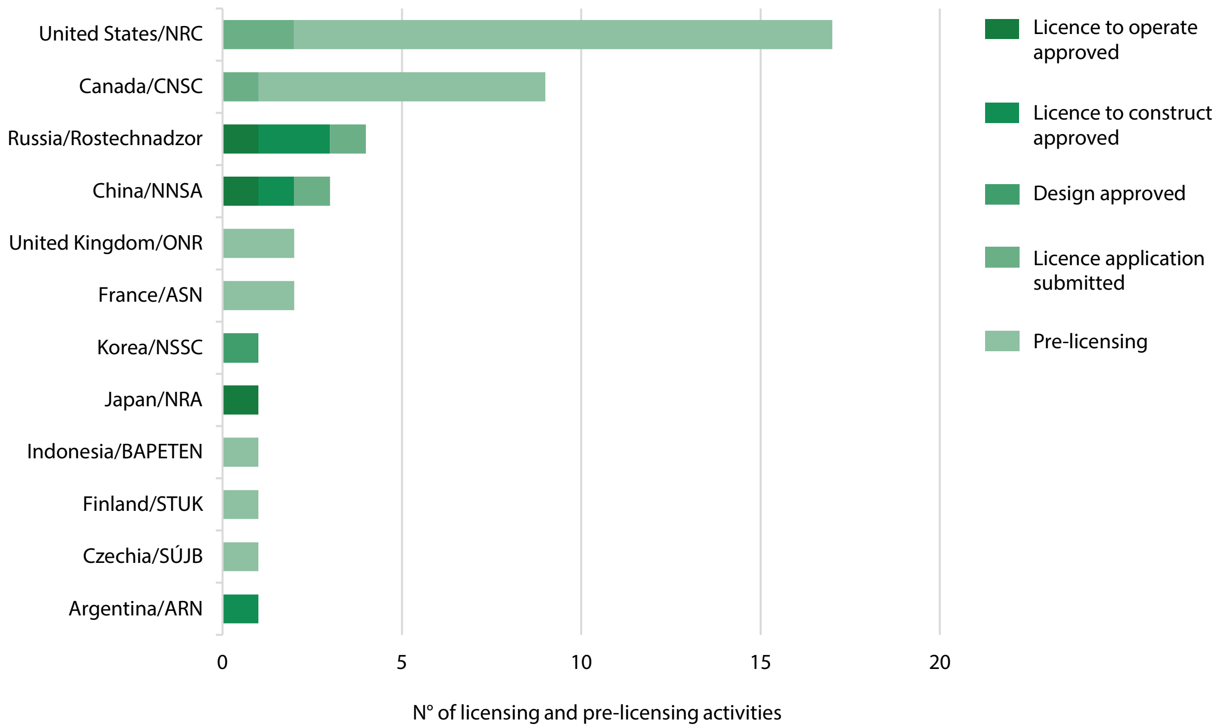


Table 4. **Licensing progress, detailed**

Licence to operate approved
• To date, there are three SMRs deployed and operating: the HTR-PM in China, the floating KLT-40S in Russia as well as the High Temperature Test Reactor (HTTR) in Japan. • Notably, the HTR-PM entered commercial operation in 2023.
Licence to construct approved
• Licences to construct have been approved for the CAREM SMR in Argentina, the ACP100 in China as well as the RITM-200N and the lead-cooled, fast-spectrum BREST-OD-300 in Russia.
Design approved
• Korea's Nuclear Safety and Security Commission has approved the SMART SMR design.
Licence/construction/design certification application submitted
• A total of 5 SMRs have submitted an application to regulators: NuScale Power's VOYGR SMR in its six-module configuration (VOYGR-6) and Kairos Power's Hermes demonstration reactor in the United States, GE Hitachi Nuclear Energy's BWRX-300 in Canada, ROSATOM's floating RITM-200S in Russia and CGN's floating ACPR50S in China.
Pre-licensing
• Twenty SMRs have started pre-licensing activities around the world. • This second edition of the *NEA SMR Dashboard* sees Radiant Industries' Kaleidos SMR entering into pre-licensing as the US NRC has reported that it expects to review a licence application for Kaleidos during the 2024 fiscal year. ARC Clean Technology's ARC-100 SMR also entered into pre-licensing with the US NRC, in addition to ongoing pre-licensing activities with the Canadian Nuclear Security Commission (CSNC) already reported in the first edition of the *NEA SMR Dashboard*.
No Information
• At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities for 23 SMRs.

Figure 27 presents the number of SMRs in pre-licensing or licensing activities with nuclear safety regulators around the world (identified by country). China, Russia and Japan have SMRs already licensed to operate. Various SMRs are engaged in pre-licensing or licensing activities in the United States, Canada, Russia and China. More are pursuing pre-licensing activities in the United Kingdom, France, Indonesia, Finland and Czechia. Most pre-licensing engagement is taking place in the United States and Canada.

Figure 27. **Count of SMRs in pre-licensing or licensing activities with nuclear safety regulators, by country**



Note: Some SMRs are engaged with nuclear safety regulators in multiple countries.

Towards regulatory frameworks to support large-scale deployment of SMRs

Current regulatory frameworks are tailored for traditional water-cooled, single-unit, land-based reactors used for on-grid electricity applications. The unique features of SMR technology, such as new fuels, diverse configurations, varying outlet temperatures and novel applications, create demand and opportunity for more flexible, risk-informed and technology-inclusive regulatory frameworks that can also enable efficiency across different jurisdictions (NEA, 2021b).

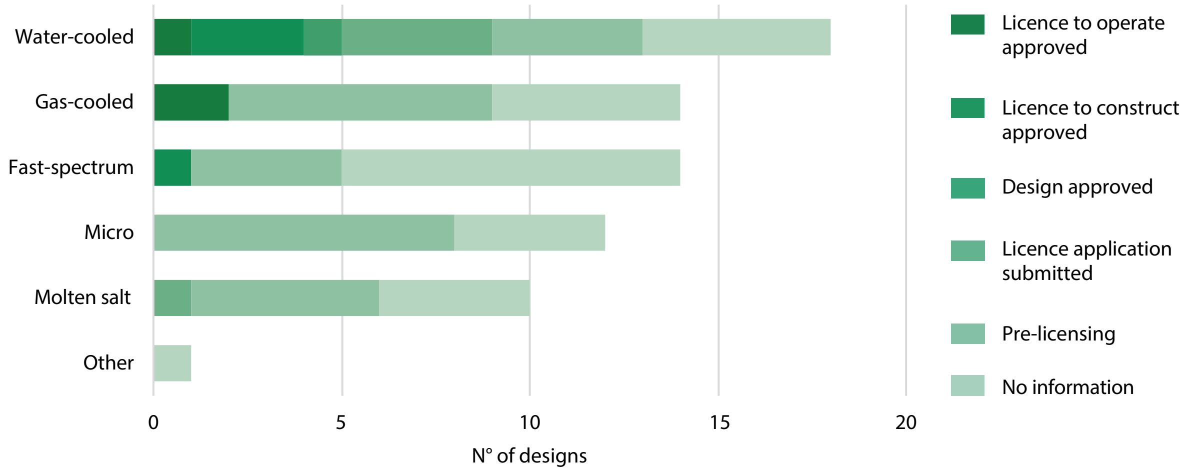
Some assessments in the *NEA SMR Dashboard* reveal encouraging trends from a regulatory standpoint that could accelerate SMR deployment. Notably, early collaboration and joint reviews between regulators are being undertaken with the primary goals of sharing knowledge, establishing best practices, finding common positions and equivalences, and avoiding costly duplications. For instance, the US NRC and the CNSC are collaborating on the reviews of IMSR by Terrestrial Energy and Xe-100 by X-energy. In Europe, NUWARD SMR by NUWARD (a subsidiary of EDF) is undergoing a joint review by national regulators from France, Czechia and Finland, and regulators from the Netherlands, Poland and Sweden have indicated their interest to join the joint review initiative.

Novel applications and deployment strategies also need interactions with other non-nuclear regulatory bodies. For example, Seaborg Technologies has engaged with the maritime classification society ABS for approvals related to deploying its CMSR concept on barges.

Other SMR developers are pursuing an incremental approach, which involves designing, licensing and constructing non-commercial demonstrators. This approach is particularly relevant for innovative designs. These non-commercial demonstrators often follow unique licensing pathways, as seen in projects like Hermes by Kairos Power and Project Pele by BWX Technologies, which is supported by the US Department of Defense.

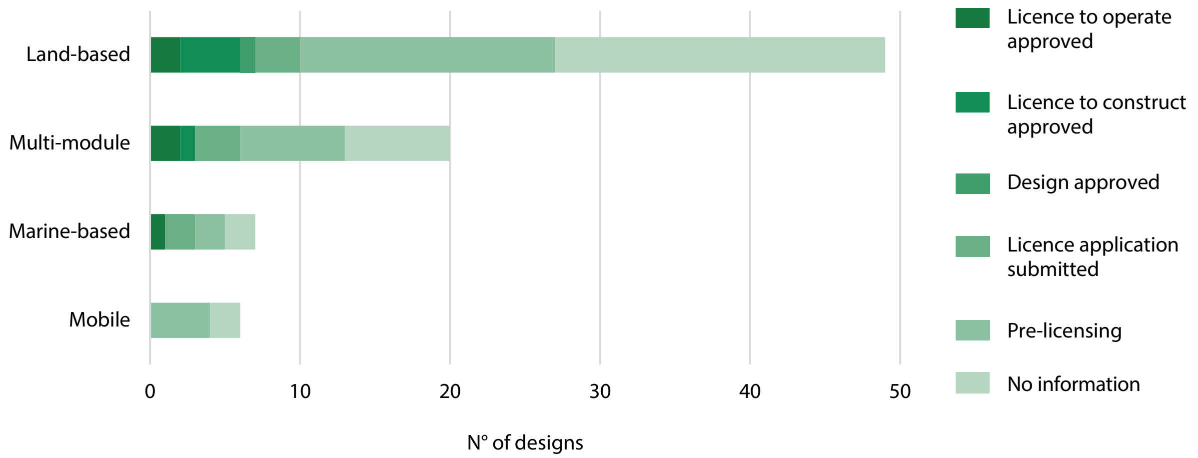
The majority of non-water-cooled and non-land-based reactor designs are in the pre-licensing phase (Figure 28 and 29). This illustrates the challenges that remain for regulators to develop necessary competencies to licence most innovative designs.

Figure 28. **Licensing progress by SMR concept**



Note: Some SMRs correspond to multiple reactor concepts (e.g. an SMR can be both a fast-spectrum and molten salt reactor).

Figure 29. **Licensing progress by SMR configuration**



Note: Some SMRs correspond to multiple reactor configurations (e.g. an SMR can be both a land-based and mobile reactor).

Siting

Real and rapid progress towards deployment in North America and Europe

Figure 30 shows the pipeline of SMRs progressing through siting around the world. For 18 SMRs there is no information related to siting that was readily available from any site owners. Fourteen SMRs have entered non-binding agreements with site owners that are considering possible deployment. Seventeen SMRs have been selected by site owners for deployment on their sites. In Russia, one SMR received its permit for construction, one started construction on site and one is already operating. In China, one SMR is being built and one is already operating. Construction started on site for one SMR in Argentina and one SMR is also already operating in Japan. More information is presented in Table 5.

Figure 30. **Siting progress worldwide**

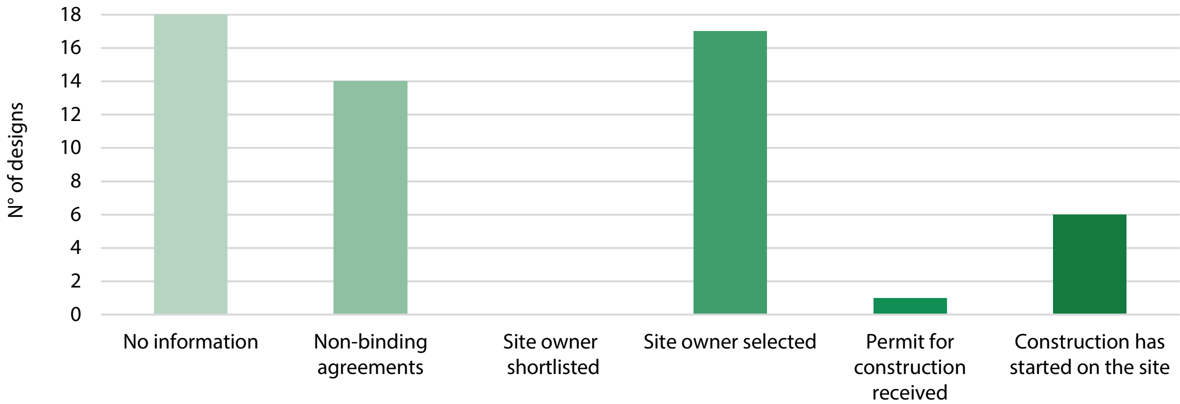
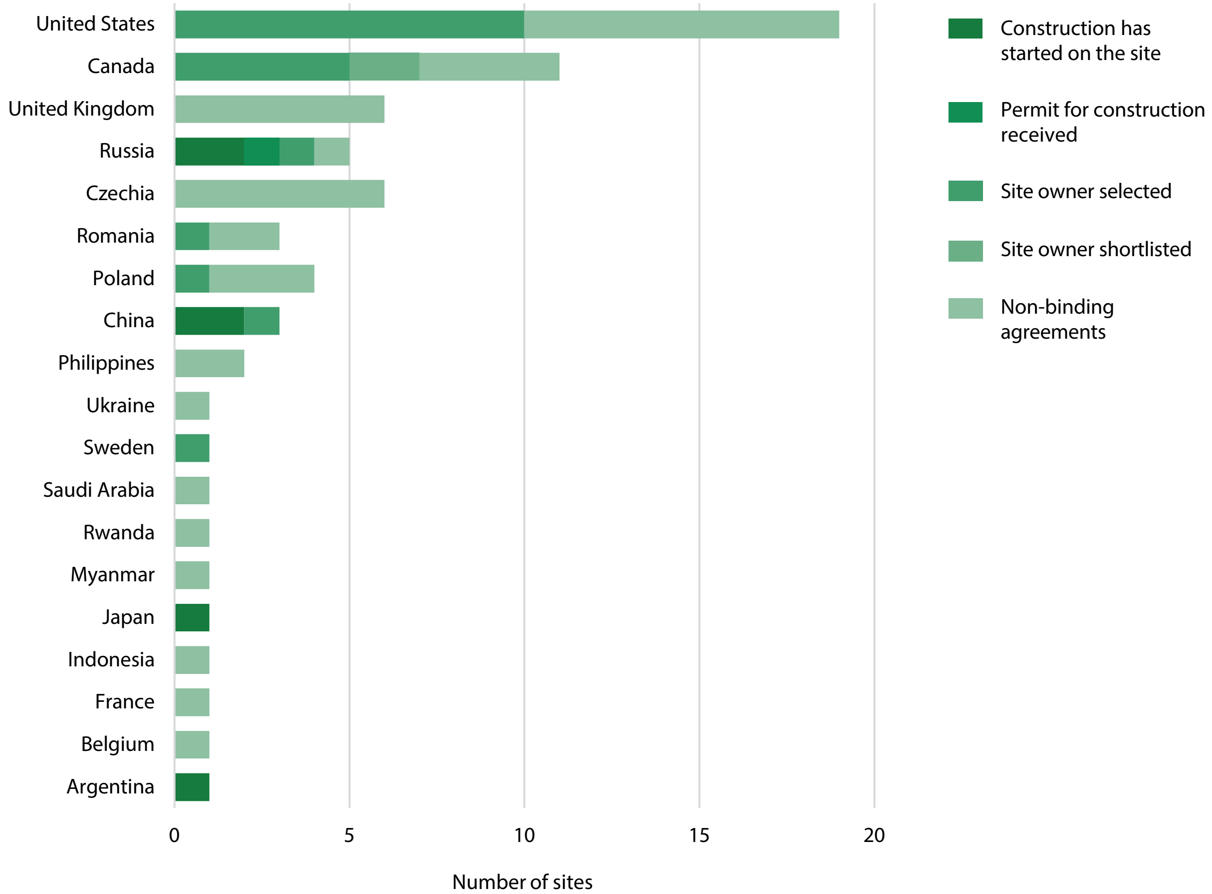


Table 5. **Siting progress, detailed**

Construction has started on the site or operation has started
• Three SMRs have already started operating: the HTR-PM in China, the floating KLT-40S in Russia as well as the High Temperature Test Reactor (HTTR) in Japan. • Construction has started on sites for three additional SMRs: the CAREM SMR in Argentina, the ACP100 in China as well as the lead-cooled, fast-spectrum BREST-OD-300 in Russia.
Received permit(s) and/or licence(s) for construction on the site
• The RITM-200N received its permit for construction in 2023.
Site owner has selected the technology
• Seventeen SMRs have been selected by site owners for deployment around the world. • Westinghouse's eVinci microreactor, Radiant Industries' Kaleidos SMR and Ultra Safe Nuclear Corporation's Pylon D1 have been selected for deployment at the Idaho National Laboratory's (INL) Demonstration and Operation of Microreactor Experiments (DOME) facility in Idaho, United States. • X-energy's Xe-100 also progressed towards siting, with Dow Chemical selecting the technology for deployment at its facility in Seadrift, Texas (United States).
Site owner shortlisted
• There are no SMRs to report with this status at this time.
Non-binding agreements
• Fourteen SMRs have entered into non-binding agreements with site owners including, for example, three SMRs that entered into non-binding agreements with site owners in 2023: BWX Technologies' BANR with the Wyoming Energy Authority and Tata Chemicals Soda Ash Partners (TCSAP) in the United States; University of West Bohemia's TEPLATOR SMR with the city of Slavutych in Ukraine; and Westinghouse's Westinghouse LFR with SCK CEN and RATEN for potential deployment in Mol, Belgium, and Pitesti, Romania, respectively.
No Information
• For 18 SMRs, there is no information related to siting that was readily available from any site owners at the time of assessments.

Figure 31 presents the number of site owners with projects for SMR deployment around the world (identified by country). China, Russia and Japan have SMRs already operating and additional SMRs are under construction in China, Russia and Argentina. Various SMRs have been selected by site owners in six countries: the United States, Canada, Russia, Romania, China and Sweden. There is a significant number of non-binding agreements between SMR developers and site owners around the world, in particular in the United States and Canada. Notably, six SMRs participating in the United Kingdom's innovative nuclear technology competition for potential deployment in the country also signed non-binding agreements with the nuclear operator ČEZ for potential deployment at the nuclear power plant site Temelin, in Czechia.

Figure 31. **Siting progress by country**



Note: Some SMRs have siting activities in multiple countries.

Sites for industrial applications are starting to emerge

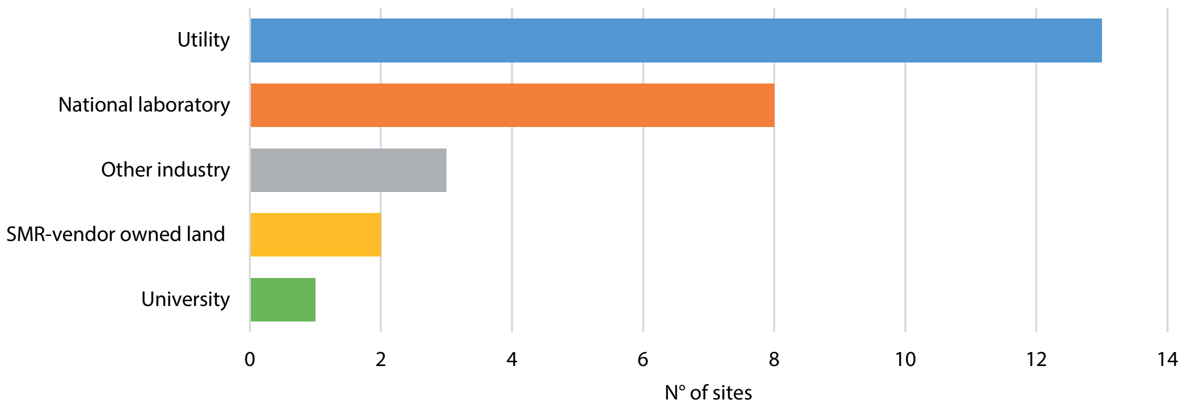
The majority of sites currently identified for SMR deployment are owned by utilities and governments. Several utilities are considering deploying SMRs at existing large-scale nuclear sites. This approach might unlock cost reductions through the reuse of existing infrastructures and may benefit from community support by creating and preserving jobs. For example, Ontario Power Generation (OPG) has selected the BWRX-300 SMR for deployment at its Darlington site in Canada, and ČEZ has signed at least six non-binding agreements with different SMR developers for potential deployment, including at its Temelin nuclear site in Czechia. Uniper formed a joint venture with Blykalla to advance the SEALER reactor concept at the Oskarshamn Nuclear Power Plant in Sweden.

In addition to using existing infrastructures, this approach leverages existing licences and supply chains to reduce construction project risks and accelerate deployment. For similar reasons, several utilities are considering deploying SMRs to replace soon-to-retire fossil-fuel assets. In the United States, for example, PacifiCorp has selected the Natrium Reactor Plant to replace the retiring coal-fired Naughton Power Plant in Kemmerer, Wyoming, and the Maryland Energy Administration has selected X-energy's Xe-100 technology to investigate the feasibility of repowering a coal site in Maryland. In Europe, RoPower, a joint venture of Nuclearelectrica and Nova Power & Gas, has a contract with NuScale Power for front-end engineering and design, environmental impact assessment, site evaluation and site-specific requirements for deployment of NuScale Power's SMR in a VOYGR-6 configuration at the Doicesti site in Romania. A forthcoming analysis from the NEA estimates the near-term market potential for coal replacement to be significant, with demand reaching up to 380 GW by 2040, mainly in the United States, Europe and Korea (NEA, forthcoming).

Governments are also supporting the deployment of SMRs through siting opportunities on government-owned sites. National laboratories are being leveraged to host initial demonstration projects, in particular for some non-water-cooled SMR technologies. For example, at least five different SMRs, notably all microreactors, have been selected for deployment on Idaho National Laboratory's owned land, including USNC's Pylon D1, Radiant Industries' Kaleidos, Westinghouse's eVinci microreactor, Oklo's Aurora powerhouse and BWX Technologies' Project Pele. Canadian Nuclear Laboratories has signed a project host agreement with Global First Power and selected a site at Chalk River Laboratories to deploy the USNC's MMR, and is discussing possible deployment of other SMRs, including KAERI's SMART SMR, at Chalk River Laboratories. New sites, particularly for non-electrical applications, are also emerging (Figure 32). For example, Canada's Belledune Port Authority has shortlisted ARC Clean Technology's SMR for potential deployment at the port's announced Green Energy Hub and Dow Chemical has selected X-energy's SMR to replace fossil fuel combined heat and power capacities at its manufacturing facility in Seadrift, Texas (United States). In Russia, a floating RITM-200S reactor is being considered to supply heat and power to the Baimskaya copper mine and mineral processing facility in Cape Nagleynyn, and ROSATOM has an agreement to provide power to Seligdar, a Russian mining company, using a land-based RITM-200N SMR for gold mining in Yakutia.

These developments highlight an important value proposition of SMRs that goes beyond on-grid power applications and targets so-called hard-to-abate sectors including heavy industries. For more details, refer to Box 4 on emerging markets for SMRs.

Figure 32. **Types of site owners for SMRs selected for deployment, under construction, or already operating**



Note: This chart only considers projects where the site owner has selected an SMR technology or SMRs are already under construction or operating. Some SMRs may be involved in multiple projects with different site owners.

Financing

SMR development is primarily driven by public-private partnerships

Figure 33 shows the pipeline of SMRs progressing through financing around the world. For 8 SMR designs there is no information available from verifiable public sources related to financing activities. Sixteen SMR designs have at least one announcement in financing, thirteen have at least five announcements or secured at least USD 100 million, and seven have ten or more announcements or secured USD 500 million in financing. The *NEA SMR Dashboard* identifies eleven SMR first-of-a-kind (FAOK) designs that are already fully financed: in the United States, Argentina, China and Russia. Finally, there is one SMR in Russia which has made progress towards Nth-of-a-kind (NOAK) financing. More information is presented in Table 6.

Figure 33. **Financing progress worldwide**

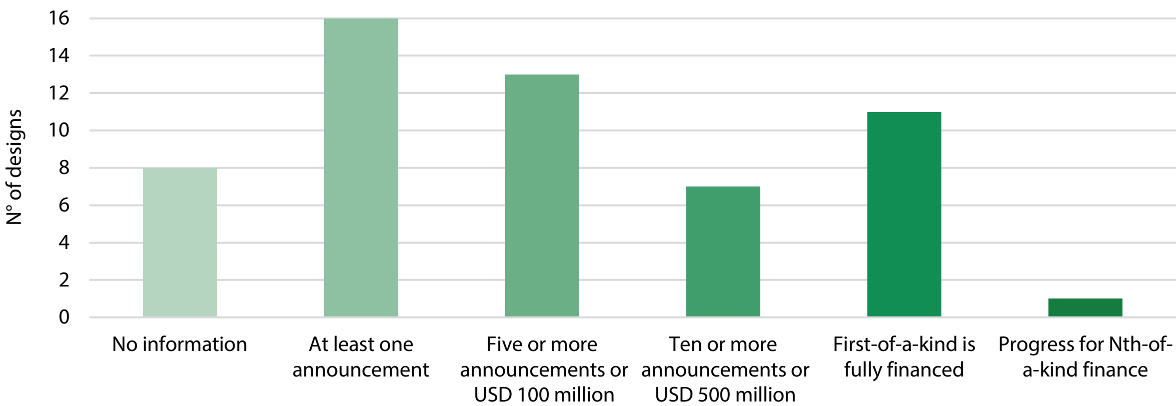


Table 6. **Financing progress, detailed**

FOAK financed and progress for NAOK finance
• The floating RITM-200S reactor in Russia is the only SMR in the *NEA SMR Dashboard* that has already demonstrated progress towards NOAK financing.
FOAK fully financed
• Eleven SMRs are assessed to have their FOAK fully financed. • In addition to the six SMRs that are already operating or for which construction has started on site (see Table 4), two FOAK projects are fully financed in the United States (Kairos Power's Hermes and BWX Technologies' Project Pele), one in Canada (GE Hitachi Nuclear Energy's BWRX-300), one in China (CGN's ACPR50S), and one in Russia (ROSATOM's RITM-200N).
Ten or more announcements or USD 500 million
• Seven SMRs have ten or more announcements or secured USD 500 million in financing.
Five or more announcements or USD 100 million
• Thirteen SMRs have five or more announcements or secured USD 100 million in financing. • Notably, Radiant Industry's Kaleidos SMR and USNC's MMR both demonstrated progress in 2023 towards FOAK financing.
At least one announcement
• Sixteen SMRs have at least one announcement in financing.
No information
• Eight SMRs have no information available from verifiable public sources related to financing activities.

The *NEA SMR Dashboard* finds that public-private partnerships are the predominant approach for financing SMRs. For example, the US DOE has awarded six SMRs – BWX Technologies' BANR, Holtec International's SMR-300, Kairos Power's Hermes, TerraPower's Natrium Reactor Plant, X-energy's Xe-100, and Westinghouse's eVinci microreactor – cost-sharing grants for up to USD 3 billion through the Advanced Reactor Demonstration Program (ARDP). In France, the France 2030 initiative has granted EUR 500 million to the NUWARD SMR project and an additional EUR 500 million for the development of new designs.

Alongside government support, the *NEA SMR Dashboard* illustrates the growing role of private equity and market-based financing for SMRs. Private companies or local community associations made minority equity investment in at least six SMRs: ARC Clean Technology's ARC-100, Moltex Energy's SSR-W, Rolls-Royce SMR's RR SMR, Seaborg Technologies' CMSR, USNC's MMR, and X-energy's Xe-100. TerraPower has also raised over USD 830 million for the Natrium Reactor Plant through one of the largest private capital raises in the advanced nuclear industry and *new*cleo launched in 2023 a financing round with the objective of raising up to USD 1.05 billion. Finally, NuScale Power became a publicly traded company in May 2022, while Oklo has announced its plan to become publicly traded in 2024.

Some SMR vendors are also progressing towards financing their FOAK by securing the purchase of electricity from end users through power purchase agreements (PPA) or off-take agreements. For instance, ROSATOM has secured an off-take agreement for its RITM-200N SMR in Yakutia and Last Energy announced it had signed four PPAs with industrial partners in the United Kingdom and Poland for its PWR-20 SMR. These agreements are particularly relevant for industrial players who do not seek to own or operate an SMR but are ready to agree to pay for reliable, low-carbon power. While off-take agreements can facilitate project financing by mitigating electricity price uncertainty, they do not address construction risks, which can be significant, especially for first-of-a-kind SMR projects. Some SMRs are creating consortia to share risks.

Supply chain

Intense collaboration to quick-start supply chain capabilities and reduce risks

Figure 34 shows the pipeline of SMRs progressing through supply chain around the world. For 7 SMR designs there is no information available from verifiable public sources related to supply chain activities. Fifteen SMR designs have participated in events or entered into non-binding announcement to develop their supply chain. Eight SMRs have entered into binding contracts for services and materials and 20 SMRs have partnered or have started joint ventures or consortia specifically with engineering, procurement and construction (EPC) companies. Three SMRs have started construction on site: in Argentina, China and Russia. More information is presented in Table 7.

Figure 34. **Supply chain progress worldwide**

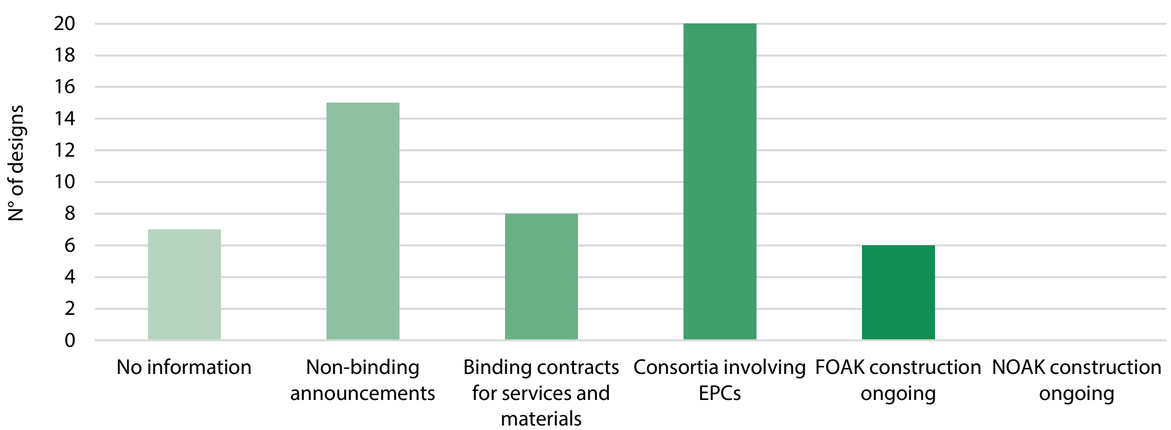
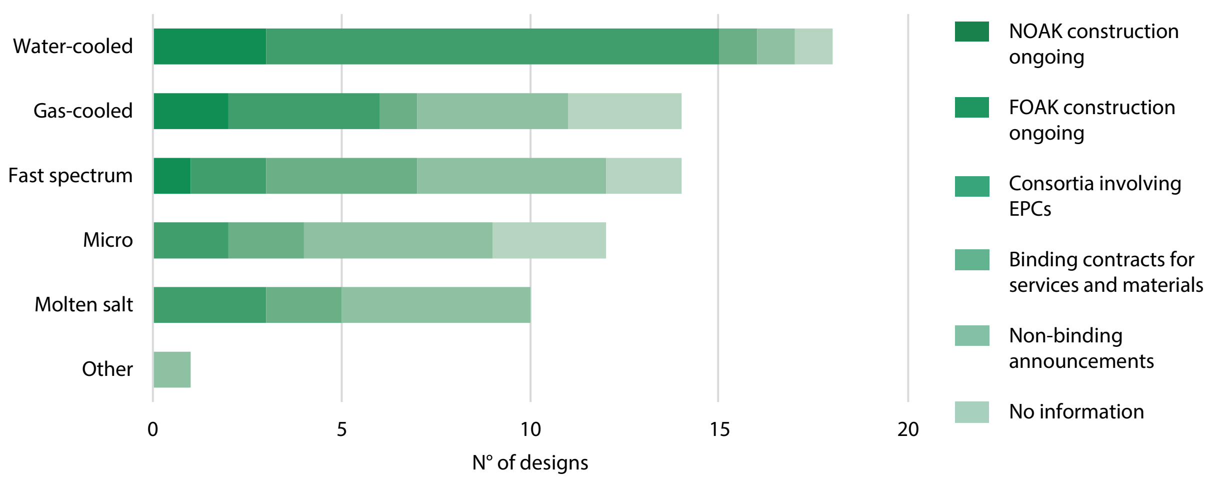


Table 7. **Supply chain progress, detailed**

NOAK construction ongoing
• To date, there are no Nth-of-a-kind SMRs under construction.
FOAK construction ongoing/complete
• Three SMRs are under construction: CAREM in Argentina, the ACP100 in China and the BREST-OD-300 in Russia.
Partnerships/joint ventures/consortia – all with EPCs
• Twenty SMRs have partnerships, joint ventures or consortia with EPC companies. • Out of these 20 SMRs, 13 are developed by either incumbent civil nuclear stakeholders or governmental research institutions, including: China General Nuclear Power Group (CGN), GE Hitachi Nuclear Energy, Holtec International, Japan Atomic Energy Agency (JAEA), Korea Atomic Energy Research Institute (KAERI), NUWARD, Rolls-Royce SMR, ROSATOM, State Power Investment Corporation (SPIC) and, Westinghouse Electric Company.
Binding contracts for services & materials
• Eight SMRs from six countries (Canada, France, Poland, Sweden, the United Kingdom and the United States) have entered binding contracts for services and materials with supply chain companies. • Notably, *new*cleo's LFR-AS-200, NCBJ's HTGR-POLA and Westinghouse's eVinci microreactor entered such binding contracts in 2023.
Supplier days/events/workshops/trade shows/non-binding agreements/MoUs/non-binding announcements
• Fifteen SMRs have entered into non-binding agreements to develop their supply chain.
No information
• For seven SMRs, no information related to supply chains was readily available.

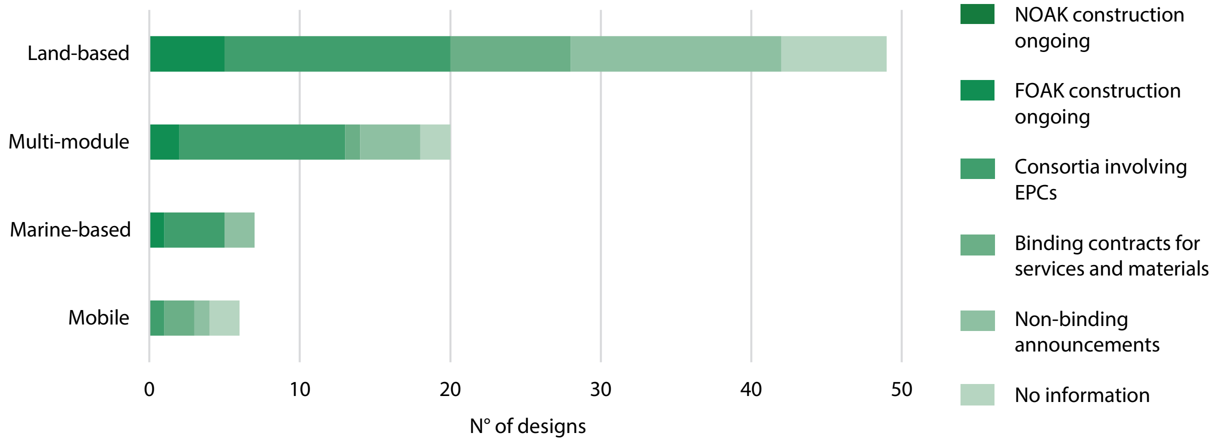
Figures 35 and 36 present SMR progress in the area of supply chains, by concepts and configurations respectively. While water-cooled, land-based technologies appear to benefit from the most mature supply chains, all technologies and concepts are represented throughout the different stages of progress. The *NEA SMR Dashboard* finds overall lower supply chain maturity for non-water-cooled technologies: 67% of microreactors as well as 50% of fast-spectrum, molten-salt, and gas-cooled reactors have not yet secured at least one binding contract for services and materials.

Figure 35. **Supply chain progress by SMR concept**



Note: Some SMRs correspond to multiple reactor concepts (e.g. an SMR can be both a fast-spectrum and molten salt reactor).

Figure 36. **Supply chain progress by SMR configuration**



Note: Some SMRs correspond to multiple reactor configurations (e.g. an SMR can be both a land-based and mobile reactor).

Water-cooled SMRs benefit from a larger pool of existing, qualified suppliers for many components. Some novel SMR concepts are also designed to incorporate existing qualified materials and components, leveraging incumbent supply chains, while establishing strategic collaborations to develop materials, components and manufacturing and construction processes.

Higher levels of supply chain integration provide greater control over critical activities and components and may help reduce construction risks, specifically for innovative designs with non-mature supply chains. Several SMR companies are leveraging or developing in-house nuclear engineering, manufacturing and construction capabilities. For example, in the United States, Kairos Power has received the American Society of Mechanical Engineers certification to manufacture U-stamped pressure vessels at its Albuquerque facility in New Mexico and Holtec International plans to expand its manufacturing capacities in Camden, New Jersey. *New*cleo has acquired at least three engineering companies in Italy with lead fast reactor experience.

The paradigm shift to fleet deployment has not started yet

The *NEA SMR Dashboard* finds that, to date, there are no indications of any SMR designs being engaged in serial construction of Nth-of-a-kind (NOAK).

One strategy to navigate market uncertainties and catalyse a robust order book for SMRs may be to form industrial consortia and "buyers' clubs" for a given design. An example of the spirit of this approach is the collaboration between Tennessee Valley Authority (TVA), Ontario Power Generation (OPG) and Synthos Green Energy for the BWRX-300 design by GE Hitachi Nuclear Energy. This partnership focuses on developing detailed designs for critical components of the BWRX-300 SMR, such as the reactor pressure vessels. In addition to constituting a sufficient order book for a unique design, this collaboration contributes to mitigating development risks and streamlining the licensing processes in the United States, Canada and Poland.

Engagement

Engagement efforts are focused on securing policy and community buy-in, talent pipeline and first markets

Figure 37 shows the pipeline of SMRs progressing on engagement with people and communities associated with their project. For 15 SMR designs, no recent information was readily available from verifiable public sources related to engagement activities. Twelve SMR designs have advanced at least one engagement activity, nine have advanced at least three engagement activities, and four have advanced at least five engagement activities. Four have advanced at least seven engagement activities and twelve have advanced more than ten engagement activities. More information is presented in Table 8.

Figure 37. **Engagement progress worldwide**

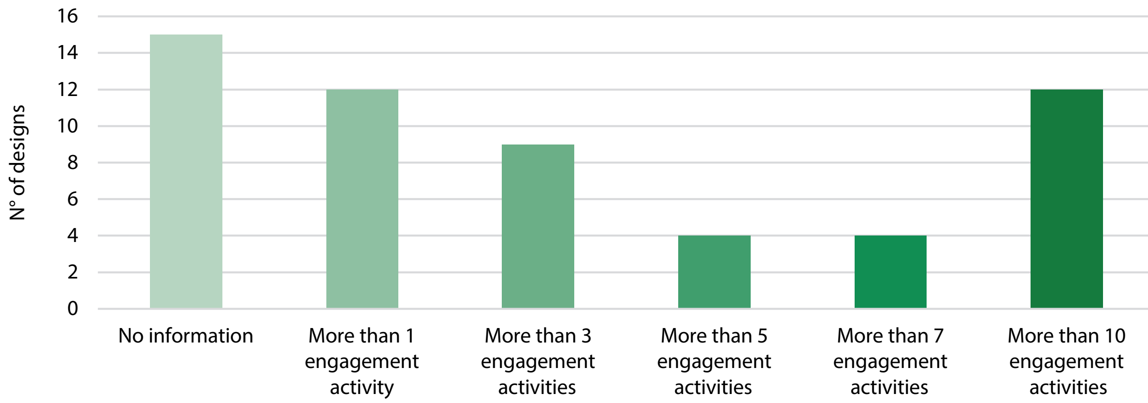


Table 8. **Engagement progress, detailed**

Ten or more engagements
• Twelve SMRs have advanced more than 10 engagement activities. • Notably, multiple national and local stakeholders in Indonesia reported to have met with ThorCon International in 2023 to advance its project of floating molten salt reactor in Indonesia.
Seven or more engagements
• Four SMRs have advanced seven or more engagement activities.
Five or more engagements
• Four SMRs have advanced five or more engagement activities.
Three or more engagements
• Nine SMRs have advanced three or more engagement activities.
One or more engagements
• Twelve SMRs have advanced one or more engagement activities.
No Information
• For 15 SMR designs, no recent information was readily available from verifiable public sources related to engagement activities.

Many SMR developers recognise the strategic importance of engaging with people and communities to build trust and public support. According to the assessments conducted for the *NEA SMR Dashboard*, approximately 70% of the SMR designs have advanced at least one engagement activity. Engagement is also the assessment area with the most progress since the first edition of the *NEA SMR Dashboard*, with almost 45% of the SMRs showing progress in 2023. Geographically, the SMRs with ten or more engagement activities are predominantly in North America and Europe.

The assessments in the *NEA SMR Dashboard* focus on the number of engagements by SMR designers with people and communities. The *NEA SMR Dashboard* shows how the nature and type of engagement activities can serve as a proxy indicator of the extent of a project's maturity. Typically, less mature technologies will focus on communicating with the general public, projects with more advanced designs will seek government and academic partnerships alongside contracts with end-users and the most mature projects engage with local and Indigenous communities. The most common types of stakeholder engagements pursued by SMR developers, along with some examples, are summarised below:

- **Government partnerships**: Securing endorsements and collaborations with relevant government ministries and agencies to support development and deployment in specific jurisdictions.
  - » ARC Clean Technology has secure support from New Brunswick provincial government in Canada for siting;
  - » CAREM construction is supported by Argentina's CNEA national agency;
  - » Rolls-Royce SMR has received endorsements from UK government officials;
  - » Terrestrial Energy advisors include former high-level government officials in Canada and the United States.
- **Academic partnerships**: Collaborating with universities for R&D, setting up training programmes and conducting student outreach to build awareness and skills.
  - » Moltex Energy engages with the University of New Brunswick's Centre for Nuclear Energy Research in Canada;
  - » NuScale opened "NuScale Energy Exploration Centers" at universities in the United States, Romania and Korea for student outreach;
  - » TEPLATOR development is taking place in collaboration with the Czech Technical University and the University of West Bohemia in Czechia.
- **Advisory boards**: Creating advisory boards or working groups with diverse experts and stakeholders to provide guidance and incorporate different viewpoints.
  - » In France, NUWARD has created an International Advisory Board with both economic and technical experts;
  - » In the United States, TerraPower has formed an advisory board with approximately 10 US utility representatives;
  - » In the United States, USNC has an advisory board that includes industry, community and government representatives.
- **Indigenous engagement**: Building relationships with Indigenous communities and collaborating to advance acceptance and workforce development:
  - » GE Hitachi Nuclear Energy is collaborating with First Nations Power Authority in Canada;
  - » Moltex Energy and ARC Clean Technology have a partnership with North Shore Mi'kmaq Tribal Council in New Brunswick, Canada;
  - » X-energy signed MoUs with First Nations Power Authority in Canada.
- **General public communications**: Preparing and presenting content tailored for the general public, aimed at communicating the benefits of nuclear power as well as the key features and value proposition of specific SMRs:
  - » Rosenergoatom organised public tours on the Akademik Lomonosov barge in Russia to showcase the KLT-40S power station. This gave the general public a chance to see the technology and learn about working in nuclear energy.
  - » JAEA hosted "Open Lab" events at its sites in Japan, including where the HTTR reactor is located, that were open to the public for tours and to discuss nuclear science and technology programmes.
  - » In Korea, KAERI signed an MoU to collaborate on enhancing public understanding and awareness of nuclear technology, including the SMART SMR, targeting the general public.
  - » Seaborg held an open-door event as part of Copenhagen Culture Night, inviting the public to meet scientists and learn about the Seaborg CMSR reactor in Denmark.
  - » In Indonesia, ThorCon organised a seminar and webinar to raise public awareness of the impacts of deploying its ThorCon 500 SMR.
  - » Teplatom participated in a press conference in Slavutych City, Ukraine, attended by the mayor, to present its TEPLATOR reactor technology.

Fuel

Fuel production capacity has to grow to meet the demand from SMRs

Figure 38 shows the pipeline of SMRs progressing towards securing a supply of licensed and qualified fuel. For 10 SMR designs there is no information available from verifiable public sources related to fuel activities. Sixteen SMR designs have non-binding agreements in place and/or studies with national laboratories related to their fuel. Six SMRs have entered into contracts with fuel supply chain companies and sixteen have operational fabrication facilities producing fuel, or plan to use same fuel as existing commercial reactors. Five SMRs have secured contracts for fuel for their FOAK and fuel loading has begun for three SMRs. More information is presented in Table 9.

Figure 38. **Fuel progress worldwide**

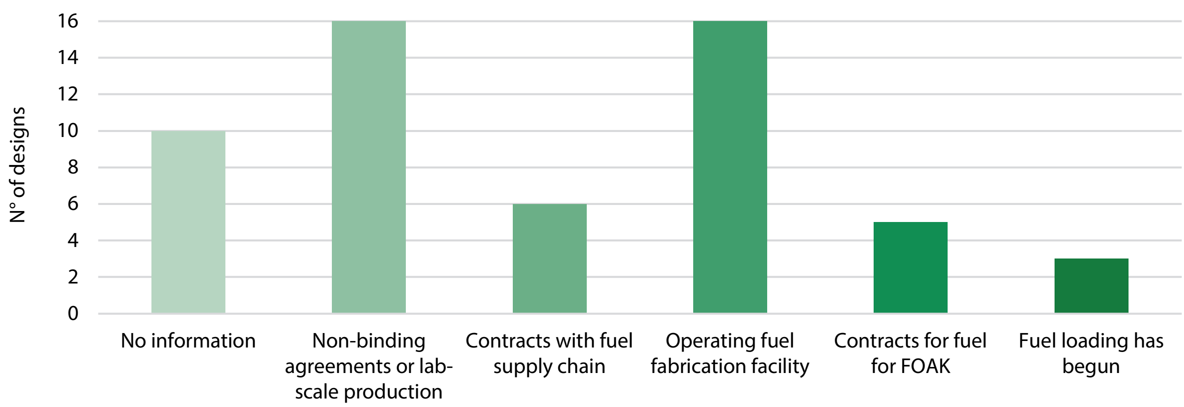
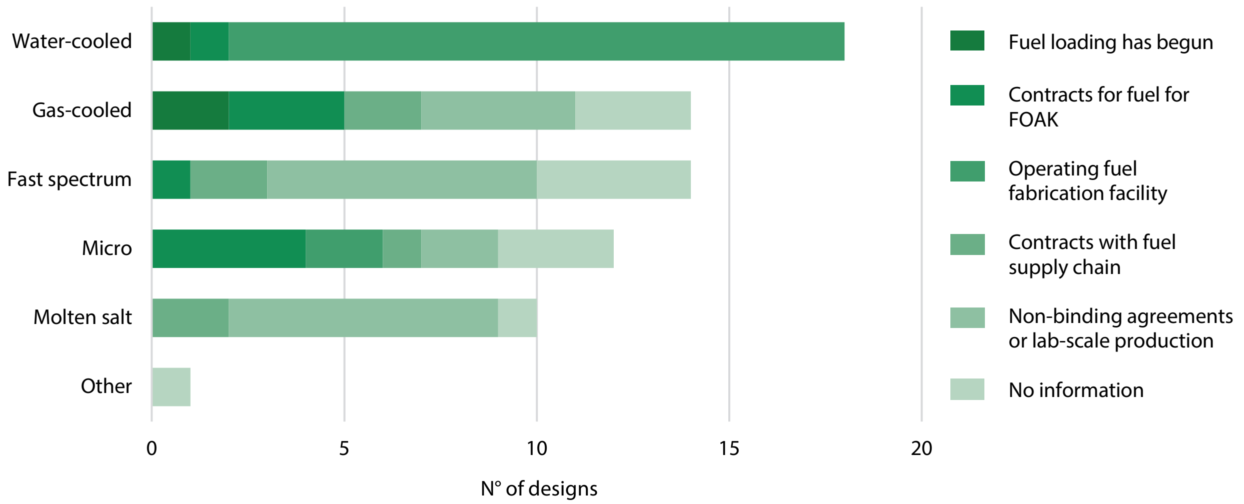


Table 9. **Fuel progress, detailed**

Fuel loading has begun
• Three SMRs have begun fuel loading: the HTR-PM in China, the floating KLT-40S in Russia and the HTTR in Japan.
Contracts for fuel for FOAK
• Five SMRs have contracts for fuel for their FOAK, including CNEA's CAREM in Argentina and four microreactors: Oklo's Aurora powerhouse, USNC's MMR and Pylon D1 as well as BWX Technologies' Project Pele.
Operating fuel fabrication facility, or uses same fuel as existing/Generation III commercial reactors
• Sixteen water-cooled SMRs have access to operating fuel fabrication facilities for their fuel, or plan to use the same fuel as existing commercial reactors.
Contracts/agreements with fuel supply chain (uranium/conversion/enrichment/fabrication)
• Six SMRs have contracts or agreements with fuel supply chain companies. These SMRs are gas-cooled reactors (Xe-100 and BANR), fast spectrum reactors (Natrium Reactor Plant and BREST-OD-300) and molten salt reactors (Hermes and IMSR).
Non-binding agreements & studies with national labs for RDD/lab-scale production of fuel
• Sixteen SMRs have non-binding agreements in place and/or studies with national laboratories related to their fuel.
No information
• For 10 SMR designs, no information was readily available from verifiable public sources related to fuel activities.

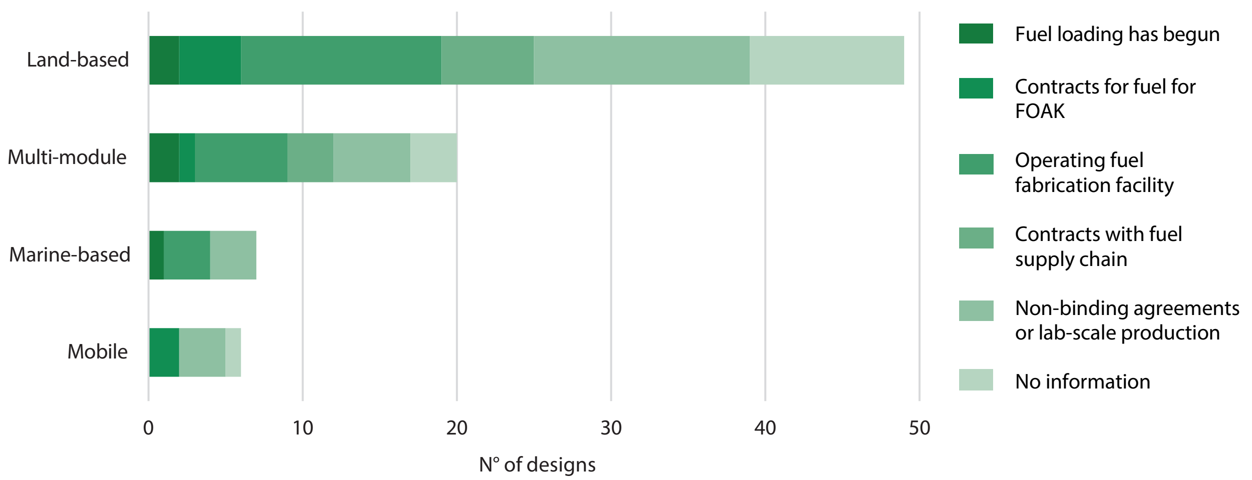
Figures 39 and 40 present SMR progress towards securing a supply of licensed and qualified fuel, by concepts and configurations respectively. Water-cooled SMRs benefit from existing nuclear fuel supply chains. For these reactors no barriers to commercial supply are expected. The *NEA SMR Dashboard* finds that gas-cooled SMRs are also seeking to leverage existing fuel production capacities. Fast spectrum and microreactor SMR concepts are making notable progress towards securing their supply of fuel but for a majority of designs more research and development is required to qualify their fuel. The *NEA SMR Dashboard* also finds that molten salt SMRs have the least mature fuel supply chains with, at the time of assessment, no operating fabrication facilities globally.

Figure 39. **Fuel progress by SMR concept**



Note: Some SMRs correspond to multiple reactor concepts (e.g. an SMR can be both a fast-spectrum and molten salt reactor).

Figure 40. **Fuel progress by SMR configuration**



Note: Some SMRs correspond to multiple reactor configurations (e.g. an SMR can be both a land-based and mobile reactor).

Some SMRs will require new types of fuel

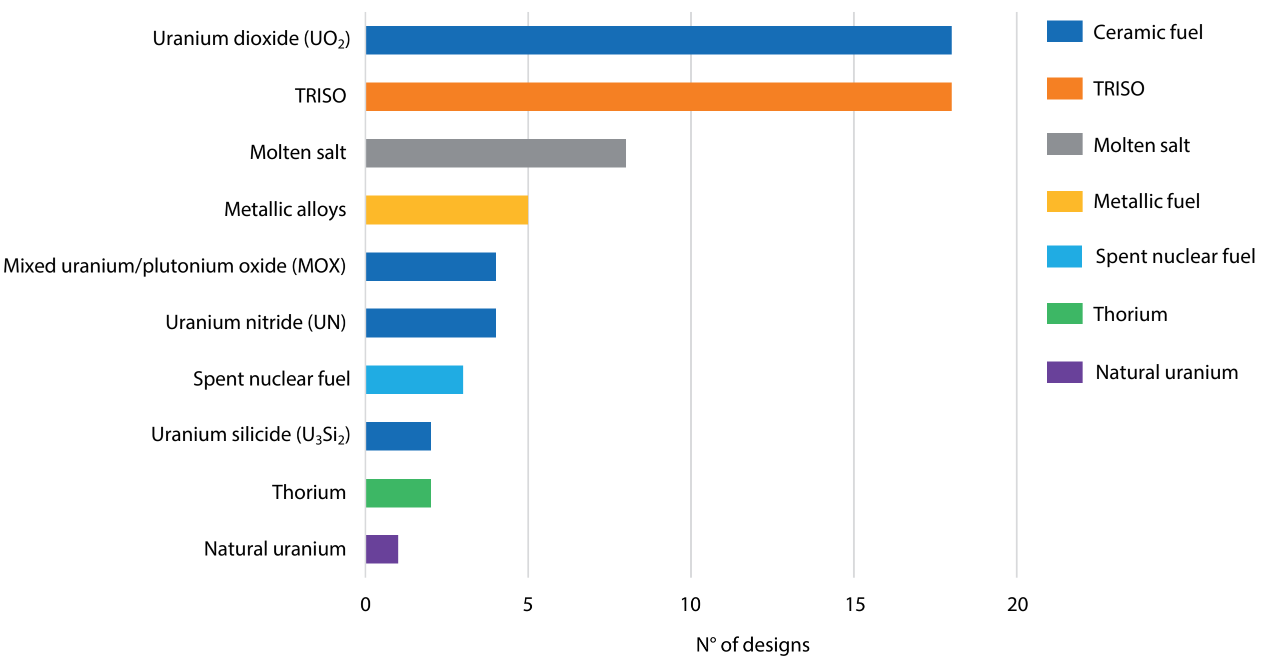
The *NEA SMR Dashboard* confirms the development of various new fuel types associated with different SMR designs (Figure 41). Ceramic uranium dioxide pellets are commonly used in SMRs that leverage existing light water reactor technology. TRISO fuel, either in the form of pebbles or prismatic blocks, is the preferred option for gas-cooled reactors and some molten salt reactors.

TRISO fuel is a type of advanced nuclear fuel composed of minuscule particles of uranium enclosed in layers of carbon and ceramic-based materials. TRISO fuel is structurally more resistant than traditional reactor fuels. Each particle acts as its own containment system thanks to its triple-coated layers. This allows TRISO particles to retain fission products under all reactor conditions (DOE, 2019).

Reactors operating with a fast spectrum and cooled with liquid metal typically use mixed uranium-plutonium oxide, metallic or nitride fuels, while molten salt reactors use molten salt fuels. Additionally, mixed oxide fuel, a type of nuclear fuel consisting of a mix of uranium and plutonium oxides, is a versatile option compatible with water-cooled and metal-cooled reactors. Few designs, however, are fully powered with mixed oxide fuel.

Ceramic uranium pellets are the most commonly used fuel, benefiting from an existing and qualified supply chain. The *NEA SMR Dashboard* also finds that TRISO fuel is the second most prevalent fuel type for SMRs, with significant progress already achieved in its development and qualification. SMR developers like X-energy, Kairos and BWXT are actively working on different types of TRISO fuel. BWXT's facility in Lynchburg, Virginia (US), for example, is licensed to produce TRISO, and several national laboratories are set to build new TRISO manufacturing capabilities in collaboration with SMR designers. Efforts are also underway to advance the commercial production of metallic and molten salt fuels with support from national governments. Collaboration with national and international laboratories is crucial for the development of new nuclear fuels, as they provide access to irradiation facilities essential for testing, data generation and qualification.

Figure 41. **SMR fuel types**



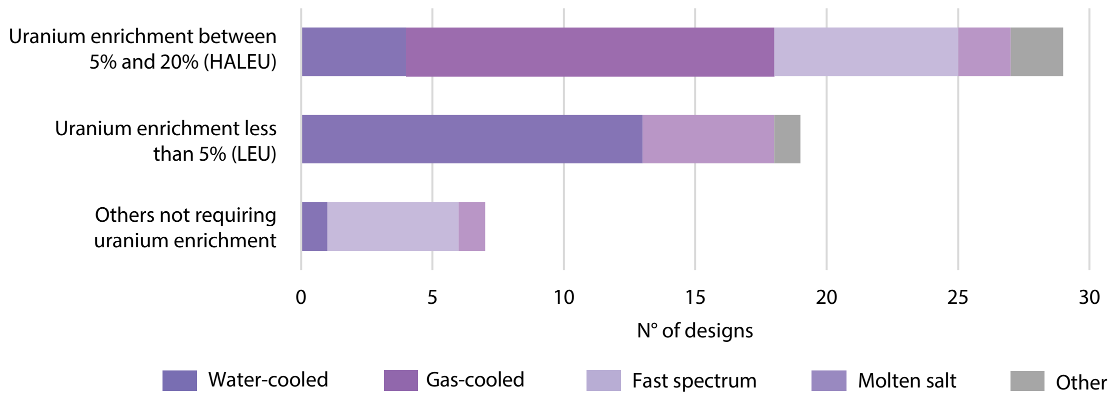
Note: Note: TRISO=tri-structural isotropic particle fuel; some designs can use different types of ceramic fuels (UO_2, MOX, UN, and U_3Si_2).

Commercial HALEU production is key to enable the deployment of several first-of-a-kind SMRs

Over 50% of the designs evaluated for the *NEA SMR Dashboard* are planning to use high-assay low-enriched uranium (HALEU) with enrichment levels between 5% and 20%. Most of the SMRs planning to use HALEU are novel concepts that are either gas-cooled, fast-spectrum or molten salt (Figure 42). HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. This shortfall could potentially delay the deployment of some SMRs. Some developers have announced delays in their project timelines due to HALEU unavailability.

Efforts to address this challenge are underway at both the national and international levels. The Inflation Reduction Act in the United States has allocated USD 700 million to enhance domestic HALEU production, with USD 500 million earmarked specifically for government procurement of HALEU (S&P, 2023). Centrus Energy Corp. has made significant progress in building HALEU production capabilities, with the delivery of the first batch of HALEU to the US Department of Energy (DOE, 2019). The company also indicates that it could significantly expand production, contingent upon sufficient funding and off-take commitments.

Figure 42. **SMR uranium enrichment requirements**



Note: XAMR from NAAREA is not included in this chart since its fuel information was not disclosed.

Summary of the key findings of the *NEA SMR Dashboard*

The *NEA SMR Dashboard* provides the most comprehensive assessment to date of the progress towards SMR commercialisation, identifying designs that are making significant progress towards commercial deployment and those that are in earlier stages of development.

A few SMRs are already operating, and there is a robust pipeline of SMRs making progress towards first-of-a-kind deployment. A large number of SMRs are presently conceptual. The breadth of designs may create opportunities to consolidate global supply chains, foster standardisation and improve the economics of SMRs for commercialisation.

Key findings in the areas of licensing, siting, financing, supply chain, engagement and fuel for SMRs are summarised below:

Licensing:

- China and Russia are leading on deployment;
- Some regulators are taking steps towards regulatory frameworks that support large-scale deployment of SMRs, notably through early collaborations and joint reviews between regulators.

Siting:

- There is real and rapid progress towards deployment in North America and Europe;
- Sites for industrial applications are starting to emerge, highlighting the capacity of SMRs to broaden the value proposition of nuclear power by targeting new industrial applications.

Financing:

- SMR development is primarily driven by public-private partnerships, particularly during the development phases;
- Financing frameworks are enhanced with power purchase agreements or off-take agreements to mitigate price uncertainty. Addressing construction risks may require the use of cost- and risk-sharing approaches between governments and the private sector, or forming industrial consortia to distribute risks among multiple stakeholders and across a larger number of projects.

Supply chain:

- Emerging SMR supply chains are characterised by intense collaborations to reduce deployment risks, with many SMRs making good progress in the establishment of their supply chains;
- Many collaborations involve contracts with engineering, procurement and construction companies, indicating that supply chains are gearing up for deployment, with timelines that are near-term and accelerating. However, most efforts are focused on successfully delivering first-of-a-kind projects, and there are still no signs of a structural paradigm shift towards fleet deployment.

Engagement:

- Many SMR developers recognise the strategic importance of engaging with key stakeholders to build trust. Engagement efforts are focused on securing policy and community buy-in, talent pipeline, and first markets.

Fuel:

- New fuel types are being developed for a number of SMRs. Some of these new fuel types have reached commercial maturity and others still require additional development efforts;
- Over 50% of the designs evaluated for the *NEA SMR Dashboard* are planning to use high-assay low-enriched uranium (HALEU). While HALEU is a technically proven fuel type, as of 2023 there was a lack of large-scale, commercial supply in OECD countries, which could potentially delay the deployment of some SMRs.

The NEA SMR Dashboard

Key information for each of the SMR designs assessed in this edition is listed in Table 10.

Table 10. **Full list of SMRs assessed in the second edition of the *NEA SMR Dashboard***

Name	Design organisation	Headquarters (city/region)	Country	Thermal power (MWth)	Outlet temperature (°C)	Spectrum (thermal/fast)	Fuel type
ARC-100	ARC Clean Technology	Washington DC	United States	286	510	Fast	Metallic U-Zr alloy
Blue Capsule	Blue Capsule Technology	Aix-en-Provence	France	150	750	Thermal	TRISO prismatic
SEALER-55	Blykalla	Stockholm	Sweden	140	550	Fast	Uranium nitride
BANR	BWXT(1)	Lynchburg, Virginia	United States	50	800	Thermal	UCO(2) TRISO and UN(3) TRISO prismatic
Project Pele	BWXT	Lynchburg, Virginia	United States	N/A	N/A	Thermal	TRISO
ACPR50S	CGN(4)	Shenzhen	China	200	320	Thermal	UO_2 pellets or UO_2-Gd_2O_3 pellets
CAREM	CNEA(5)	Buenos Aires	Argentina	100	326	Thermal	UO_2 pellets
ACP100	CNNC(6)	Beijing	China	385	320	Thermal	UO_2 pellets
Energy Well	CVŘ(7)	Husinec, Central Bohemian Region	Czechia	20	700	Thermal	TRISO prismatic
DF300	Dual Fluid Energy	Vancouver, British Columbia	Canada	600	1 000	Fast	Liquid metallic U-Cr alloy
A-HTR-100	Eskom	Sandton	South Africa	100	1 200	Thermal	TRISO pebble
LFTR	Flibe Energy	Huntsville, Alabama	United States	600	650	Thermal	Molten salt
SC-HTGR(8)	Framatome	Lynchburg, Virginia	United States	625	750	Thermal	TRISO prismatic
BWRX-300	GE Hitachi Nuclear Energy	Wilmington, North Carolina	United States	870	288	Thermal	UO_2 pellets
Calogena	Gorgé	Paris	France	30	100	Thermal	UO_2 or uranium silicide
HEXANA	Hexana	Aix-en-Provence	France	800	510	Fast	MOX
SMR-300	Holtec International	Jupiter, Florida	United States	1 000	N/A	Thermal	UO_2 pellets

(1) BWX Technologies; (2) UCO = Uranium oxycarbide; (3) UN = Uranium nitride; (4) China General Nuclear Power Group; (5) Argentina's National Atomic Energy Commission; (6) China National Nuclear Corporation; (7) Research Centre Řež; (8) Steam Cycle High Temperature Gas-cooled Reactor.

Table 10. **Full list of SMRs assessed in the second edition of the *NEA SMR Dashboard*** *(cont'd)*

Name	Design organisation	Headquarters (city/region)	Country	Thermal power (MWth)	Outlet temperature (°C)	Spectrum (thermal/fast)	Fuel type
HTR-PM	INET[9]	Beijing	China	500	750	Thermal	TRISO pebble
GTHTR300	JAEA[10]	Ibaraki	Japan	600	950	Thermal	TRISO prismatic
HTTR	JAEA	Ibaraki	Japan	30	950	Thermal	TRISO prismatic
Jimmy SMR	Jimmy	Paris	France	10	550	Thermal	UCO TRISO prismatic
SMART	KAERI[11]	Daejon	Korea	365	322	Thermal	UO_2 pellets
Hermes	Kairos Power	Alameda, California	United States	35	650	Thermal	TRISO pebble
PWR-20	Last Energy	Washington DC	United States	60	300	Thermal	UO_2 pellets
SSR-W[12]	Moltex Energy	Saint John, New Brunswick	Canada	750	590	Fast	Molten salt
FLEX	MoltexFLEX	Warrington	United Kingdom	60	700	Thermal	Molten salt
XAMR	NAAREA	Nanterre	France	80	625	Fast	Molten salt
HTGR-POLA	NCBJ[13]	Otwock	Poland	30	750	Thermal	TRISO prismatic
LFR-AS-200	*new*cleo	London	United Kingdom	480	530	Fast	MOX
BREST-OD-300	NIKIET[14]	Moscow	Russia	700	535	Fast	MNUP[15] fuel
VOYGR	NuScale Power	Portland, Oregon	United States	250	321	Thermal	UO_2 pellets
NUWARD SMR	NUWARD	Paris	France	1 080	307	Thermal	UO_2 pellets
Aurora Powerhouse	Oklo	Santa Clara, California	United States	40	500	Fast	Metallic U-Zr Alloy
Otrera 300	Otrera Nuclear Energy	Aix-en-Provence	France	300	550	Fast	MOX
Kaleidos	Radiant Industries	El Segundo, California	United States	1.9	700	Thermal	TRISO Prismatic
RR SMR	Rolls-Royce SMR	Manchester	United Kingdom	1 358	325	Thermal	UO_2 pellets
KLT-40S	ROSATOM	Moscow	Russia	300	316	Thermal	UO_2 pellets
RITM-200M	ROSATOM	Moscow	Russia	396	318	Thermal	UO_2 pellets

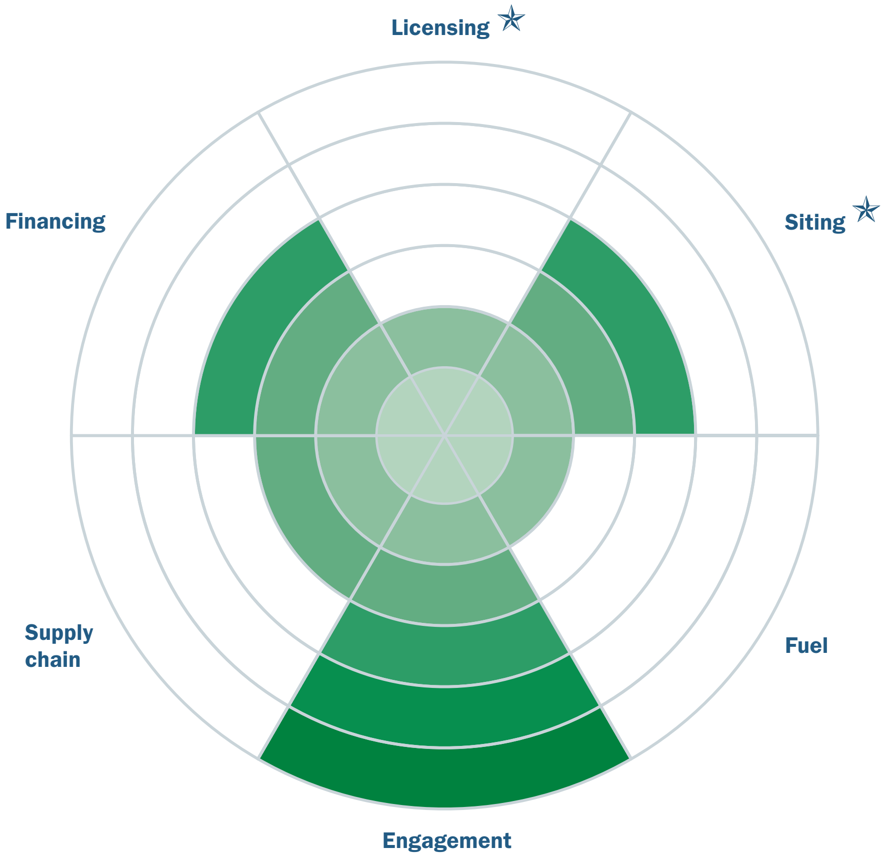
(9) Tsinghua University Institute of Nuclear and New Energy Technology; (10) Japan Atomic Energy Agency; (11) Korea Atomic Energy Research Institute; (12) Stable Salt Reactor-Wasteburner; (13) National Centre for Nuclear Research; (14) N.A. Dollezhal Research and Design Institute of Power Engineering; (15) MNUP = Mixed uranium-plutonium nitride.

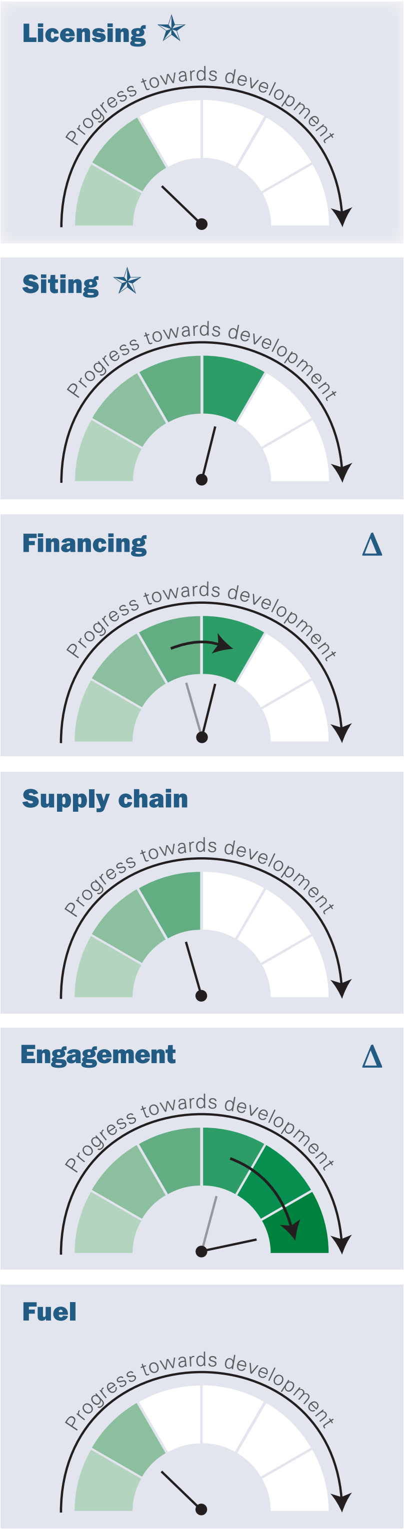
Table 10. **Full list of SMRs assessed in the second edition of the *NEA SMR Dashboard*** *(cont'd)*

Name	Design organisation	Headquarters (city/region)	Country	Thermal power (MWth)	Outlet temperature (°C)	Spectrum (thermal/ fast)	Fuel type
RITM-200N	ROSATOM	Moscow	Russia	190	321	Thermal	UO_2 pellets
RITM-200S	ROSATOM	Moscow	Russia	396	318	Thermal	UO_2 pellets
CMSR(16)	Seaborg Technologies	Copenhagen	Denmark	250	670	Thermal	Molten salt
HAPPY200	SPIC(17)	Beijing	China	200	120	Thermal	UO_2 pellets
HTMR-100	Stratek Global	Centurion, Pretoria	South Africa	100	750	Thermal	TRISO pebble
Natrium Reactor Plant	TerraPower	Bellevue, Washington	United States	840	500	Fast	Metallic U-Zr alloy
IMSR(18)	Terrestrial Energy	Oakville, Ontario	Canada	884	700	Thermal	Molten salt
ThorCon 500	ThorCon International	Dubai	United Arab Emirates	1 100	704	Thermal	Molten salt
Thorizon One	Thorizon	Amsterdam	Netherlands	250	550	Thermal or fast	Molten salt
MoveluX	Toshiba Energy Systems & Solutions Corporation	Kawasaki, Kanagawa	Japan	10	680	Thermal	Uranium silicide
4S	Toshiba Energy Systems & Solutions Corporation	Kawasaki, Kanagawa	Japan	30 and 135	510	Fast	Metallic U-Zr alloy
MMR(19)	USNC(20)	Seattle, Washington	United States	10 to 50	660	Thermal	TRISO prismatic
Pylon D1	USNC	Seattle, Washington	United States	1	727	Thermal	TRISO prismatic
TEPLATOR	UWB and CIIRC CTU(21)	Prague	Czechia	170	180	Thermal	SNF from LWRs(22) or natural uranium
AP300™ SMR	Westinghouse Electric Company	Cranberry Township, Pennsylvania	United States	990	325	Thermal	UO_2 pellets
eVinci microreactor	Westinghouse Electric Company	Cranberry Township, Pennsylvania	United States	15	750	Thermal	TRISO
Westinghouse LFR	Westinghouse Electric Company	Cranberry Township, Pennsylvania	United States	950	530-650(23)	Fast	UO_2 pellets or MOX; then UN pellets
Xe-100	X-energy	Rockville, Maryland	United States	200	750	Thermal	TRISO-X pebble

(16) Compact Molten Salt Reactor; (17) State Power Investment Corporation; (18) Integral Molten Salt Reactor; (19) Micro-Modular Reactor; (20) Ultra Safe Nuclear Corporation; (21) University of West Bohemia and Czech Technical University in Prague; (22) In particular, spent nuclear fuel assemblies from VVER, BWR or PWR reactors as fuel; (23) Temperatures for phase 1 (left) and phase 2 (right).

ARC Clean Technology – ARC-100





★ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: Sodium-cooled fast reactor using metallic uranium alloy fuel with a 20-year refuelling cycle.

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) and is engaged in pre-licensing activities with the US Nuclear Regulatory Commission (NRC). In June 2023, New Brunswick Power (NB Power) submitted a Licence to Prepare Site application to the CNSC as well as an Environmental Impact Assessment registration to the New Brunswick Department of Environment and Local Government for the ARC-100 project.

Siting ☆

The ARC-100 reactor has been selected by NB 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

Between 2018 and 2023, ARC Clean Technology was granted about USD 60 million in public funding from the UK's Advanced Modular Reactor competition (2018), Japan's Nuclear Energy X Innovative Promotion programme (2021), the US' Advanced Reactor Concepts programme (2020), Natural Resources Canada through the Clean Electricity Predevelopment Program (2023) as well as the Canadian Nuclear Research Initiative and the Province of New Brunswick (2018 and 2021). ARC Clean Technology also announced the closing of its Series A funding round with CAD 30 million (USD 23 million) from combined private and New Brunswick public funding (2022). In 2023, the North Shore Mi'kmaq Tribal Council (NSMTC) and its member communities made an equity investment of CAD 1 million (USD 768 000) in ARC Clean Technology.

Supply chain

ARC Clean Technology has been collaborating with GE Hitachi Nuclear Energy (GEH) since 2017 under an agreement that includes in-kind contributions from GEH to provide engineering and design expertise. It also has commercial agreements with engineering companies including Hatch and AECOM. 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 also hosted and participated in multiple supply chain events.

Engagement

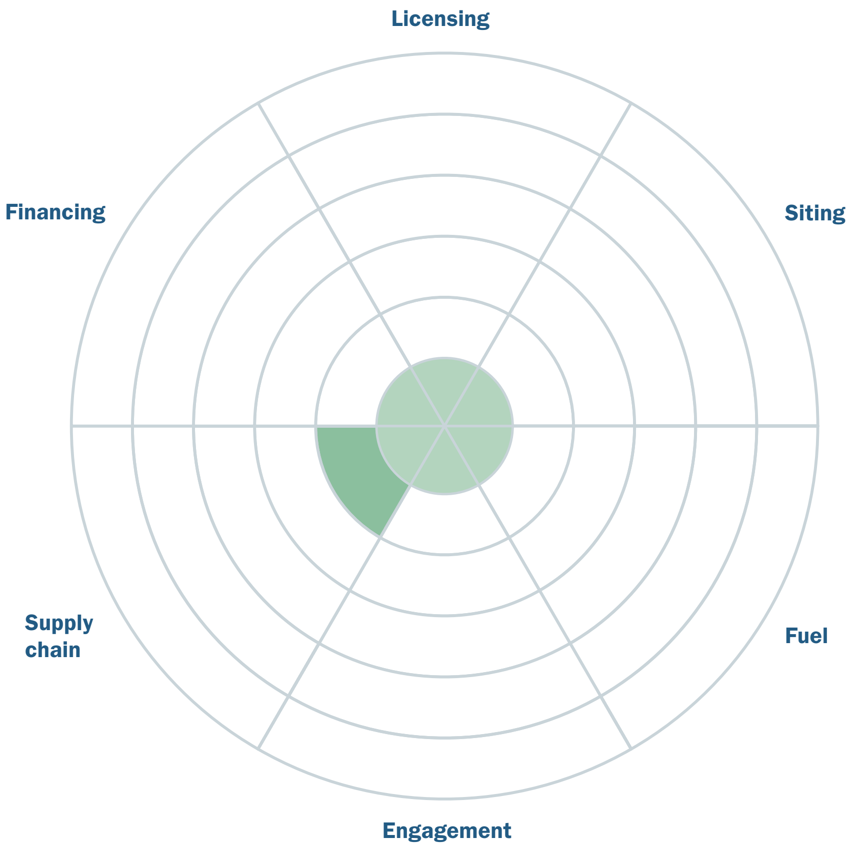
ARC Clean Technology has received endorsement from the province of New Brunswick for siting the ARC-100 reactor. ARC Clean Technology has sponsored engagement activities with various Indigenous communities, labour unions, and civil society organisations in the Atlantic Canada region. ARC Clean Technology has a partnership with NSMTC and entered into an equity agreement in September 2023 with NSMTC and its seven member communities for benefits sharing. It is also 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 a member of the Atlantic Clean Energy Alliance and the Atlantica Centre for Energy.

Fuel

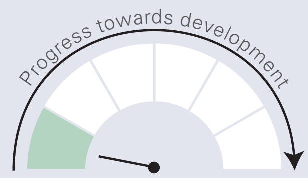
HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. ARC Clean Technology signed a letter of intent with Centrus for HALEU supply and is partnering with Canadian Nuclear Laboratory to develop a fuel manufacturing process. ARC Clean Technology has also been awarded a voucher under the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative by the US DOE to support qualification of ARC's fuel in collaboration with the US Argonne and Idaho National Laboratories.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, CAD 1.302 equals USD 1.000.

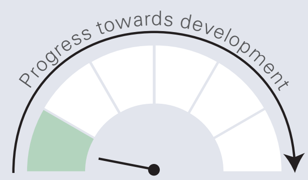
Blue Capsule Technology – Blue Capsule



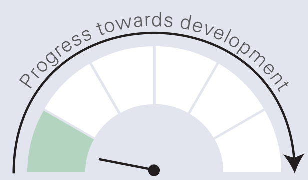
Licensing



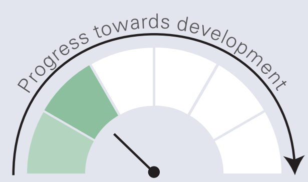
Siting



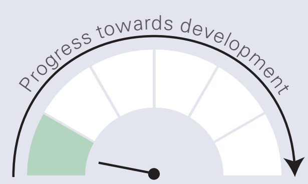
Financing



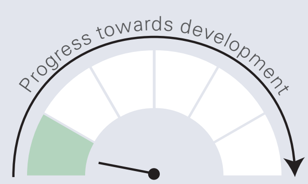
Supply chain



Engagement



Fuel



Reactor description: Sodium-cooled thermal spectrum SMR using TRISO fuel, and air as its heat sink.

Thermal power (MWth)	150
Outlet temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	LEU or HALEU

Assessment of Blue Capsule's progress to deployment

Licensing

At the time of assessment, there was no additional information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

At the time of assessment, no information about financing was readily available from verifiable public sources.

Supply chain

In 2022, Blue Capsule Technology and Egis signed a Memorandum of Understanding to co-operate on civil engineering as well as external and seismic hazard analysis. In 2023, Blue Capsule Technology signed a Memorandum of Co-operation with Elyse Technology to explore the coupling of the Blue Capsule reactor to provide heat for the Elyse biomass pyrolysis process. Blue Capsule is one of five SMR projects selected in mid-2023 by the French Commissariat à l'énergie atomique et aux énergies alternatives (the Alternative Energies and Atomic Energy Commission, or CEA) under CEA's French Atomic Sustainable Technologies programme, aimed at advancing commercialisation of SMR projects. Blue Capsule is expected to benefit from CEA's experience in designing, building and operating sodium-cooled reactors.

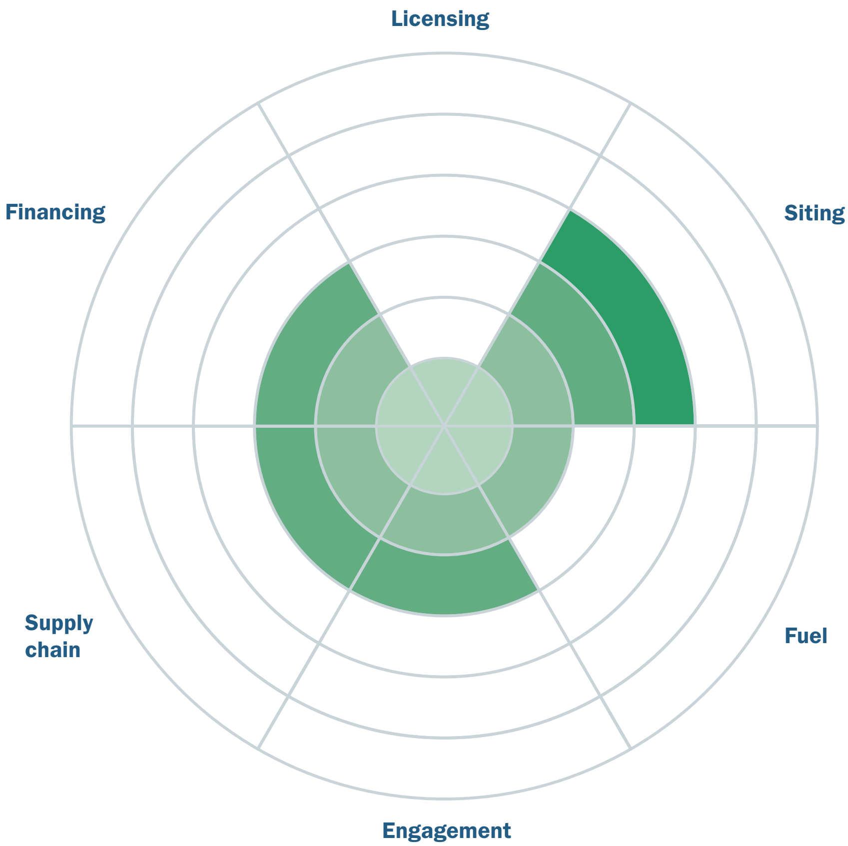
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

The Blue Capsule SMR is designed to be fuelled with either LEU (preferred) or HALEU. With LEU the Blue Capsule SMR design will use online refuelling. With HALEU this would not be necessary, although not excluded. HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

Blykalla – SEALER-55

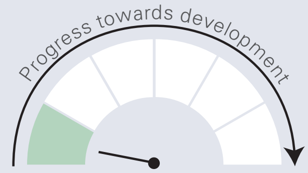


Δ Indicates change since 2023.

Reactor description: Lead-cooled fast reactor developed in Sweden.

Thermal power (MWth)	140
Outlet temperature (°C)	550
Spectrum (thermal/fast)	Fast
Fuel type	Uranium nitride
Fuel (LEU/HALEU/HEU)	HALEU

Licensing



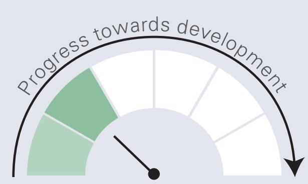
Siting

Financing

Supply chain

Engagement Δ

Fuel



Assessment of SEALER-55's progress to deployment

Licensing

In 2023, the Swedish Radiation Safety Authority reported meeting with Blykalla (previously Leadcold) to discuss SMR pre-licensing engagement options. In support of the United Kingdom's Advanced Modular Reactor project, the UK Office for Nuclear Regulation (ONR) completed a three-stage engagement process with Blykalla to explore regulatory pathways for advanced nuclear technologies and build ONR capacities to license lead-cooled fast reactors. At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

Blykalla 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 (SEALER E) at the Oskarshamn site by 2024, to be followed by the deployment of the nuclear demonstration reactor (SEALER D) at the same site by 2030. Blykalla is aiming to deploy a commercial version of SEALER-55 by 2032.

Financing

Blykalla received more than SEK 99 million (USD 9.8 million) from the Swedish Energy Agency, as well as an investment of SEK 25 million (USD 2.5 million) from Norrsken, and awards of SEK 1.7 million (USD 168 000) and EUR 0.1 million (USD 105 000) from Euratom and Eurostars respectively. The Swedish Strategic Research Foundation provided SEK 50 million (USD 4.9 million) over 2021-2026 for lead-cooled reactor research at the Oskarshamn site to support SEALER development. Blykalla also has an agreement with the utility NewClearEnergy, where a percentage of electricity sales will be used to support the development of SEALER. Through Phase 1 of the UK government's Advanced Modular Reactor Feasibility and Development project, Blykalla was awarded a contract for a feasibility study of SEALER-55.

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. Blykalla has formed a joint venture with Uniper, which aims to construct an electrically heated prototype to advance the SEALER-55 reactor concept.

Engagement

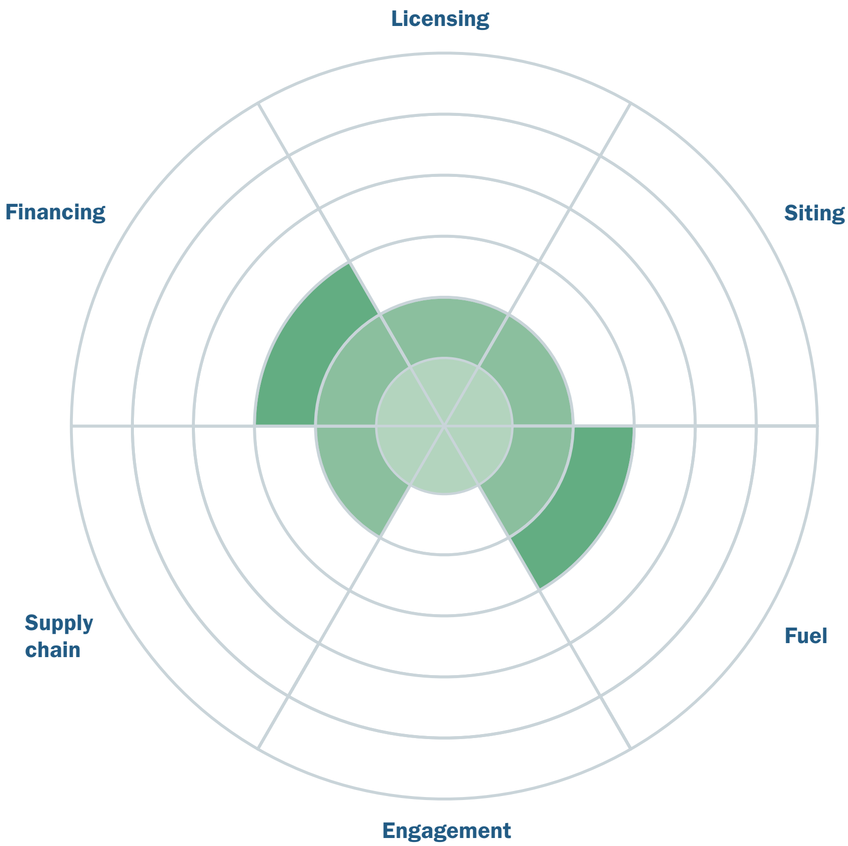
KTH professor and founder of Blykalla, Janne Wallenius, received the KTH Innovation Award 2022, which recognises work on solutions to humanity's greatest challenges. Janne Wallenius also engages the public in Sweden extensively through videos, radio, and print news. Additionally, in April 2023, Janne Wallenius was invited to deliver a presentation on the future of nuclear energy to Swedish member of the parliaments.

Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. Blykalla 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. Blykalla also participates in the EU funded FREDMANS Project with specific work packages on manufacturing, recyclability and management of nitride nuclear fuel.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, SEK 10.114 and of EUR 0.950 are equal to USD 1.000.

BWX Technologies (BWXT) – BWXT Advanced Nuclear Reactor (BANR)

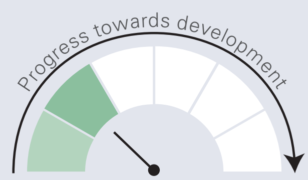


Licensing

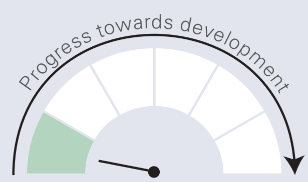
Siting Δ

Financing

Supply chain



Engagement



Fuel

Δ Indicates change since 2023.

Reactor description: Transportable high-temperature gas-cooled microreactor using TRISO fuel.

Thermal power (MWth)	50
Outlet temperature (°C)	800
Spectrum (thermal/fast)	Thermal
Fuel type	UCO TRISO (baseline core) and UN TRISO (upgraded core) prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of BANR's progress to deployment

Licensing

The BWXT Advanced Nuclear Reactor (BANR) is one of two modular, transportable, high-temperature micro gas-cooled SMRs under development by BWXT, along with the BWXT SMR for the US Department of Defense Project Pele at the Idaho National Laboratory (INL). Experience gained in Project Pele may help inform and accelerate work on the BANR. BWXT submitted a regulatory engagement plan for the BANR to the US Nuclear Regulatory Commission (NRC) in 2022 to initiate pre-licensing activities. The engagement plan details proposed submittal dates for technical and topical reports. Additionally, in 2022, BWXT submitted a Quality Assurance Topical Report that supports fuel development activities for the BANR.

Siting

The Wyoming Energy Authority (WEA) contracted BWXT to evaluate the suitability of the BANR SMR for possible deployment in the US state of Wyoming. Tata Chemicals Soda Ash Partners (TCSAP), a subsidiary of Tata Chemicals North America Inc., signed a collaboration agreement with BWXT to explore the potential deployment of the BANR SMR at the TCSAP's Green River site in Wyoming. The BANR SMR would supply electricity and steam for trona ore mining and production of soda ash, used in the manufacture of glass and soap.

Financing

In 2020, it was announced that BWXT would receive a Risk Reduction award under the US Department of Energy (DOE) Advanced Reactor Demonstration Program. In 2022, BWXT finalised a cost-share award for the development of BANR, with DOE contributing USD 89 million and BWXT contributing USD 22.3 million. In 2023, WEA awarded a paid contract to BWXT to evaluate the suitability of the BANR SMR for possible deployment in the state of Wyoming.

Supply chain

BWXT operates a diverse supply chain specialised in the nuclear sector, including engineering, procurement and construction capabilities. BANR is expected to benefit from BWXT's established supply chain from Project Pele, in which BWXT has been selected to be the prime contractor and integration lead. BWXT is collaborating with L&H Industrial, an international manufacturer of heavy industrial equipment, to assess the potential for Wyoming's existing supply chain to support BANR SMR development and deployment in Wyoming.

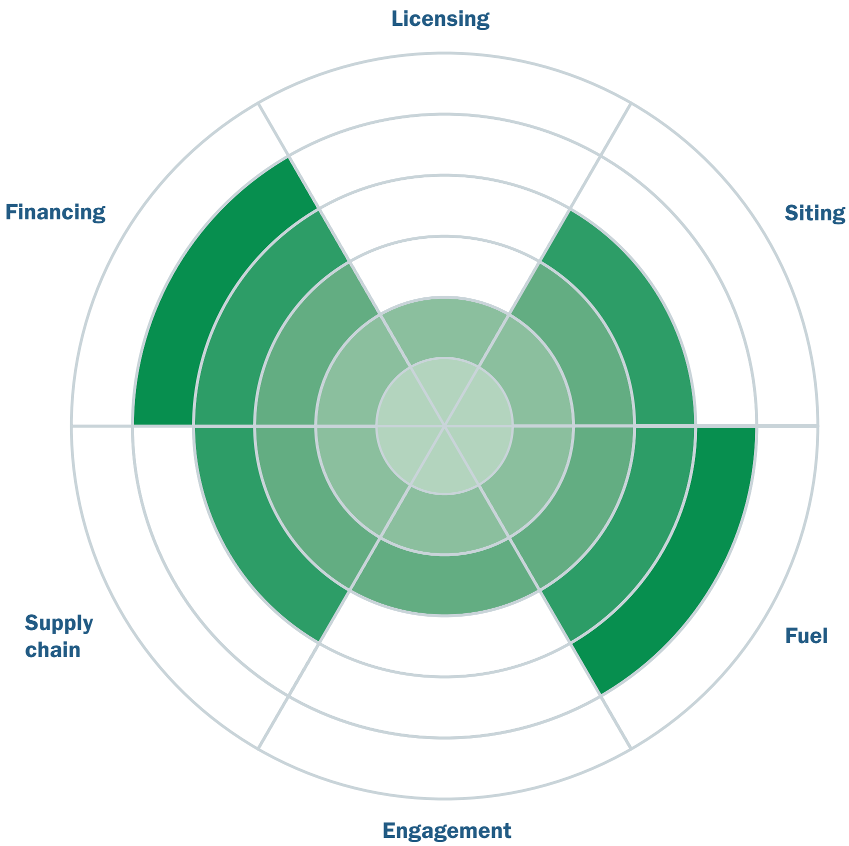
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

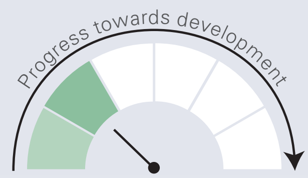
HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. As of 2023, BWXT owns and operates the only private facilities in the United States licensed to down-blend high-enriched uranium into HALEU. In 2023, BWXT was awarded USD 47 million by the National Nuclear Security Administration to produce a limited quantity of HALEU. BWXT plans to use Uranium Oxycarbide (UCO) TRISO for the baseline core and Uranium Nitride (UN) TRISO for the upgraded core. BWXT plans to fabricate TRISO fuel at their facilities in Virginia. BWXT has also been working with the INL and Oak Ridge National Laboratory on the simulation, manufacturing and testing of their UN TRISO fuel.

BWX Technologies (BWXT) – Project Pele



Reactor description: Micro, mobile gas-cooled demonstration reactor for government and possible later commercial applications.	
Thermal power (MWth)	Not available
Outlet temperature (°C)	Not available
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO
Fuel (LEU/HALEU/HEU)	HALEU

Licensing



Siting

Financing

Supply chain

Engagement

Fuel

Assessment of Project Pele's progress to deployment

Licensing

Project Pele is a defence reactor prototype commissioned by the US Department of Defense (DOD) Strategic Capabilities Office (SCO). Due to the defence classification of this project, there is limited information available in public sources. It does not fall under the purview of the US Nuclear Regulatory Commission (NRC). The DOD and the US Department of Energy (DOE) have signed an Interagency Agreement for Project Pele to be tested and operated under DOE authorisation, with some technical support and advice from the NRC. A final Environmental Impact Statement (EIS) has been released by the DOD SCO in accordance with the National Environmental Policy Act. The next step will be to submit the design for a Preliminary Documented Safety Analysis approval.

Siting

In 2022, the DOD SCO released the final EIS validating its plans for the Project Pele SMR to be constructed off-site and delivered to the Idaho National Laboratory's (INL) Critical Infrastructure Test Range Complex, where the fuel will be loaded and DOE will test and operate it. BWXT aims to deliver its Project Pele SMR to the INL in early 2025.

Financing

The DOD has announced that the Project Pele prototype reactor will be completed under a cost-type contract valued at USD 300 million. Additionally, BWXT has received USD 42.5 million from the DOD to develop the reactor design and fuel, as well as USD 37 million from INL to manufacture the Project Pele core.

Supply chain

BWXT operates a diverse supply chain specialised in the nuclear sector – including engineering, procurement and construction. BWXT has been selected by the DOD to be the prime contractor and integration lead for Project Pele, and is responsible for building and demonstrating the prototype. The project team also includes Northrop Grumman, Rolls-Royce LibertyWorks and Torch Technologies. The Army Corps of Engineers was also engaged as the technical lead on the National Environmental Policy Act Environmental Impact Statement. In 2023, BWXT announced that it and its sub-suppliers had begun fabricating parts for Project Pele, including forging the containment vessel and making moderator blocks.

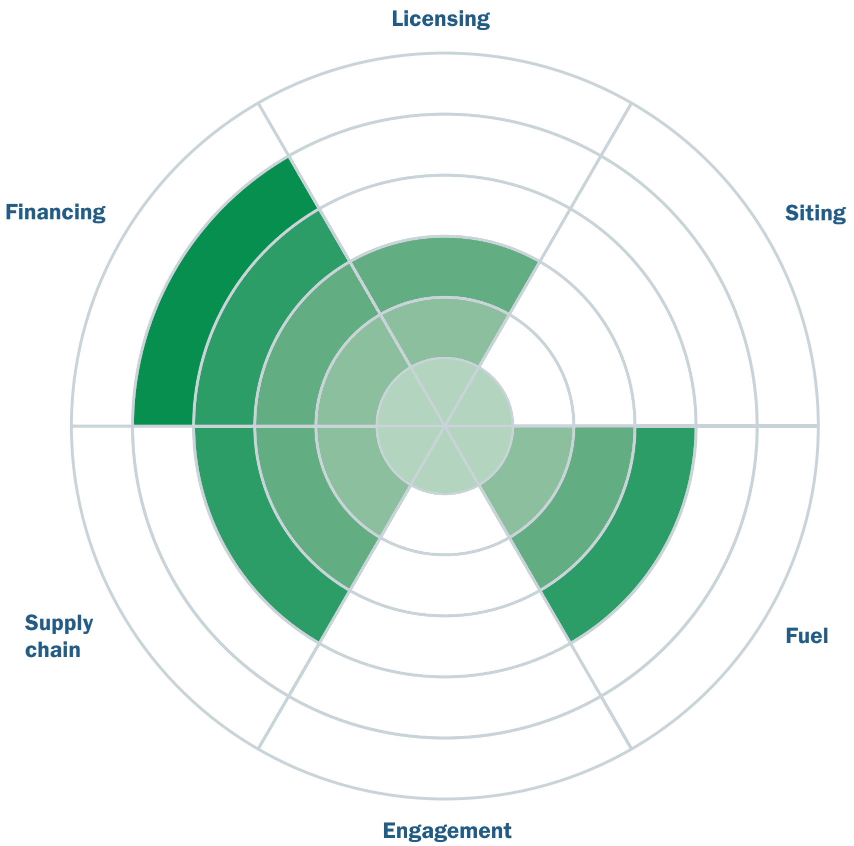
Engagement

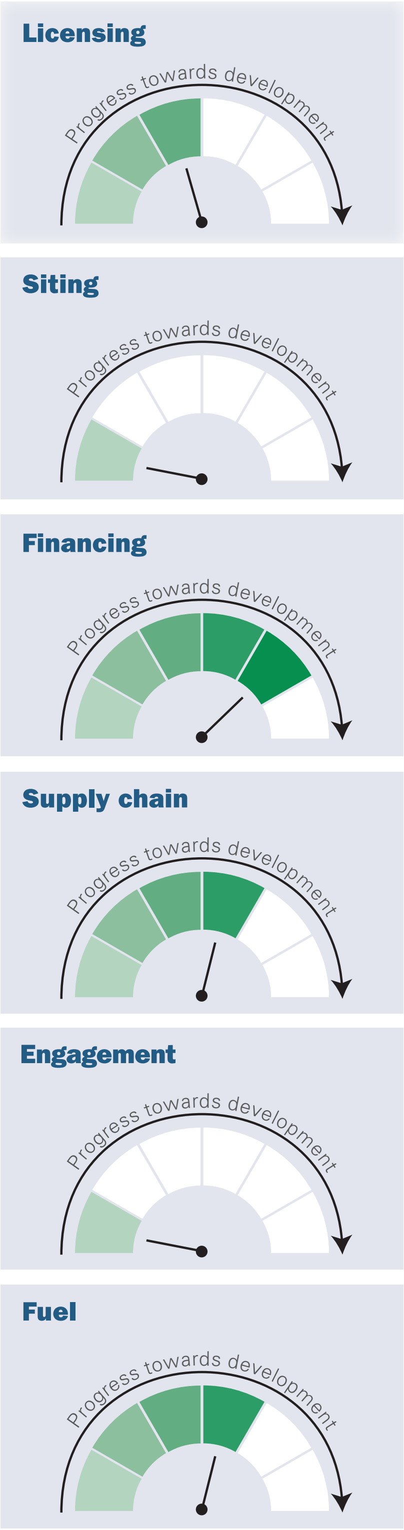
Dr Jeff Waksman, Project Pele Program Manager, was invited to participate in the Energy Communities Alliance (ECA) 2022 forum. The ECA is a non-profit organisation that aims to facilitate dialogue between the US DOE and local government representatives adjacent to, or impacted by, US DOE activities. On 15 April 2022 he also appeared on Boise State Public Radio News to discuss public engagement about the project. The DOD also undertook public engagement through a public comment period during 2021-2022. In October 2023, Dr Waksman provided an update on Project Pele to the Frontiers Project Meeting in Anchorage, Alaska, hosted by the Atlantic Council in partnership with INL and the University of Alaska.

Fuel

The INL has contracted BWXT to produce the necessary TRISO fuel for the Project Pele first-of-a-kind prototype demonstration unit. As of 2023, BWXT owns and operates the only privately-owned facilities in the United States licensed to possess and process HEU for down-blending into HALEU. The BWXT facilities are located in Lynchburg, Virginia. Under the contract with INL, BWXT will down-blend HEU stockpiles from National Nuclear Security Administration to produce HALEU for Project Pele.

CGN (China General Nuclear Power Group) – ACPR50S





Reactor description: Floating pressurised light water reactor.	
Thermal power (MWth)	200
Outlet temperature (°C)	320
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets or UO_2-Gd_2O_3 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of ACPR50S's progress to deployment

Licensing

In 2017, China General Nuclear Power Group (CGN) submitted the first version of the preliminary safety analysis report of the ACPR50S to China's National Nuclear Safety Administration (NNSA). In 2022, the NNSA approved the assembly and manufacturing activities of the pressure vessel and reactor module for the ACPR50S. The licensing activities of the ACPR50S are also expected to benefit from interactions with the China Classification Society and Lloyd's Register to define safety requirements for floating nuclear power plants.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

China's National Development and Reform Commission approved the development of 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 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 the China Shipbuilding Industrial Corporation as shipbuilder. In 2016, a purchase agreement for the pressure vessel was signed between CGN and Dongfang Electric. In 2023, CGN completed the experimental research for the design of a part of the ACPR50S reactor safety injection system in collaboration with Chongqing University.

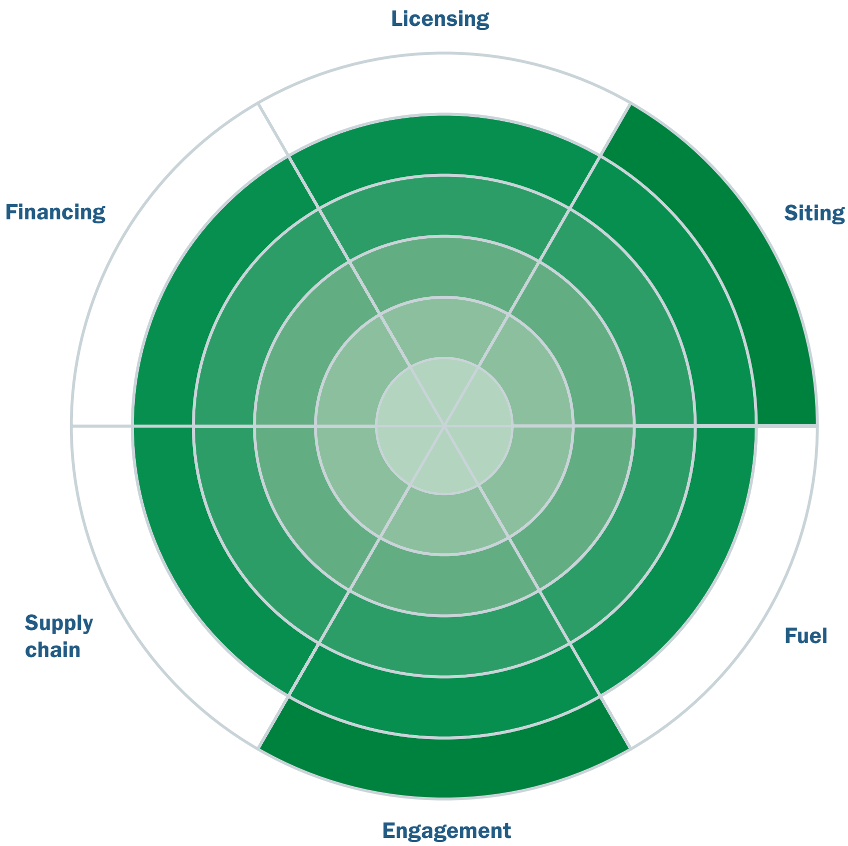
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

The ACPR50S is designed to use low-enriched fuel, either in the form of UO_2 pellets, or UO_2 pellets containing gadolinium oxide (UO_2-Gd_2O_3). The low-enriched UO_2 pellets are the current industry standard for water-cooled power reactor technologies and therefore rely on well-established fuel supply chains. CNNC Jianzhong Nuclear Fuel Co., Ltd., a subsidiary of China National Nuclear Corporation (CNNC), has a powder metallurgical fabrication line for Gd_2O_3 and UO_2 sintered pellets in Yibin, Sichuan.

CNEA (Argentina's National Atomic Energy Commission) – CAREM



Licensing

Siting

Financing

Supply chain

Engagement

Fuel

Reactor description: Integral pressurised water reactor.

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, Argentina's nuclear regulator, granted the authorisation for site use and construction to the Comisión Nacional De Energia Atómica (CNEA) in September 2013. The 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 reactor.

Supply chain

CAREM's construction started in 2014 and was ongoing as of 2023. 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. Nucleoelectrica Argentina SA is providing the construction and technical assistance under contracts signed in 2021 and 2023. In 2023, CNEA also signed a new contract with an Argentinian engineering, procurement and construction company, Industrias Metalúrgicas Pescarmona Sociedad Anónima, for the manufacture of auxiliary components.

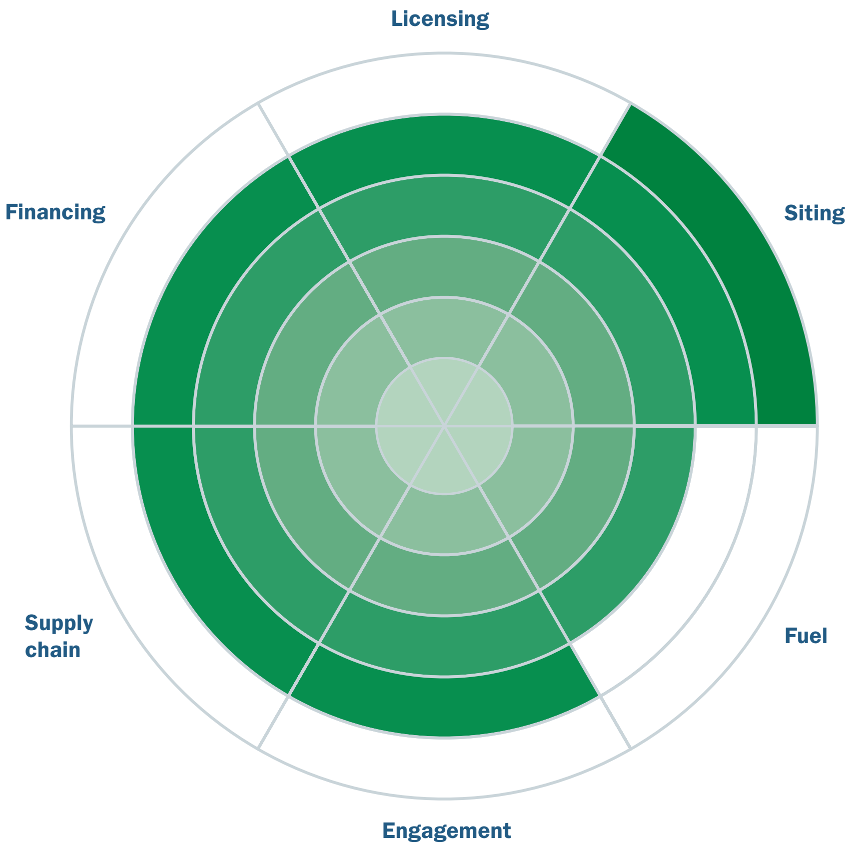
Engagement

Argentina has co-operation agreements with Bolivia for activities in the field of peaceful uses of nuclear energy, including but not limited to engagement about CAREM. Argentina also has a Memorandum of Understanding with Indonesia for co-operation on nuclear energy, including CAREM. From 2022 to 2023, CNEA hosted more than ten national and subnational government officials, including the President of Argentina and the governor of Río Negro Province, to discuss the CAREM project. CNEA is engaged with the National University of General San Martín on a market study for the commercialisation of CAREM. In 2022, the Deliberative Council of Zárate, the city where CAREM is being constructed, met in the facilities of the Atucha Nuclear Complex and unanimously agreed to support of the CAREM project.

Fuel

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

CNNC (China National Nuclear Corporation) – ACP100



Δ Indicates change since 2023.

Reactor description: Integrated pressurised light water reactor, also known as the Linglong One.

Thermal power (MWth)	385
Outlet temperature (°C)	320
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Licensing

Siting

Financing

Supply chain

Engagement Δ

Fuel

Assessment of ACP100's progress to deployment

Licensing

China's National Nuclear Safety Administration (NNSA) approved the ACP100 preliminary safety analysis report in 2020. In June 2021, the NNSA approved the Quality Assurance Outline (Construction Phase) of the ACP100 demonstration reactor project, followed by the issuance of the construction license in July 2021. In 2021, the Ministry of Ecology and Environment of the People's Republic of China approved the Environmental Impact Report (Construction Phase) of the demonstration project.

Siting

In 2017, the Hainan provincial government agreed to site one ACP100 unit on the existing Changjiang Nuclear Power Plant site. Construction started in 2021. The unit is planned to be commercially operational in 2026.

Financing

The People's Republic of China's National Development and Reform Commission approved the construction of a ACP100 demonstration reactor in June 2021. This ACP100 demonstration reactor 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 the ACP100 demonstration reactor involves various Chinese companies, including 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, China First Heavy Industry as the supplier of the reactor vessel, as well as Harbin Electric Corporation and Dongfang Electric Corporation as suppliers for other parts of the reactor. The ACP100 demonstration reactor core and steel containment dome were installed in August and November 2023, respectively.

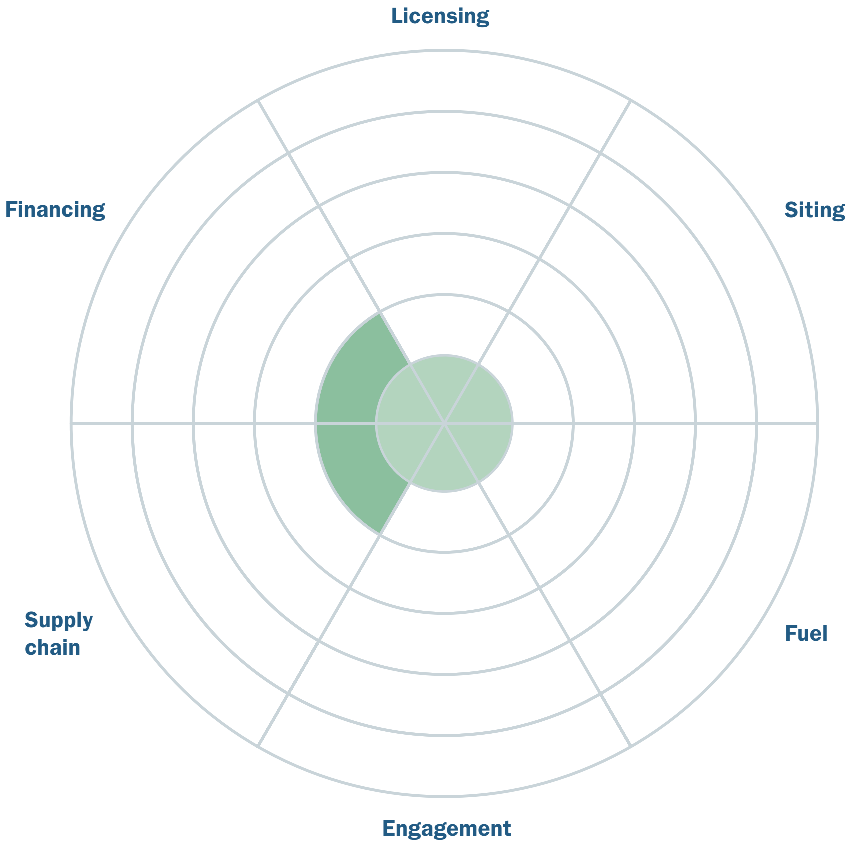
Engagement

In 2014, CNNC presented the progress of the ACP100 demonstration project at the 12^{th} National Committee of the Chinese People's Political Consultative Conference. In 2017, CNNC met with members of the Changjiang County Party Committee and the Governor to discuss the ACP100 demonstration project. The national and local governments support the ACP100 demonstration project, including through policy statements, media interviews, and site visits to promote the project. In 2017, CNNC said it had met with foreign countries including Brazil, Canada, Egypt, Indonesia, Iran, Mongolia, Pakistan, Saudi Arabia and the United Kingdom to discuss the ACP100 demonstration project and explore opportunities for potential co-operation.

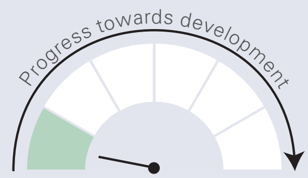
Fuel

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

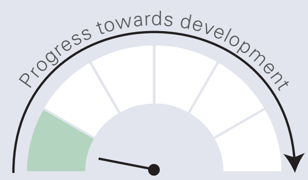
CVŘ (Research Centre Řež) – Energy Well



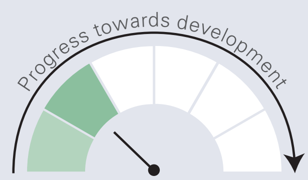
Licensing



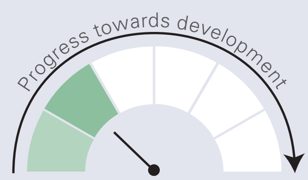
Siting



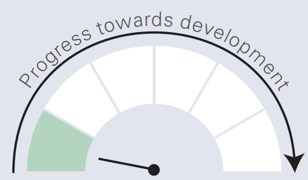
Financing



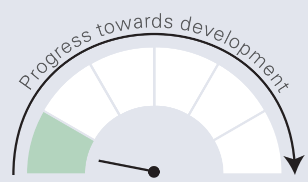
Supply chain



Engagement



Fuel



Reactor description: Micro molten salt-cooled reactor fuelled by HALEU TRISO fuel in a solid prismatic fuel assembly.

Thermal power (MWth)	20
Outlet temperature (°C)	700
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of Energy Well's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

In its 2020 Annual Report, Research Centre Řež (CVŘ) highlighted that the Energy Well SMR received funding from the Technology Agency of the Czech Republic to support work towards the pre-conceptual design.

Supply chain

CVŘ has reported that ŠKODA JS (since acquired by ČEZ) is a key partner in the development of the transport container. CVŘ has stated its intention to work with the supply chain within Czechia and foresees potentially working with MICO and ATEKO for the main reactor components, with ZAT and DEL for instrumentation and control, with the Division of ENERGOPROJEKT within ÚJV Řež for primary engineering, and with the Sigma Group for pumps and valves.

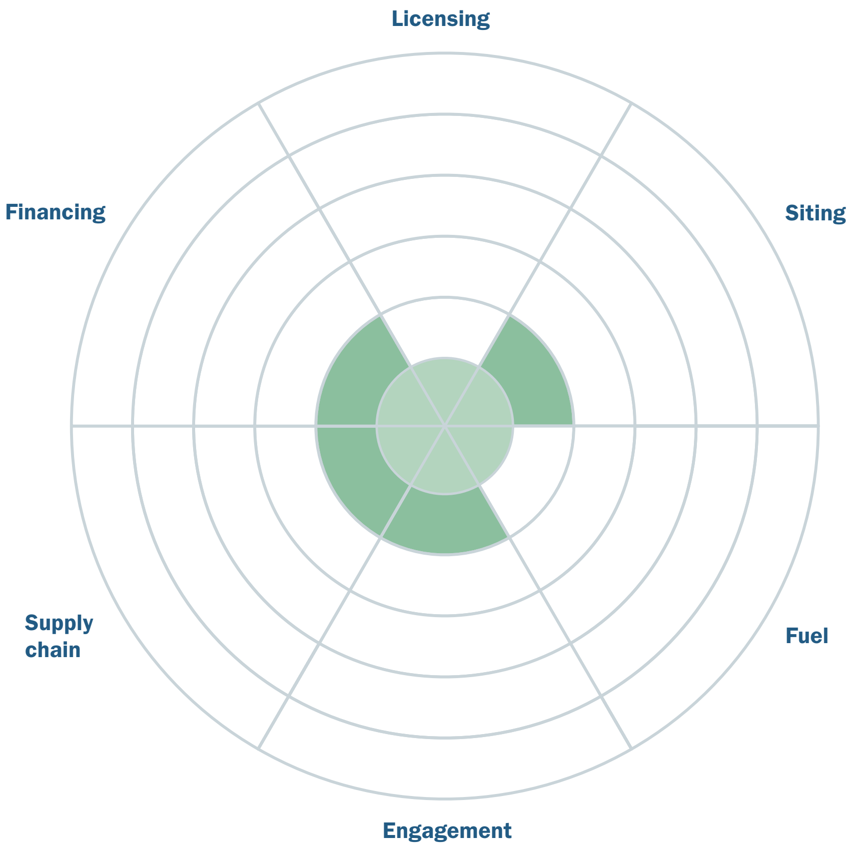
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

Dual Fluid Energy – DF300

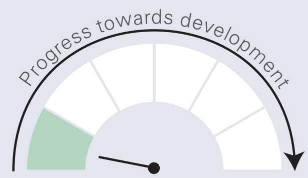


Δ Indicates change since 2023.

Reactor description: Liquid lead-cooled SMR using liquid metallic fuel with a high actinide density.

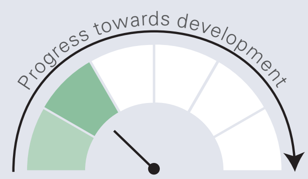
Thermal power (MWth)	600
Outlet temperature (°C)	1 000
Spectrum (thermal/fast)	Fast
Fuel type	Liquid metallic U-Cr alloy
Fuel (LEU/HALEU/HEU)	HALEU

Licensing

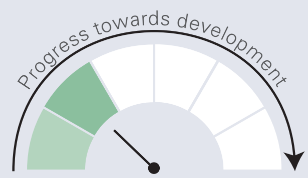


Siting Δ

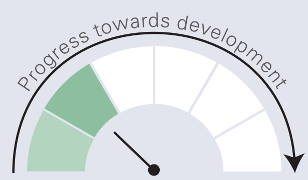
Financing



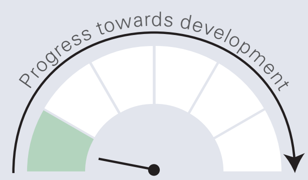
Supply chain



Engagement



Fuel



Assessment of DF300's progress to deployment

Licensing

Dual Fluid Energy joined Canada's SMR Action Plan in 2021 with a commitment to engage the Canadian Nuclear Safety Commission through its pre-licensing Vendor Design Review Process. At the time of assessment, there was no additional information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

In 2023, Dual Fluid Energy signed a partnership agreement with the Rwanda Atomic Energy Board (RAEB) to build a 1 MW test reactor to demonstrate the Dual Fluid concept with a criticality experiment at a site located on a new nuclear research campus in Nyamata, south of the Rwandan capital, Kigali. The test reactor is expected to be operational by 2026, with subsequent technology testing to be completed by 2028. Following a successful criticality experiment with the 1 MW test reactor, RAEB may support the deployment of a prototype DF300 reactor on its site.

Financing

In June 2021, Dual Fluid announced that it had raised almost CAD 7 million (USD 5.4 million) in its first round of private financing for collaborations with research institutions on safety analysis in accordance with international regulatory standards, company build-up and laboratory setup. In October 2023, Dual Fluid announced that the company had started a financing round to raise an additional EUR 70 million (USD 73.7 million) for the test reactor project in Rwanda.

Supply chain

Dual Fluid signed a Memorandum of Understanding with the TRIUMF particle accelerator centre in British Columbia, Canada, to conduct materials research. The first measurement campaign started in June 2023. Dual Fluid is engaged with research institutions such as the Technical University of Munich, the Technical University of Dresden, the Polish National Centre for Nuclear Research and the Swiss Paul Scherrer Institut to conduct research and demonstrate the safety of the Dual Fluid concept. In September 2023, the Government of Rwanda agreed to provide the necessary infrastructure for Dual Fluid to conduct the criticality demonstration experiment project in Nyamata, Rwanda. Dual Fluid has agreed to provide practical training with Rwandan scientists in the field of nuclear technology.

Engagement

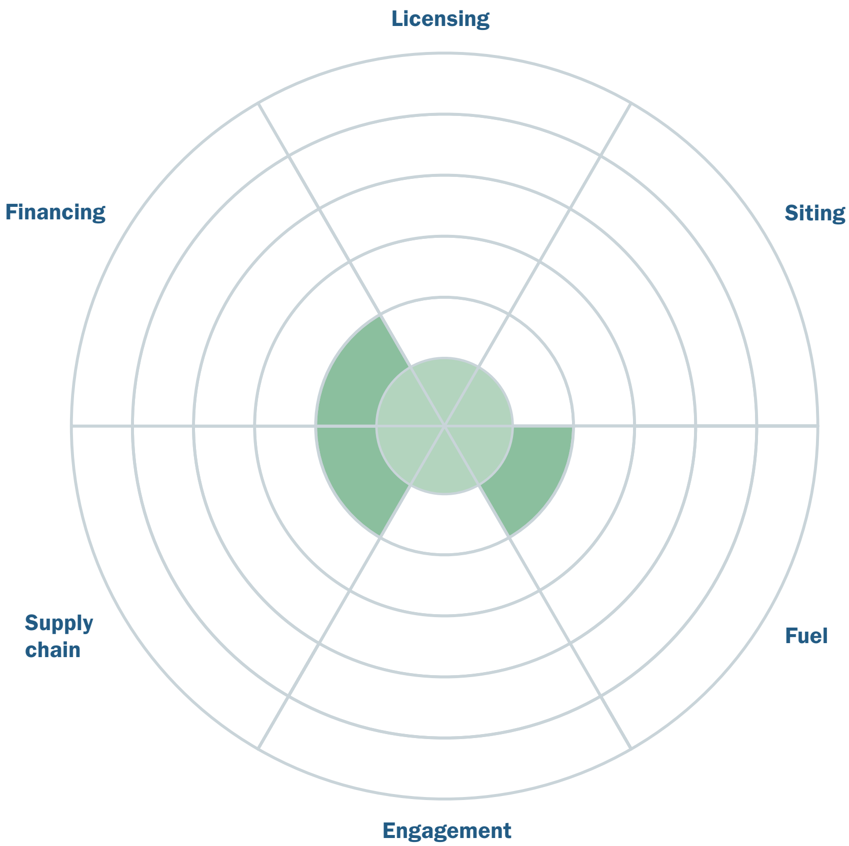
In 2013, Dual Fluid entered its reactor design in the GreenTec Awards, a national environmental contest in Germany, under the energy category. The Dual Fluid reactor was designated by the GreenTec judges, a 54-person jury and the public as one of the top three technologies in the competition. In 2022, Dual Fluid was selected as one of the Deep Tech Pioneers for the 2023 Global Summit, organised by Hello Tomorrow, a startup accelerator with a presence in 30 countries.

Fuel

The Dual Fluid design principle allows for a high density of fissile material in the liquid fuel. For the DF300, a mixture of 80% actinide and 20% chromium is intended for an initial fuel inventory utilising either enriched uranium or reactor-grade plutonium. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

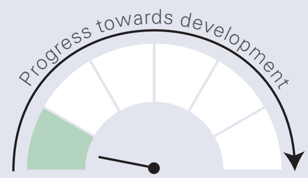
Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, CAD 1.302 and EUR 0.950 are equal to USD 1.000.

Eskom – A-HTR-100

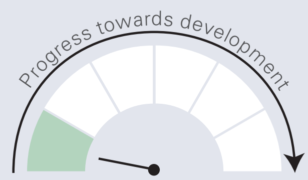


Reactor description: Very high-temperature pebble-bed gas reactor using intermediary heat storage for plant flexibility.	
Thermal power (MWth)	100
Outlet temperature (°C)	1 200
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO pebble
Fuel (LEU/HALEU/HEU)	HALEU

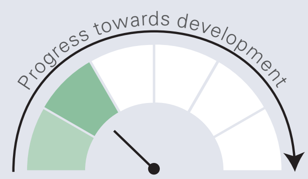
Licensing



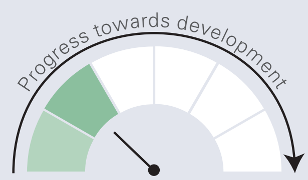
Siting



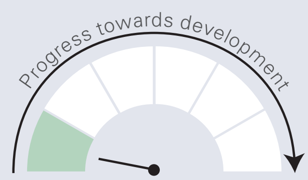
Financing



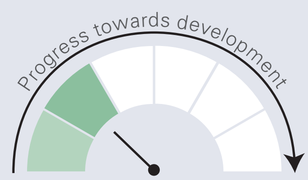
Supply chain



Engagement



Fuel



Assessment of A-HTR-100's progress to deployment

Licensing

Eskom is currently exploring the feasibility of reactivating the A-HTR-100 SMR based on the Pebble Bed Modular Reactor (PBMR) research initiative that has been in a state of "care and maintenance" since 2010. At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities

Siting

In their 2019-2024 Research, Testing and Development Research Direction Report, Eskom anticipated a demonstration of the A-HTR-100 technology to be completed at the Pelindaba Nuclear Facility by 2022. At the time of assessment, no information related to siting was readily available from any site owners.

Financing

Research activities within the Eskom Research, Testing and Development (RT&D) business unit are publicly funded, as Eskom is wholly owned by the Government of South Africa. In 2017, Eskom said that the ongoing research to develop the A-HTR-100 SMR was being funded through Eskom's internal research and development budget.

Supply chain

Eskom is exploring the feasibility of deploying the A-HTR-100 as a research initiative through its RT&D group and in collaboration with academia and research institutions, primarily through the South African Nuclear Engineering, Science and Technology collaborative forum. Eskom has conducted joint research on heat exchangers and materials for the A-HTR-100 design with the North-West University, and has also advanced research with Nelson Mandela Metropolitan University, and the University of Cape Town. In 2016, Eskom RT&D signed a Strategic Partnership Agreement with the Council for Scientific and Industrial Research to enhance skills and knowledge related to the A-HTR-100 in both organisations.

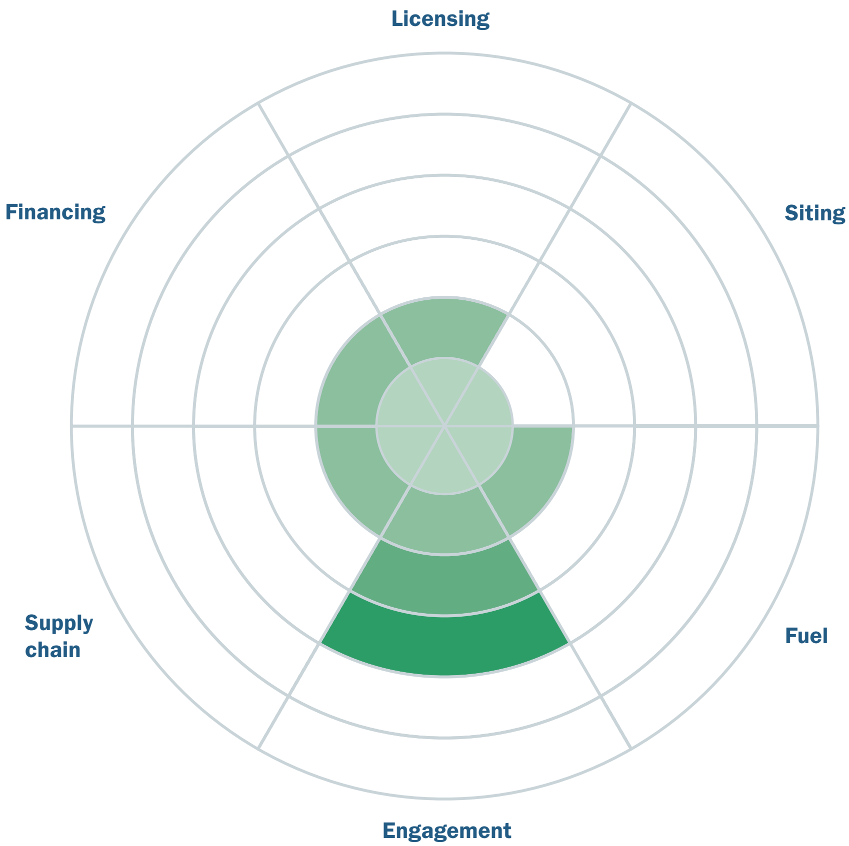
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

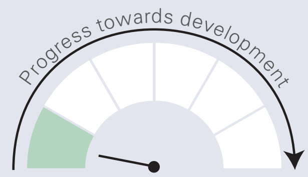
HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. The South African Nuclear Energy Corporation (NECSA) has a TRISO pebble fuel manufacturing laboratory in Pretoria, South Africa, which has been in care and maintenance since 2010. In 2017, NECSA announced that it is working to restart this facility to serve new potential customers for TRISO. As part of the Nuclear Grand Challenge, Eskom RT&D is advancing nuclear fuel components for the A-HTR-100. Eskom will leverage previous validation experiments on TRISO manufactured by NECSA for the PBMR programme, which includes irradiation performance testing at the Idaho National Laboratory in the United States.

Flibe Energy – LFTR

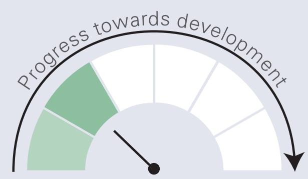


Licensing

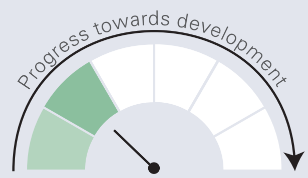
Siting



Financing

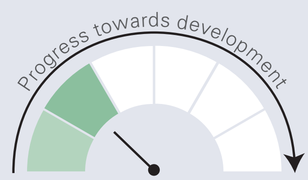


Supply chain



Engagement

Fuel



Reactor description: Lithium fluoride molten salt reactor to produce power and isotopes using uranium fuel and breeding thorium.

Thermal power (MWth)	600
Outlet temperature (°C)	650
Spectrum (thermal/fast)	Thermal
Fuel type	Molten salt
Fuel (LEU/HALEU/HEU)	LEU, Thorium

Assessment of LFTR's progress to deployment

Licensing

Flibe Energy has been engaged in pre-licensing activities with the US Nuclear Regulatory Commission (NRC) for the LFTR since 2013, when Flibe Energy first submitted its notice of intent to submit a licence application to the NRC for the LFTR and radioisotope production facility.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

In July 2018, Flibe Energy raised over USD 2.6 million in funding for a molten salt fuel study in collaboration with Pacific Northwest National Laboratory, which included over USD 2 million from the US Department of Energy (DOE). In October 2018, Flibe Energy raised more than USD 4.6 million in Series A private funding.

Supply chain

In 2019, Flibe Energy was awarded a voucher under the US DOE Gateway for Accelerated Innovation in Nuclear (GAIN) initiative to assess the LFTR design from a safeguards perspective in partnership with Oak Ridge National Laboratory.

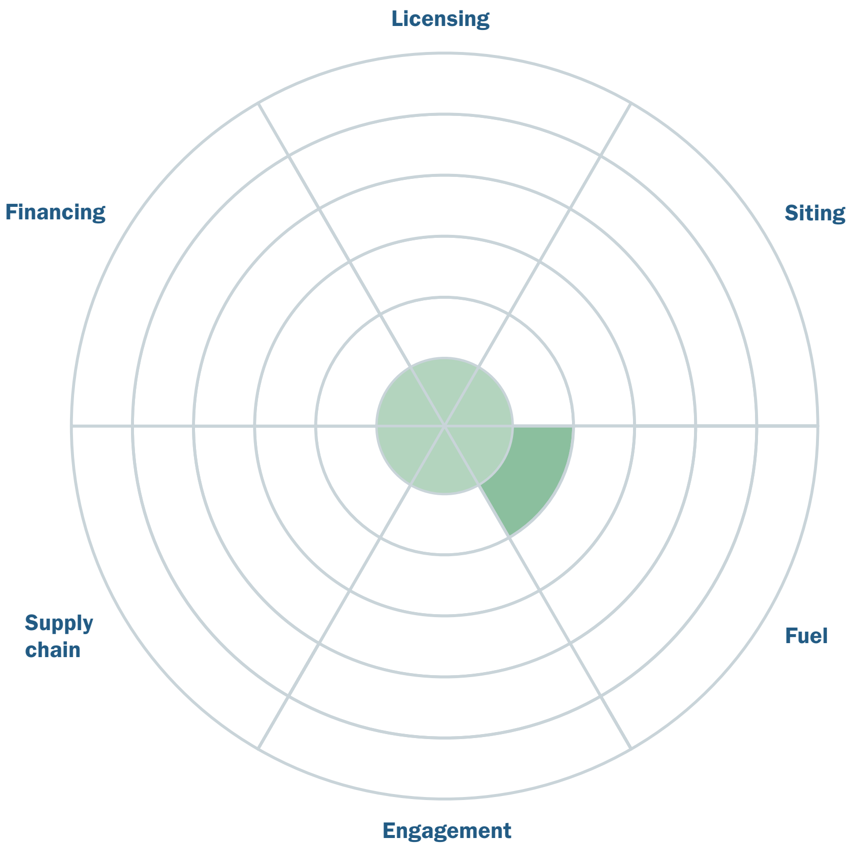
Engagement

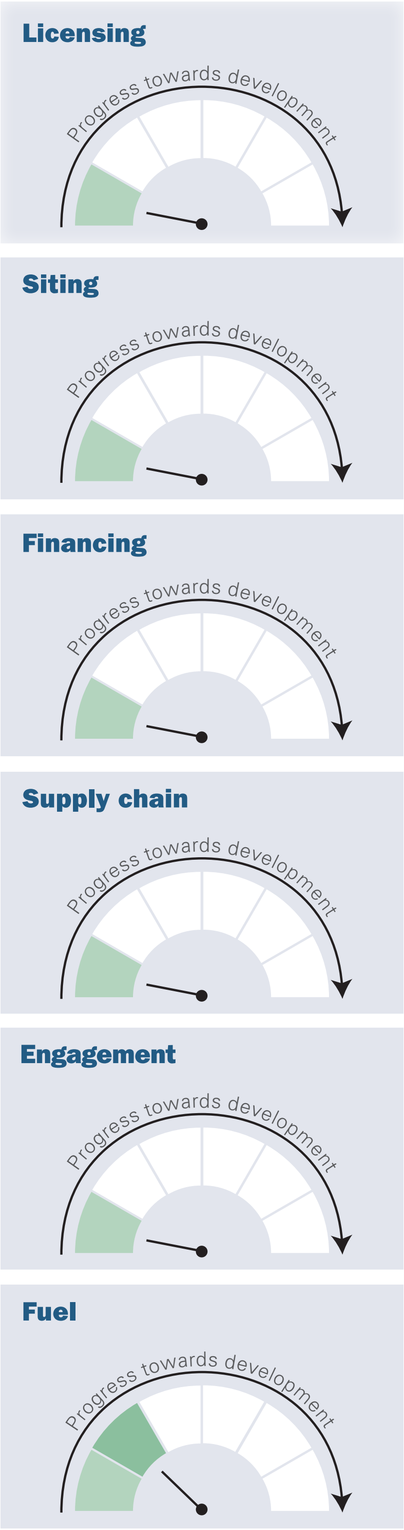
The founder of Flibe Energy, Kirk Sorensen, has engaged public audiences extensively through TED Talks, Google TechTalks and YouTube. Kirk Sorensen also engages university students and the general public through seminars and lectures around the world. In 2019, Flibe Energy discussed LFTR with the Wyoming Legislative Joint Committee on Minerals, Business & Economic Development. In May 2023, Flibe Energy participated in the 2023 Next Frontier Energy Summit, organised by the Wyoming Energy Authority with the Governor of Wyoming and sponsored by the University of Wyoming to discuss the LFTR technology.

Fuel

LFTR is designed to use thorium in a blanket salt to breed U-233, a fissile material that can be used as new fuel. LFTR would initially use low enriched uranium as a fuel, but could transition to U-233 later. Flibe Energy has been awarded two vouchers under the US DOE GAIN initiative to work on research and development of the LFTR fuel in partnership with the Argonne National Laboratory and Pacific Northwest National Laboratory.

Framatome – Steam Cycle High Temperature Gas-cooled Reactor (SC-HTGR)





Reactor description: High temperature helium-cooled reactor, using TRISO fuel, for cogenerating heat and electricity.

Thermal power (MWth)	625
Outlet temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of SC-HTGR's progress to deployment

Licensing

Framatome is engaged in the Gemini 4.0 European project that has a work package focused on discussing a possible licensing process for a generic high temperature reactor. At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

At the time of assessment, no information related to financing was readily available from verifiable public sources.

Supply chain

Framatome has extensive experience as a provider of components for the nuclear island of light water and marine propulsion reactors. Framatome also has a long history of working on HTR technology development. In the 2000s Framatome (then Areva) was involved in HTR-related projects such as the ANTARES Reactor Project, and also had a close working relationship with SIEMENS and INTERATOM on HTR development. At the time of assessment, no information was readily available related to the establishment of agreements related to the supply of components for the SC-HTGR.

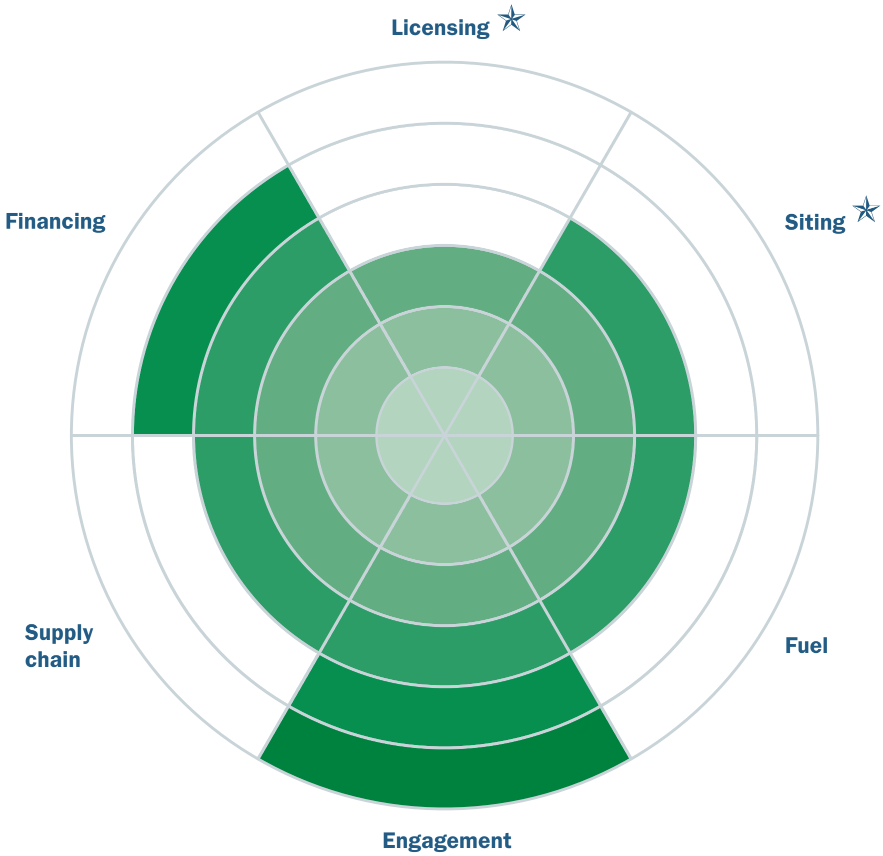
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

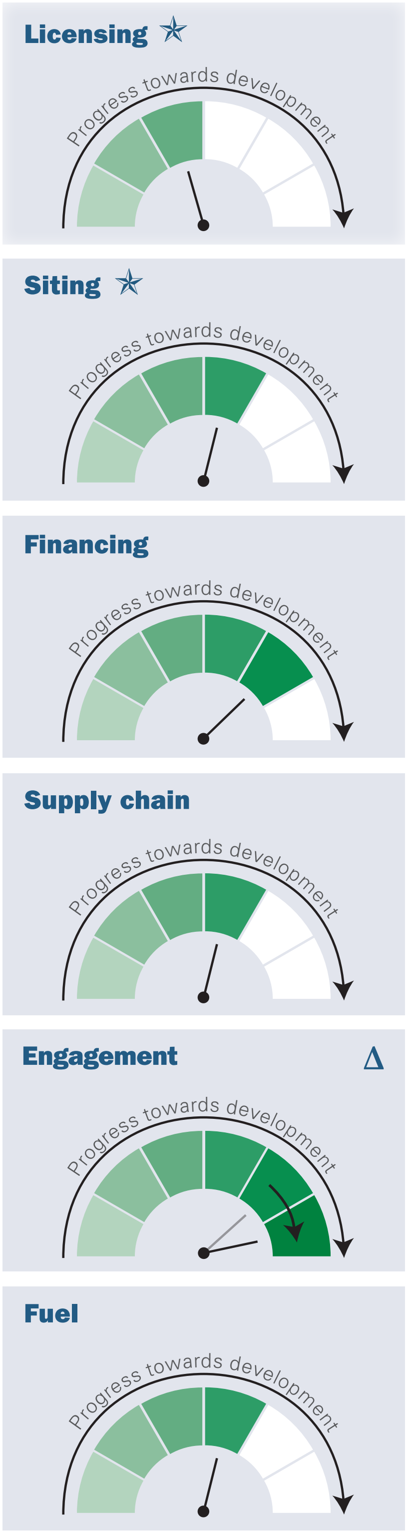
HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. Framatome has considerable experience designing, producing, irradiating and qualifying HTR TRISO fuels dating back to the 2000s. Framatome owns and operates a fuel fabrication facility in Washington state, Unite States, licensed for LEU up to 5%. Framatome has initiated pre-licensing with the US Nuclear Regulatory Commission (NRC) to upgrade its licence for HALEU up to 20%. In early 2023, Framatome and Ultra Safe Nuclear Corporation signed a non-binding Heads of Terms agreement supporting the creation of a joint venture to manufacture TRISO particles at commercial scale in the United States by late 2025.

GE Hitachi Nuclear Energy – BWRX-300



★ Active in multiple jurisdictions or countries.
Δ Indicates change since 2023.

Reactor description: Land-based boiling water reactor.	
Thermal power (MWth)	870
Outlet temperature (°C)	288
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU



Assessment of BWRX-300's progress to deployment

Licensing

In 2023, GE Hitachi Nuclear Energy (GEH) completed a combined Phase 1 and 2 Vendor Design Review (VDR) with the Canadian Nuclear Safety Commission (CNSC) for the BWRX-300. In its VDR report of the BWRX-300, the CNSC did not identify any fundamental barriers to licensing. Ontario Power Generation (OPG) submitted an application to the CNSC for a licence to construct one BWRX-300 reactor at OPG's Darlington New Nuclear Project site in Canada in 2022. GEH is engaged in pre-licensing activities with regulators in the United States and the United Kingdom. The US Nuclear Regulatory Commission (NRC) has approved five topical reports for BWRX-300. In 2023, Poland's Ministry of Climate and Environment issued a General Opinion indicating the BWRX-300 is compliant with the national nuclear safety requirements.

Siting

OPG has begun preparing its Darlington site for construction of one BWRX-300. In 2023, the Ontario government announced it is starting planning and licensing with OPG for three additional BWRX-300 SMRs at the Darlington site. BWRX-300 has also been selected for potential deployment by: SaskPower in Canada; Fermi Energia in Estonia; and ORLEN Synthos Green Energy in Poland. Tennessee Valley Authority has partnered with GEH for potential deployment at the Clinch River site, United States. BWRX-300 also has a Memorandum of Understanding (MoU) with nuclear operator ČEZ for potential deployment in Czechia and has been selected by Great British Nuclear to progress to the next phase of the United Kingdom's innovative nuclear technology competition for potential deployment in the United Kingdom.

Financing

GEH has attracted private and public support for the development of the BWRX-300 first-of-a-kind at Darlington. This includes almost CAD 1 billion (USD 768 million) in public financing 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. In 2023, GEH, TVA, OPG and Synthos Green Energy (SGE) announced an agreement to invest in the development of the BWRX-300 standard design and detailed design for key components, with an investment of around USD 400 million.

Supply chain

Given GEH's experience developing boiling water reactors similar to the BWRX-300 SMR, there is an opportunity to leverage existing supply chains. To support BWRX-300 deployment in Canada, GEH is collaborating with OPG to design, plan, license and prepare the Darlington site. With an interest in deploying the SMR in the United States, TVA has separate agreements in place with both GEH 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 include a collaboration with a UK architecture firm to provide input on the design.

Engagement

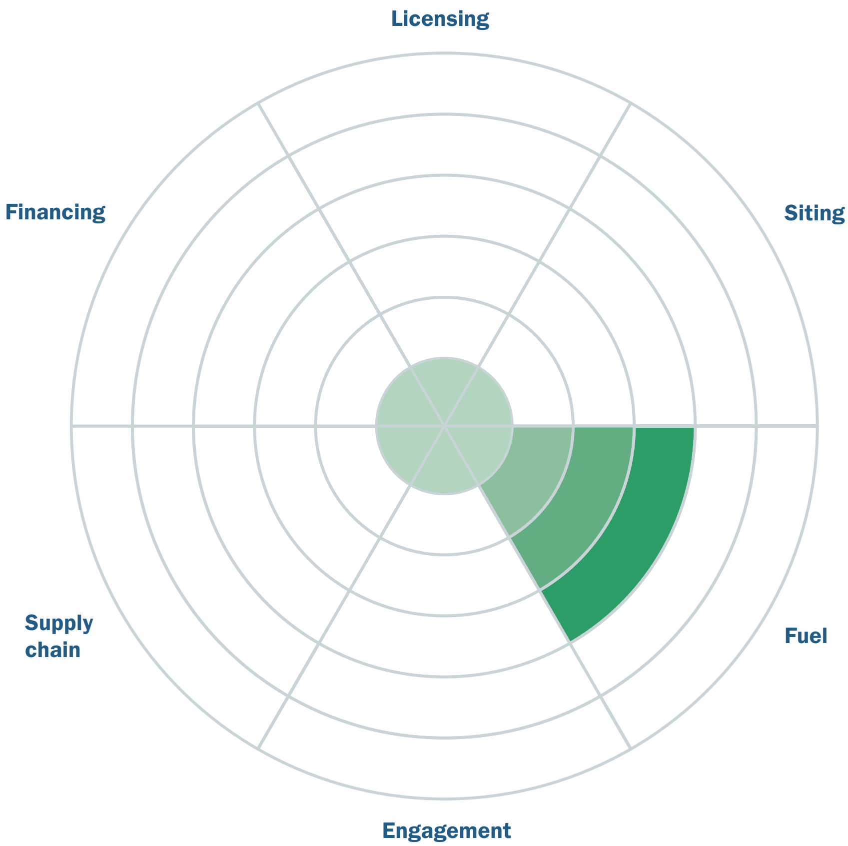
In Canada, the Darlington project has been endorsed by provincial and federal governments. OPG engages the public through information sessions, workshops and hearings. GEH has formed a collaboration with the First Nations Power Authority to engage communities on SMRs and to train individuals from Indigenous communities in Canada to support its workforce. GEH 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, GEH has established a series of MoUs including with ČEZ in the Czechia and with Kärnfull Next in Sweden.

Fuel

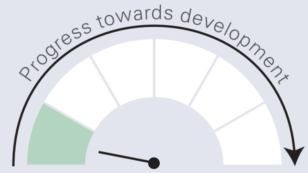
The BWRX-300 reactor uses fuel that is proven, commercially available and currently being used in operating boiling water reactors. There are no barriers expected in the fuel supply chain for this SMR.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, CAD 1.302 equals USD 1.000.

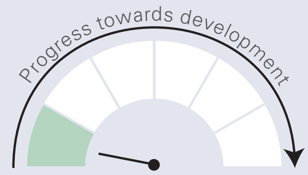
Gorgé – Calogena



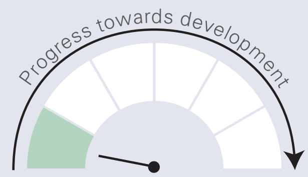
Licensing



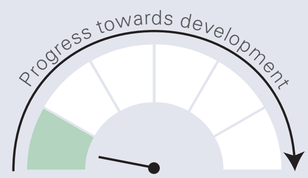
Siting



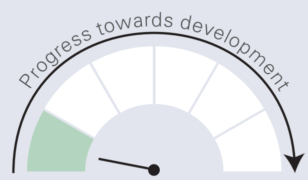
Financing



Supply chain



Engagement



Fuel

Reactor description: Closed-core, pool-type water-cooled microreactor intended for district heating.

Thermal power (MWth)	30
Outlet temperature (°C)	100
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 or uranium silicide
Fuel (LEU/HALEU/HEU)	LEU

Assessment of Calogena's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

Gorgé is currently developing its fund-raising strategy for the Calogena project with the support of INSKIP, a French consulting firm for startups. The Gorgé group has expressed its intention to invest its own capital ("several tens of millions of euros") for the initial phases of the project. At the time of assessment, no additional information about financing was readily available from verifiable public sources.

Supply chain

Gorgé has experience engineering and manufacturing equipment for nuclear power plants and has 200 engineers working in the nuclear power and innovation sector. At the time of assessment, no information about supply chain readiness was readily available from verifiable public sources.

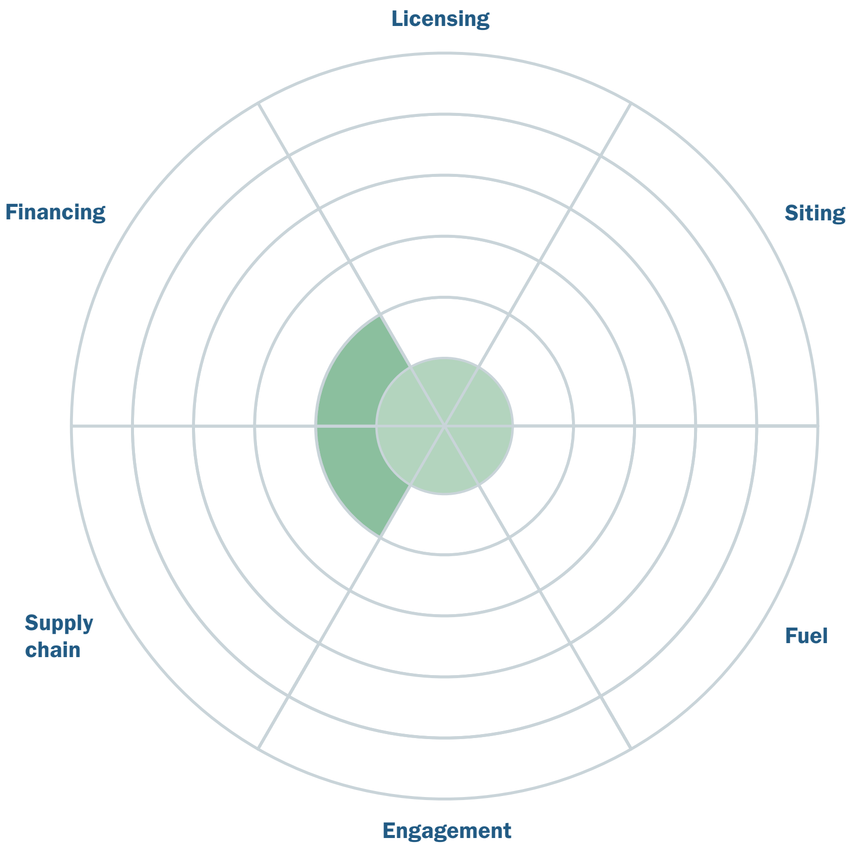
Engagement

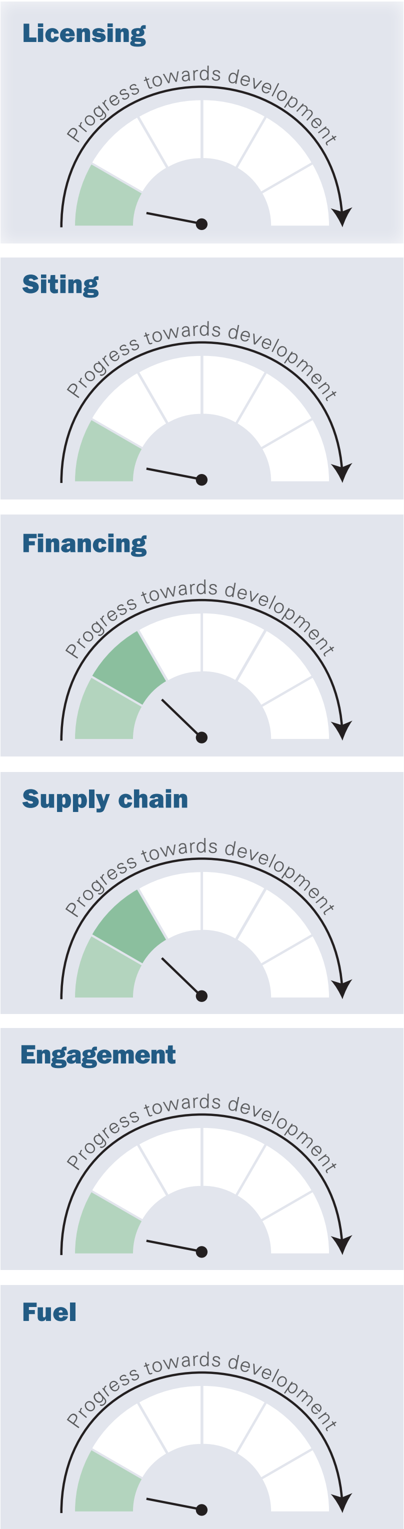
At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

The Calogena reactor plans to use low-enriched fuel, either in the form of UO_2 pellets, which are the current industry standard for water-cooled power reactor technologies, or in the form of plate fuel using either uranium aluminium alloys or uranium silicide, which is currently widely used in research reactors and commercially available.

Hexana – HEXANA





Reactor description: Sodium-cooled fast reactor with two 400 MWth reactor modules and a high-temperature heat storage system.

Thermal power (MWth)	800 (plant deployed with two modules of 400 MWth)
Outlet temperature (°C)	510
Spectrum (thermal/fast)	Fast
Fuel type	MOX
Fuel (LEU/HALEU/HEU)	Depleted uranium and plutonium

Assessment of HEXANA's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

In 2023, Framatome and the French Commissariat à l'énergie atomique et aux énergies alternatives (French Alternative Energies and Atomic Energy Commission, or CEA) announced that they will each invest EUR 2 million (USD 2.1 million) in the HEXANA project to support Hexana's efforts to prepare an application to the France 2030 programme supported by the French Public Bank for Investments.

Supply chain

Hexana was one of two spin-offs from the CEA announced in March 2023. In April 2023, the CEA announced that it would invest its know-how in support of Hexana. Hexana's supply chain strategy will seek to leverage existing capabilities, including from Framatome and Electricité de France. Hexana convened its first supply chain workshop with Framatome in July 2023, and announced its intention to leverage Framatome's experience developing primary circuit components. In June 2023, Hexana and Bureau Veritas announced their collaboration to explore technical aspects of deploying the Hexana SMR, including risk management, co-siting of industrial and nuclear facilities, regulatory support, and technical equipment qualification.

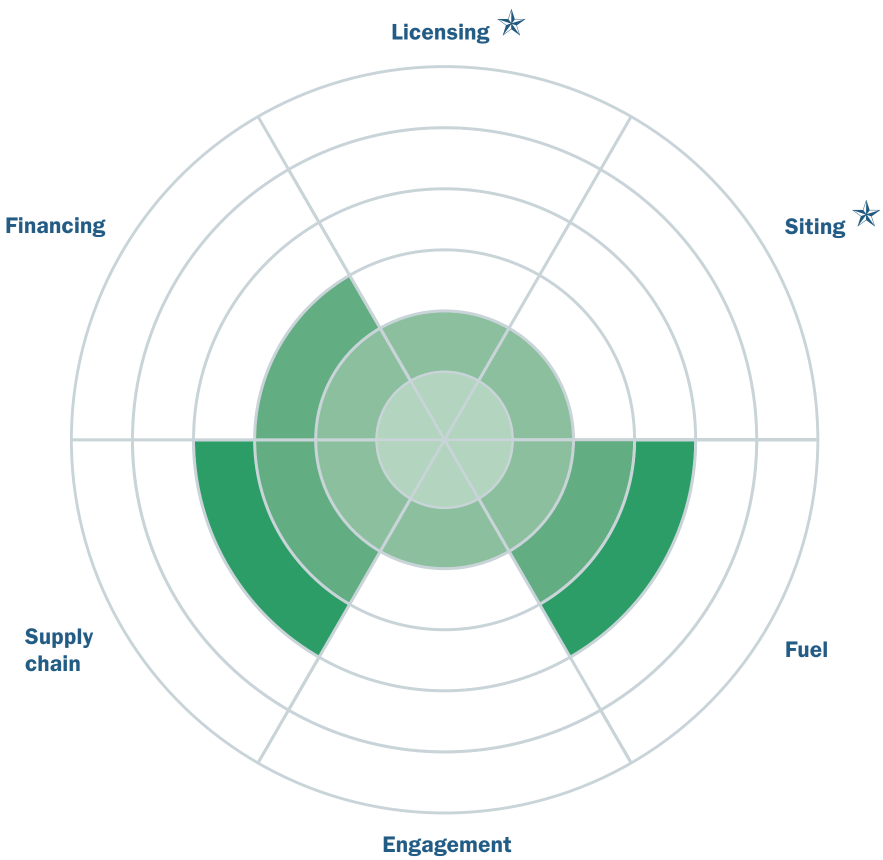
Engagement

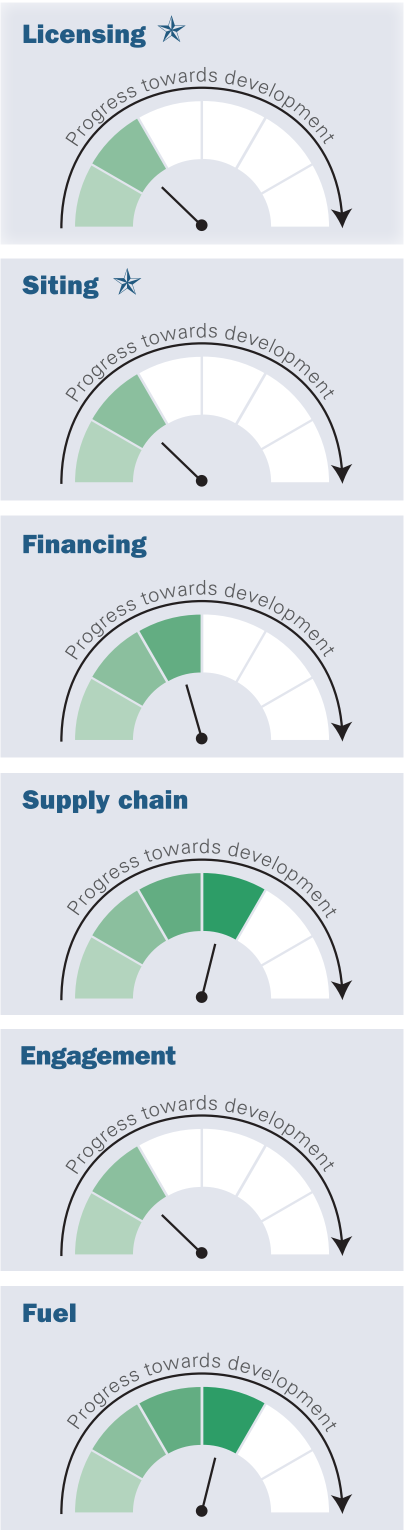
At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

Hexana plans to use mixed plutonium-uranium oxide fuel (MOX). MOX fuel is a technically proven fuel type; however, there are presently limited suppliers, in particular for fast reactors. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

Holtec International – SMR-300





★ Active in multiple jurisdictions or countries.

Reactor description: Land-based pressurised light water reactor.

Thermal power (MWth)	1 000
Outlet temperature (°C)	N/A
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of SMR-300's progress to deployment

Licensing ✯

In 2023, Holtec International (Holtec) renamed its "SMR-160" to "SMR-300" and increased its size from 525 MWth to 1 000 MWth. Prior to this change, Holtec had completed Phase 1 of the pre-licensing Vendor Design Review with the Canadian Nuclear Safety Commission in 2018 and was undergoing pre-licensing activities with the US Nuclear Regulatory Commission (NRC). Future licensing work for the SMR-300 is expected to benefit from pre-licensing activities for the SMR-160. In January 2023, Holtec submitted an application to the UK Office for Nuclear Regulation to enter step 1 of the Generic Design Assessment (GDA). As of November 2023, the SMR-300 had not yet started the GDA process.

Siting ✯

In the United States, Holtec has a Memorandum of Agreement to assess SMR deployment feasibility at Entergy Corporation sites. Holtec is also considering deploying an SMR at its Oyster Creek nuclear site in New Jersey. In 2023, Holtec met with the NRC to discuss deploying the SMR-300 at its Palisades site in Michigan, acquired in 2022. Holtec has a Memorandum of Understanding (MoU) with ČEZ in Czechia to evaluate SMR feasibility at the Temelin nuclear power plant site and an MoU as well as a 2023 co-operation agreement with NAEK Energoatom to plan the deployment of SMRs in Ukraine. SMR-300 was shortlisted with five other SMRs by Great British Nuclear to move to the next phase of the United Kingdom's innovative nuclear technology competition for potential deployment in the United Kingdom.

Financing

Holtec has secured USD 116 million from the US Department of Energy (DOE) Advanced Reactor Demonstration Program to advance early-stage design, engineering and licensing. Holtec is also a member of the Mid-Atlantic Clean Hydrogen Hub (MACH2), which was selected to receive up to USD 750 million from the US DOE. MACH2 includes Holtec's Oyster Creek site where Holtec is considering deploying its SMR-300. In 2023, the Korea Trade Insurance Corporation and the Export-Import Bank of Korea signed agreements with Holtec and Hyundai Engineering & Construction to potentially support financing of Holtec SMR projects with Hyundai.

Supply chain

Holtec has partnerships and in-house nuclear engineering, manufacturing and construction capabilities. In 2022, the DOE approved part I of a loan application from Holtec to expand manufacturing capacities in the United States. Holtec has contracted Mitsubishi Electric for instrumentation and control systems for its SMR; and Kiewit Power Constructors and Hyundai Engineering and Construction for civil works. Holtec is also working with Idaho National Laboratory on a plant simulator. In 2018 and 2023, Holtec signed an MoU and a co-operation agreement with NAEK Energoatom for the possible development of a manufacturing hub in Ukraine. Holtec also signed agreements in 2022 to support partial localisation of production with Skoda in Czechia and Global Energy Group in the United Kingdom.

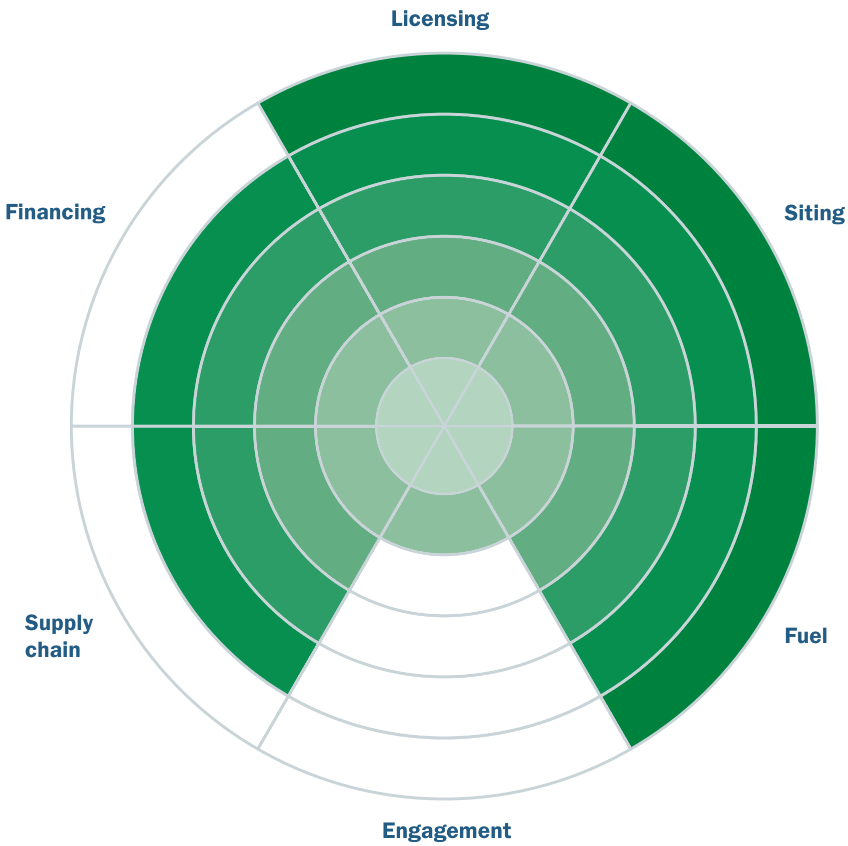
Engagement

In 2022, Joe Delmar and Pat O'Brien, Senior Director and Senior Manager of Holtec's Government Affairs and Communications division, were invited to present Holtec's activities, including the development of their SMR, to Van Buren County Council, Michigan. In 2023, Gareth Thomas, Senior International Program Manager at Holtec International, appeared in the Southwest Public Policy Institute's podcast dedicated to SMRs.

Fuel

The SMR-300 uses LEU, the fuel used in most existing light water reactors. In 2018, Holtec International signed an MoU with Global Nuclear Fuel, a joint venture led by GE Hitachi Nuclear Energy, to develop nuclear fuel and control rod drive mechanisms for Holtec's SMR. In 2020, Holtec signed a contract with Framatome, a French nuclear fuel manufacturer, to supply nuclear fuel for their SMR.

INET (Tsinghua University Institute of Nuclear and New Energy Technology) – HTR-PM



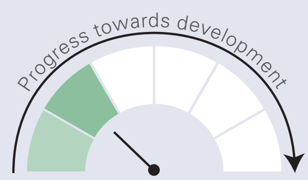
Licensing

Siting

Financing

Supply chain

Engagement



Fuel

Reactor description: 500 MWth plant with two 250 MWth pebble bed high temperature gas reactor modules coupling to one steam turbine.

Thermal power (MWth)	500 (plant deployed with two modules of 250 MWth)
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 after receiving an operating licence from China's National Nuclear Safety Administration on 20 August 2021. The HTR-PM is operating at full power and is connected to the electrical grid.

Siting

The HTR-PM is connected to the electrical grid as the 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 was developed by Tsinghua University's Institute of Nuclear and New Energy Technology (INET) and constructed by China National Nuclear Corporation (CNNC). China Huaneng Group operates the FOAK HTR-PM, which is owned by a consortium composed of China Huaneng, China Nuclear Engineering Corporation, and INET. CNNC collaborated with the consortium to provide engineering, procurement and construction services and to manufacture fuel elements. Up to 93.4% of the equipment was manufactured domestically.

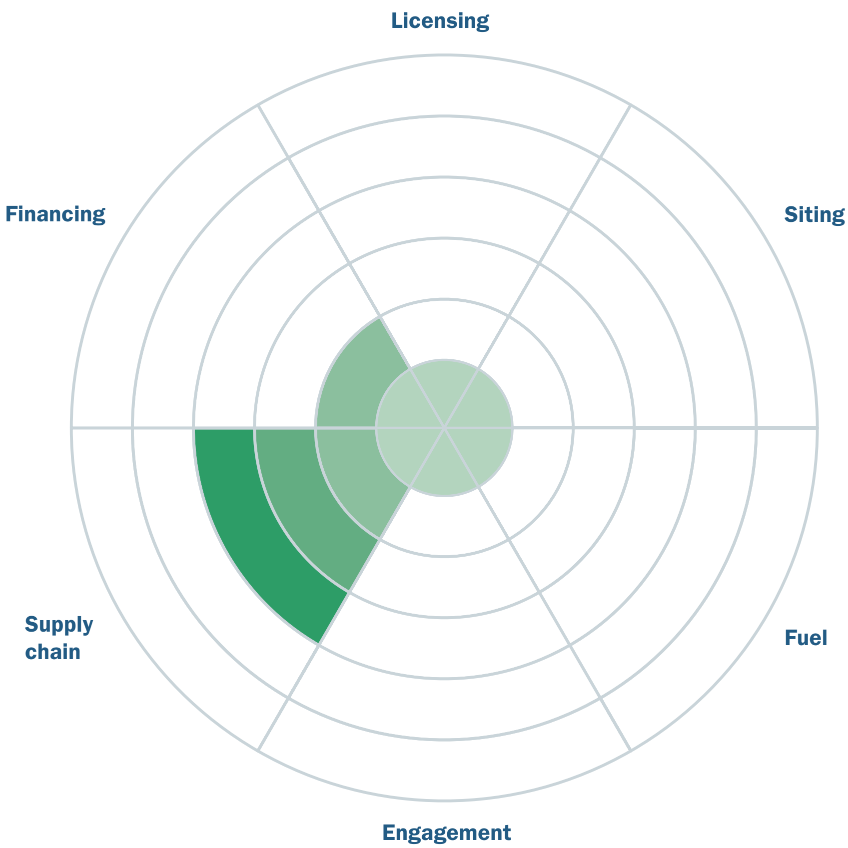
Engagement

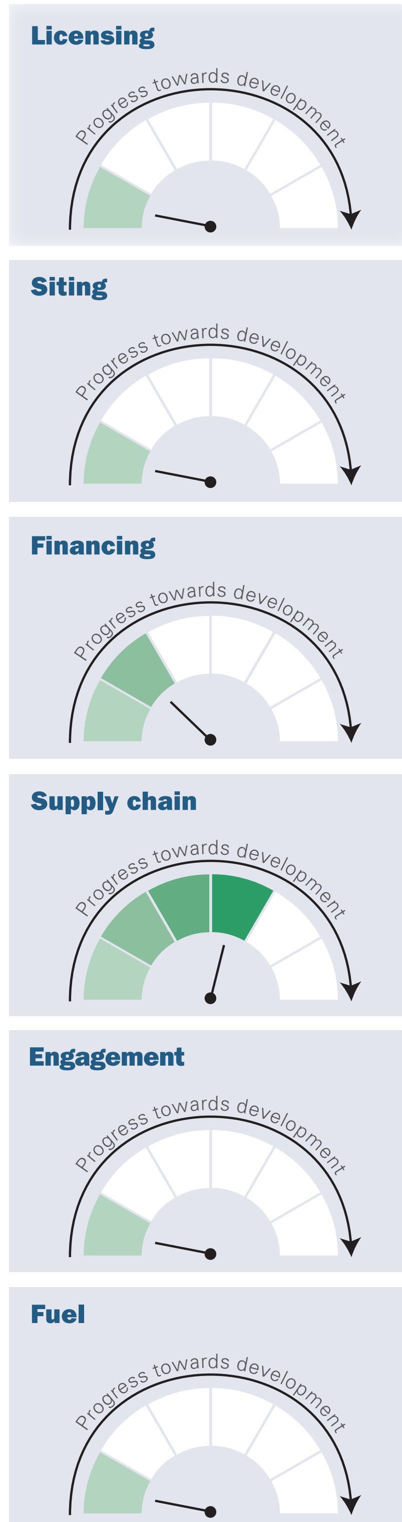
Tsinghua University's Institute of Nuclear and New Energy Technology, which is part of the consortium that owns the HTR-PM project, creates opportunities for engagement with students. In December 2021, an event to celebrate the first grid connection of the HTR-PM was held at the Shidaowan site, which featured participation from heads of ministries and commissions, provincial and municipal leaders, and representatives from industry and research institutions.

Fuel

HTR-PM fuel is licensed for operation.

JAEA (Japan Atomic Energy Agency) – GTHTR300





Reactor description: High temperature gas-cooled reactor designed as a commercial plant concept with a helium gas turbine.

Thermal power (MWth)	600
Outlet temperature (°C)	950
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of GTHTR300's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

The basic design for the GTHTR300 was completed in 2003 by the Japan Atomic Energy Agency (JAEA) with funding from the Ministry of Education, Culture, Sports, Science and Technology. At the time of assessment, no additional information about financing was readily available from verifiable public sources.

Supply chain

Mitsubishi Heavy Industries, Toshiba, IHI Corp, Fuji Electric and domestic nuclear fuel industries in Japan have existing supply chain capabilities developed under the HTTR project.

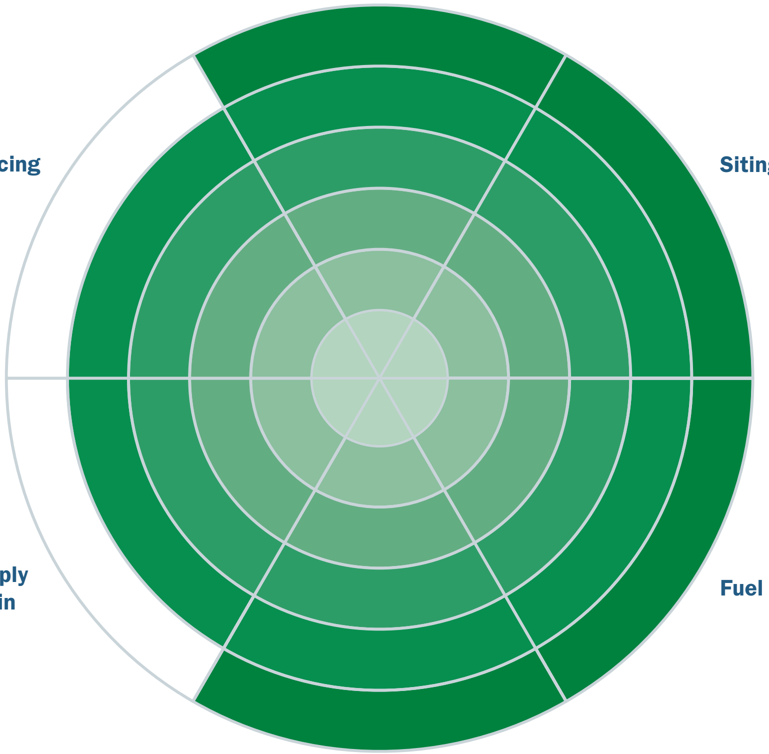
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

The GTHTR300 utilises HALEU fuel. HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

JAEA (Japan Atomic Energy Agency) – HTTR



Licensing

Siting

Financing

Supply chain

Engagement

Fuel

Reactor description: High temperature gas-cooled reactor designed to demonstrate nuclear heat application systems.

Thermal power (MWth)	30
Outlet temperature (°C)	950
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	LEU, HALEU

Assessment of HTTR's progress to deployment

Licensing

The High Temperature Test Reactor (HTTR) is fully licensed by the Nuclear Regulatory Authority (NRA) of Japan. The first criticality of the HTTR was achieved on 10 November 1998. The reactor outlet coolant temperature of 850°C under full thermal power of 30 MWth was achieved on 6 December 2001. The reactor outlet coolant temperature of 950°C under full thermal power of 30 MWth was achieved on 19 April 2004.

Siting

The HTTR initially started operating at the site of the Oarai Research and Development Institute of the Japan Atomic Energy Agency (JAEA) in Oarai, Ibaraki Prefecture. The HTTR stopped operating in 2011 and was restarted in 2021. In 2023, the HTTR was taken offline for maintenance.

Financing

The HTTR is a one-of-a-kind high temperature gas-cooled reactor (HTGR). The HTTR project was fully financed by the Japanese government.

Supply chain

The HTTR is a one-of-a-kind HTGR. The construction finished in 1997, led by Toshiba, Hitachi, Fuji Electric and Mitsubishi Heavy Industries (MHI), with MHI as the managing company. The JAEA is working with MHI on a project for mass production of hydrogen utilising the HTTR commissioned by the Ministry of Economy, Trade and Industry's Agency for Natural Resources and Energy.

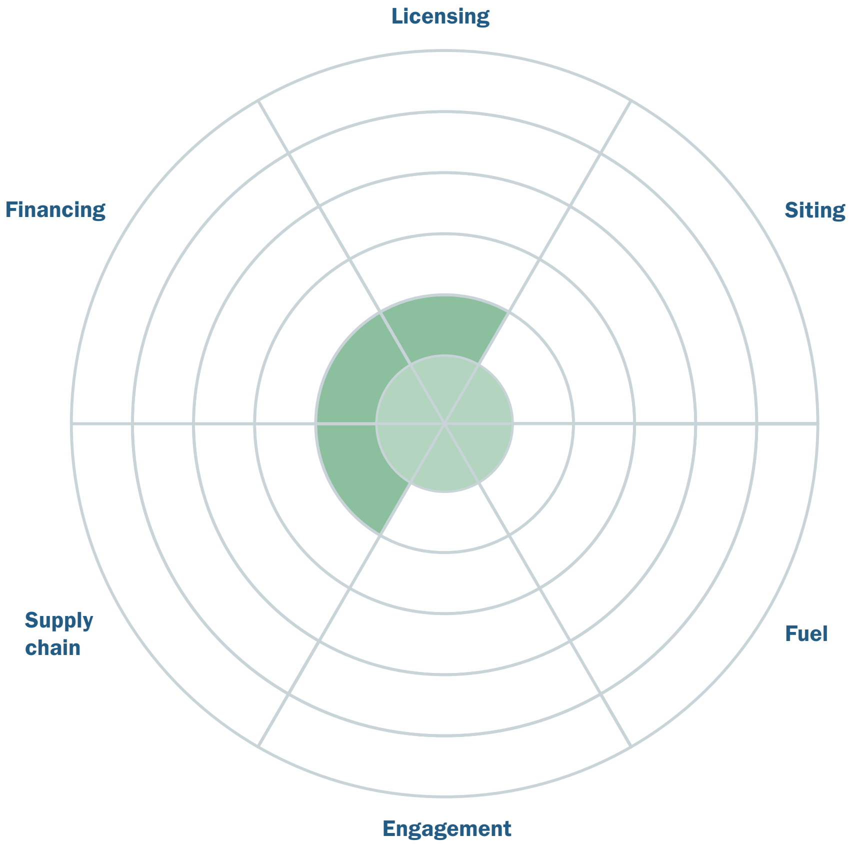
Engagement

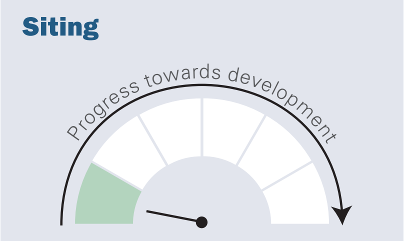
The JAEA has regularly hosted "Open Lab" events at its sites, including the Oarai site where the HTTR is located, during which the general public was invited to tour the laboratories and ask questions. With hundreds of Open Lab events, the JAEA has engaged with thousands of members of the public on its nuclear science and technology programme, including the HTTR. In addition, JAEA Oarai staff regularly deliver science lectures for the public, including discussions about the capabilities of the HTTR and the JAEA's research facilities. The JAEA also makes presentations and participates in discussions during meetings of the local government through the Ibaraki Prefecture Nuclear Safety Committee.

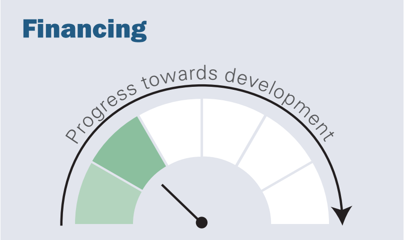
Fuel

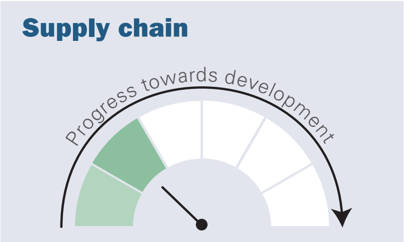
The first and second core fuels of the HTTR were manufactured by Nuclear Fuel Industries. The first core fuel was loaded in 1998 and the second core fuel is stored by the JAEA on site and is ready for the HTTR.

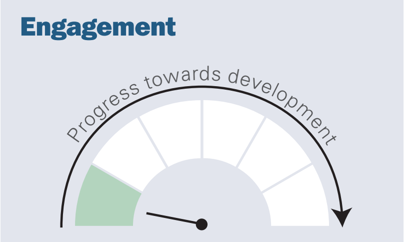
Jimmy – Jimmy SMR

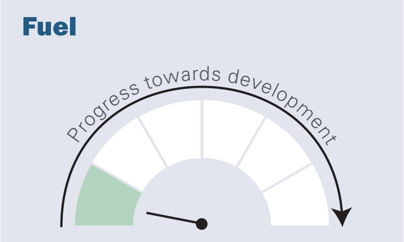












Reactor description: Gas-cooled microreactor for the production of industrial process heat.

Thermal power (MWth)	10
Outlet temperature (°C)	550
Spectrum (thermal/fast)	Thermal
Fuel type	Uranium Oxycarbide (UCO) TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of Jimmy SMR's progress to deployment

Licensing

In May 2022, the Autorité de sûreté nucléaire (the Nuclear Safety Authority, or ASN) and the Institut de radioprotection et de sûreté nucléaire (Institute for Radiation Protection and Nuclear Safety, or IRSN) started a preliminary pre-licensing analysis of Jimmy's safety options file (known as DOS). The IRSN, the primary entity providing technical analytical support to the ASN, completed and published its analysis in September 2022.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

Jimmy raised more than EUR 17 million (USD 17.9 million) in private sector financing during 2022 from investors that included Eren Group, Noria, Otium Capital and Polytechnique Ventures. Jimmy was one of the 127 awardees of the BPI France 2021-2022 competition for innovation under the i-Nov programme, which co-finances startups with up to EUR 5 million (USD 5.3 million). Jimmy was also one of the awardees for two government-sponsored startup incubator programmes: French Tech Green20 and French Tech 2030.

Supply chain

Jimmy is a member of the Nuclear Valley network, a group of more than 400 companies involved in the French nuclear supply chain.

Engagement

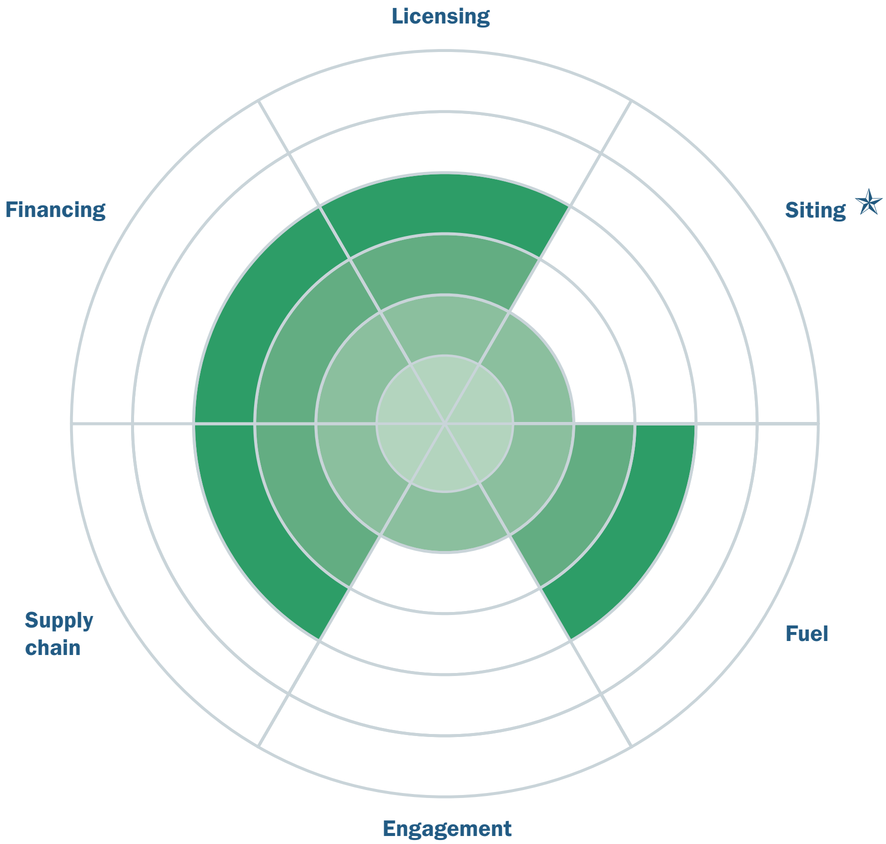
At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

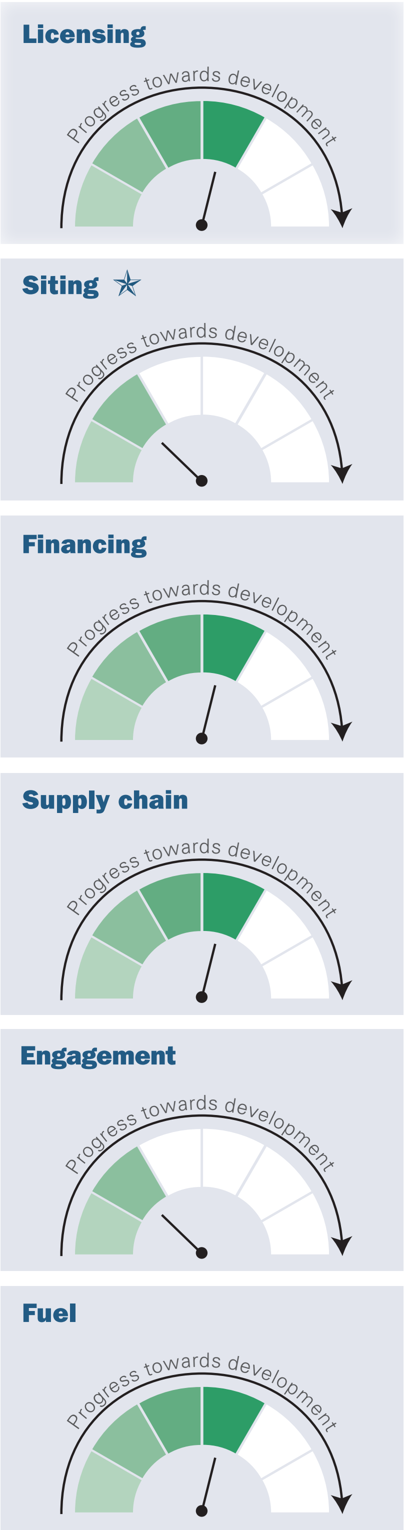
HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, EUR 0.950 equals USD 1.000.

KAERI (Korea Atomic Energy Research Institute) – SMART



☆ Active in multiple jurisdictions or countries.



Reactor description: Pressurised light water reactor.

Thermal power (MWth)	365
Outlet temperature (°C)	322
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of SMART's progress to deployment

Licensing

Korea Atomic Energy Research Institute (KAERI) received a Standard Design Approval for the System-integrated Modular Advanced ReacTor (SMART) SMR from the Korean Nuclear Safety and Security Commission (NSSC) in 2012.

Siting ✯

In 2015, KAERI signed a Memorandum of Understanding (MoU) with King Abdullah City for Atomic and Renewable Energy (K.A.CARE) in Saudi Arabia to assess the potential of siting multiple SMART SMRs at K.A.CARE. In 2023, KAERI signed a MoU with the Government of Alberta, Canada, to collaborate on the possible deployment of SMART SMR technology in the Canadian province. In September 2023, KAERI signed another MoU with the Atomic Energy of Canada Limited (AECL) to accelerate potential demonstration of the SMART reactor at the AECL-owned and Canadian National Laboratories-managed Chalk River site.

Financing

The Government of Korea, Korea Electric Power Corporation (KEPCO), and various others, including POSCO, Daewoo and STX Heavy Industries have contributed KRW 310 billion (USD 240 million) in financing for development of the SMART SMR plus an additional KRW 170 billion (USD 131.6 million) to support the Standard Design Approval process. In 2015, the South Korean Ministry of Science and ICT announced that KAERI was partnering with K.A.CARE on pre-project engineering to construct SMART units in Saudi Arabia, supported by investments by the two partners totalling USD 130 million (USD 100 million from Saudi Arabia and USD 30 million from South Korea).

Supply chain

KAERI and K.A.CARE have established the joint venture "SMART EPC", led by Korea Hydro & Nuclear Power (KHNP). KHNP also signed an MoU with KEPCO Engineering & Construction (E&C) to jointly develop SMART units in Saudi Arabia. For the SMART reactor: KEPCO E&C and POSCO conducted the balance of plant design; KEPCO Nuclear Fuel designed the fuel; Hyosung Goodsprings developed the reactor coolant pumps and conducted reactor coolant pump performance testing; BHI designed the fuel handling system; Soosan ENS verified the reactor protection system and engineered the safety feature component control system; and Doosan Enerbility is providing design and engineering services for major components. KAERI also has an MoU for R&D with AECL.

Engagement

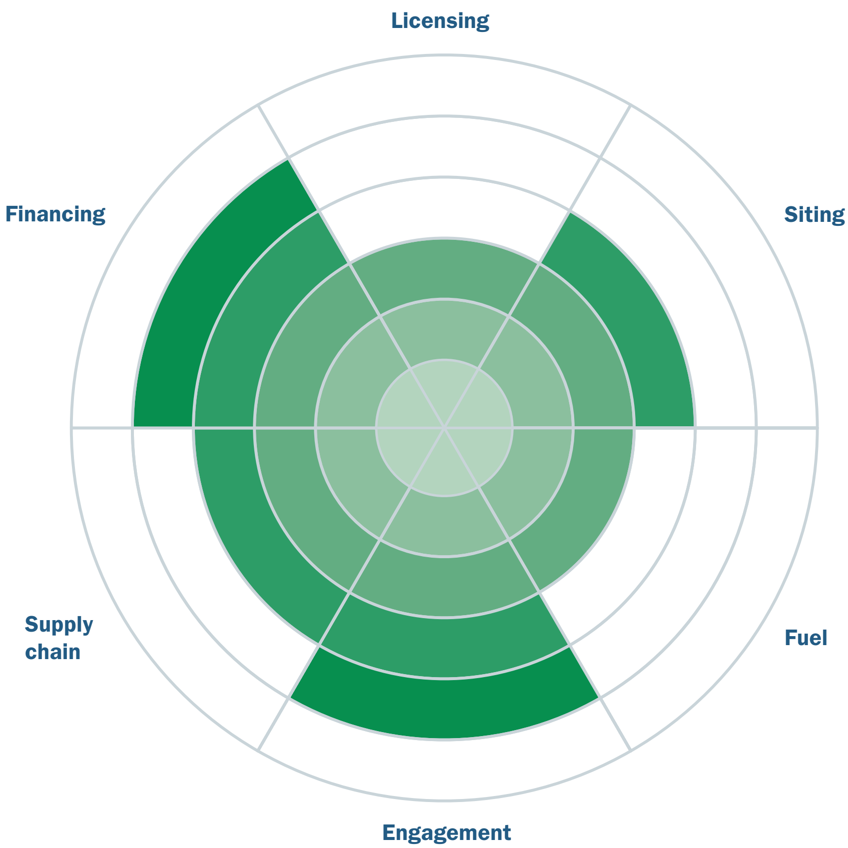
The Korea Atomic Energy Cultural Foundation and KAERI signed an MoU in 2009 to collaborate on enhancing public understanding and awareness of nuclear technology, including the SMART SMR. In April 2023, KAERI and the Government of Alberta, Canada, signed an MoU to develop SMRs, including SMART, for emissions reduction in Alberta.

Fuel

SMART utilises the same fuel as the current industry standard for similar design water-cooled reactor technologies. Given this, no barriers are expected in the fuel supply chain for this SMR.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, KRW 1 291.447 equals USD 1.000.

Kairos Power – Hermes



Licensing

Siting

Financing

Supply chain

Engagement Δ

Fuel

Δ Indicates change since 2023.

Reactor description: High temperature fluoride salt-cooled demonstration reactor using TRISO pebble fuel.

Thermal power (MWth)	35
Outlet temperature (°C)	650
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, non-power demonstration reactor planned on the East Tennessee Technology Park campus in Oak Ridge, Tennessee (United States), supporting the development of Kairos Power's 320 MWth commercial KP-FHR technology. Kairos Power has submitted a Construction Permit Application (CPA) to the US Nuclear Regulatory Commission (NRC) under a regulatory pathway distinct from commercial reactors' licensing process. In August 2023, the NRC released a final environmental impact statement and recommended issuing the construction permit for Hermes' demonstration reactor. The NRC held Kairos Power's hearing for Hermes's CPA in October 2023. Kairos Power is aiming to receive the construction permit for its Hermes SMR before the end of 2023.

Siting

Kairos Power is working 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 (DOE). The construction permit application to build the one-of-a-kind Hermes reactor on this site was submitted to the NRC in November 2021.

Financing

In March 2019, the DOE selected Kairos Power to receive USD 1 million to accelerate the licensing of the KP-FHR through the development of advanced modelling and simulation capabilities. In December 2020, the DOE selected Kairos Power to receive slightly more than USD 300 million over seven years as part of the Advanced Reactor Demonstration Program (ARDP) initiative. This funding will support the design, licensing and construction of Hermes. Kairos Power will contribute, matching funds over the DOE's amount under the ARDP initiative to deploy Hermes.

Supply chain

In 2022, Kairos Power and Materion commissioned a Molten Salt Purification Plant in Alabama, United States. Kairos Power has received the American Society of Mechanical Engineers certification to manufacture U-stamped pressure vessels at its facility in Albuquerque, New Mexico. Kairos Power has received six vouchers from the Gateway for Accelerated Innovation in Nuclear initiative by the DOE and is working with Oak Ridge and Argonne National Laboratories to develop corrosion-resistant alloys. Kairos Power has an advisory consortium of four North American nuclear operators for advice on technology, licensing, manufacturing, construction and commercialisation. Kairos Power also has a collaborative agreement with Tennessee Valley Authority for engineering, operations and licensing support.

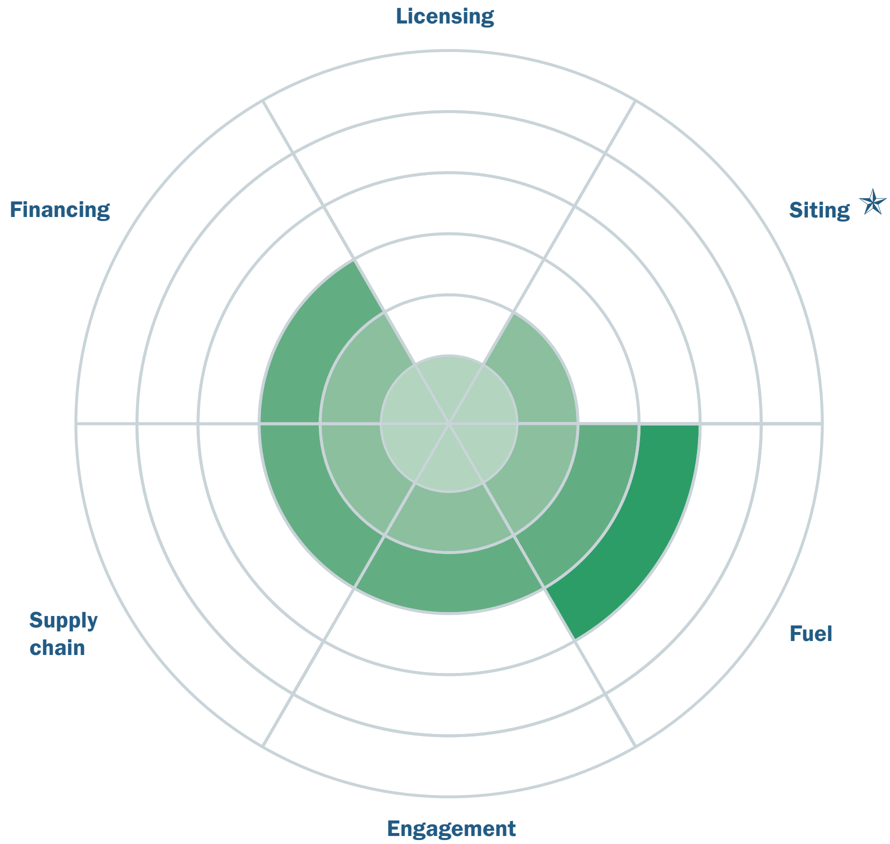
Engagement

Kairos Power has launched a virtual meeting space and partnered with the American Museum of Science and Energy to support engagement with local communities. Kairos Power's activities to advance the deployment of nuclear technologies have received endorsements in New Mexico from Senator Martin Heinrich and 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 and local officials. Kairos Power is also partnering with local organisations – including the East Tennessee Economic Council (ETEC), the Energy, Technology, and Environmental Business Association (ETEBA), and the Oak Ridge Chamber of Commerce on community engagement activities.

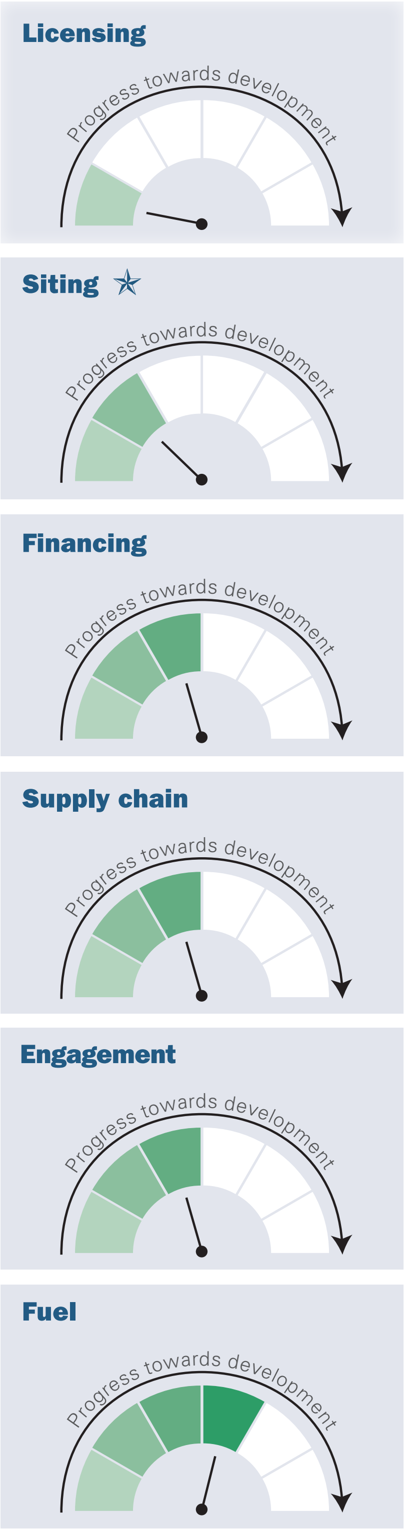
Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. In 2023, Kairos Power and Urenco US signed a Memorandum of Understanding to explore future collaboration areas towards securing HALEU supply for Kairos KP-FHR commercial reactors. 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.

Last Energy – PWR-20



★ Active in multiple jurisdictions or countries.



Reactor description: Micro pressurised light water reactor.	
Thermal power (MWth)	60
Outlet temperature (°C)	300
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of PWR-20's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting ☆

In 2022, the Prime Minister of Romania announced the intention to demonstrate and deploy the Last Energy SMR in collaboration with the state-owned Regia Autonomă Tehnologii pentru Energia Nucleară (the Technologies for Nuclear Energy State Owned Company, or RATEN) at their nuclear site in Mioveni. In 2022 and 2023, Last Energy signed agreements with site owners in Poland, including: virtual Power Purchase Agreements (PPAs) with the Katowice and the Legnica Special Economic Zones; and Letters of Intent for the deployment of PWR-20 in Poland with the Polish energy group Enea. In 2023, Last Energy also signed three PPAs in the United Kingdom. These include one virtual PPA and two physical PPAs.

Financing

Last Energy has received USD 24 million in venture capital funding in two rounds: USD 3 million in a first round in 2020 led by First Round Capital; and USD 21 million in a second round led by Gigafund. Last Energy has also signed four PPAs with industrial partners in the United Kingdom and Poland, including a data centre and hydrogen production capacity. The PPAs set out that an estimated USD 18.9 billion in revenue could be generated from 34 PWR-20 SMRs over 24 years.

Supply chain

In 2022, Last Energy contracted Hydrock in the United Kingdom for a strategic review of key components and started working with Atkins and Wood on the development of the PWR-20. Last Energy also joined Britain's Energy Coast Business Cluster, a membership organisation for the nuclear decommissioning supply chain, to facilitate sourcing local content for projects in the United Kingdom and Europe. In 2023, Last Energy built a mechanical demonstration of the nuclear island in Brookshire, Texas United States, and joined the Texas Advanced Nuclear Reactor Working Group. In 2023, Last Energy signed a letter of intent with the Polish manufacturer Energoinstal S.A. for the construction of a prototype module, and presented it at the Polish Investment and Trade Agency Business Forum 2023 in Warsaw.

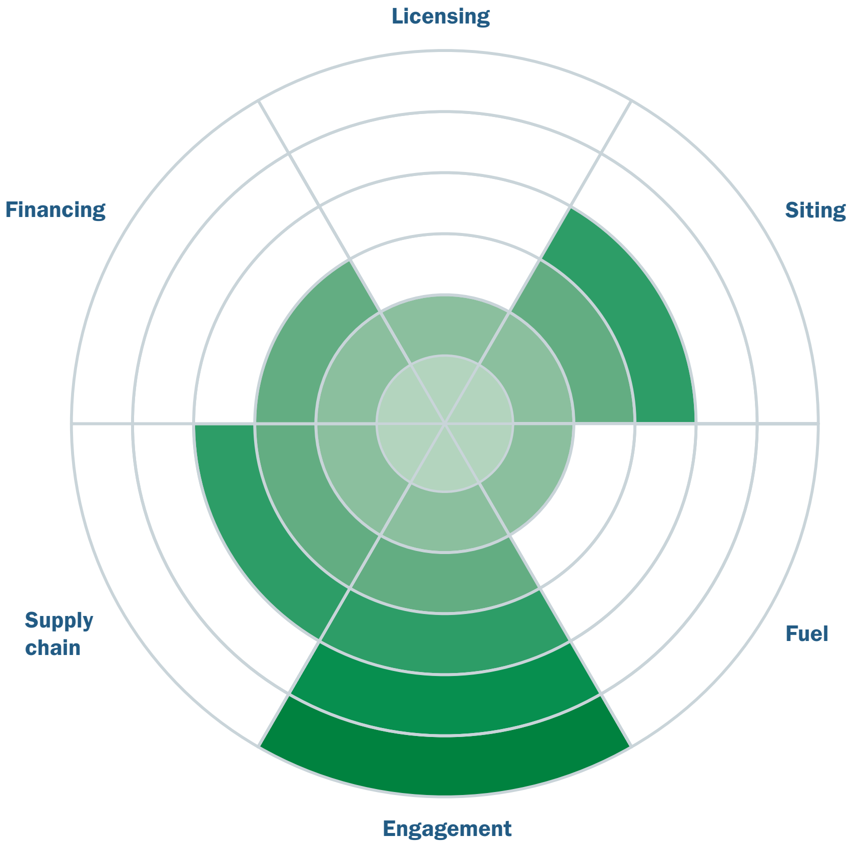
Engagement

Last Energy has received endorsements from local and federal governments in Poland and Romania. Prime Minister Nicolae Ciuca of Romania announced his government's intention to collaborate on the demonstration and deployment of the Last Energy PWR-20. Alongside the Prime Minister, Enea's CEO, Pawel Majewski, highlighted the potential positive impact of deploying the PWR-20 for the Polish economy. In 2022, Last Energy testified in front of the UK Parliamentary Science and Technology Committee on modular manufacturing techniques. In the Netherlands, Last Energy is a member of the Limburg Alliance, a regional alliance created by local authorities to assess the benefits of SMRs.

Fuel

The PWR-20 SMR plans to use fuel that is the current industry standard for water-cooled reactor technologies of similar design. There are no barriers expected in the fuel supply chain for this SMR.

Moltex Energy
– Stable Salt Reactor-Wasteburner (SSR-W)



Δ Indicates change since 2023.

Reactor description: Molten salt reactor that plans to use recycled spent nuclear fuel.	
Thermal power (MWth)	750
Outlet temperature (°C)	590
Spectrum (thermal/fast)	Fast
Fuel type	Molten salt
Fuel (LEU/HALEU/HEU)	Recycled spent fuel

Licensing

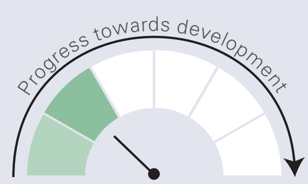
Siting

Financing

Supply chain

Engagement Δ

Fuel



Assessment of SSR-W's progress to deployment

Licensing

The Stable Salt Reactor – Wasteburner (SSR-W) design from Moltex Energy (Moltex) 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 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

The SSR-W has been selected by New Brunswick Power (NB Power) for deployment in the Canadian province of New Brunswick. Moltex has a Memorandum of Understanding (MoU) with NB Power to evaluate the construction of its first SSR-W at the Point Lepreau Nuclear Generating Station site. Moltex expects to have both its spent fuel recycling facility and reactor in operation by early- to mid-2030s. The company is also supporting NB Power with site evaluation and preparation activities.

Financing

Moltex 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, the Canadian government, the Ontario Power Generation's Centre for Canadian Nuclear Sustainability and the UK government's Advanced Reactor Initiative. Multimillion investments have been secured from engineering company IDOM and a crowdfunding process via the Shadow Foundr platform. In March 2023, SNC-Lavalin (now AtkinsRéalis) made a minority equity investment. In September 2023, the North Shore Mi'kmaq Tribal Council and its 7 member communities made an equity investment of CAD 2 million (USD 1.5 million).

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, CAD 1.302 equals USD 1.000.

Supply chain

In the Canadian 2022 Provincial Strategic Plan for the Deployment of SMRs, the Government of New Brunswick set out its objective to advance supply chain readiness for SMRs, including Moltex, in collaboration with Canadian Manufacturers and Exporters and Opportunities New Brunswick. In April 2022, Moltex announced a partnership with AtkinsRéalis 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. Moltex has also been awarded a voucher under the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative by the US DOE to study conjugate heat transfer in the SSR-W in partnership with Argonne National Laboratory.

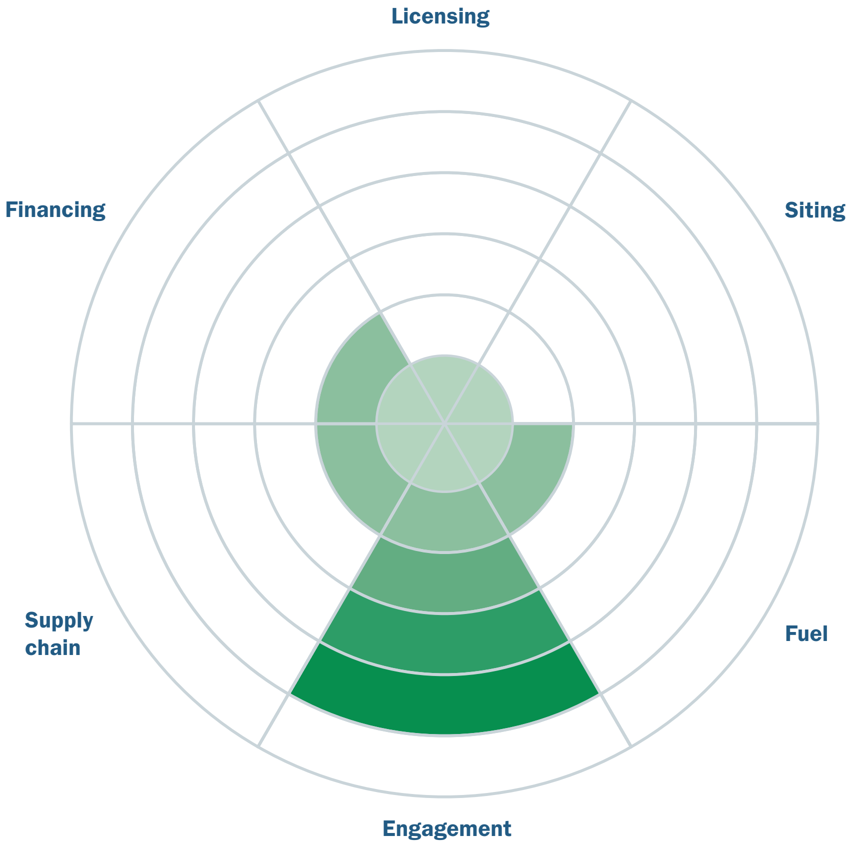
Engagement

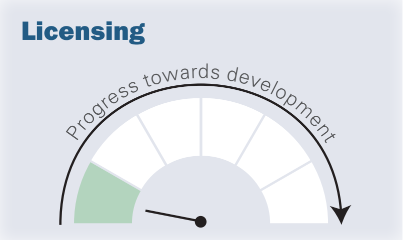
Moltex has received endorsements from provincial and federal governments in Canada. Moltex has sponsored engagement activities with various Indigenous and civil society organisations in the Atlantic Canada region. Moltex has a partnership with the North Shore Mi'kmaq Tribal Council, and entered into an equity agreement in September 2023 with the North Shore Mi'kmaq Tribal Council and its member communities for benefits sharing. Moltex has advanced collaborations with the First Nations Power Authority to deepen Indigenous engagement on nuclear energy broadly and SMR technology specifically. The Centre for Nuclear Energy Research at the University of New Brunswick (UNB) is also engaged with Moltex on SMR research and talent development.

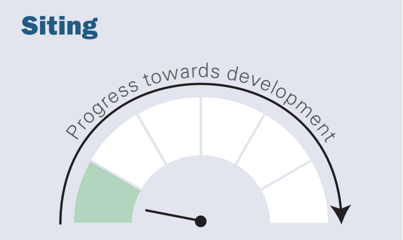
Fuel

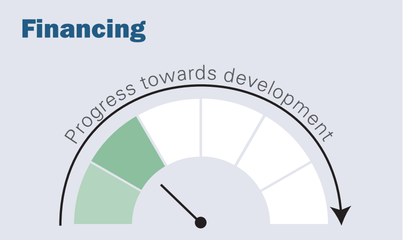
UNB and Canadian National Laboratories (CNL) are supporting SSR-W fuel development through CNL's Canadian Nuclear Research Initiative. Ontario Power Generation has invested CAD 1 million (USD 768 000) to support the demonstration of the technical viability of using spent Canada Deuterium Uranium (CANDU) reactor fuel in the Moltex Energy SSR-W through the company's Waste to Stable Salt (WATSS) process. Experiments to demonstrate the WATSS process have been conducted using simulated fuel, and Moltex is partnering with CNL on additional experiments using spent fuel from CANDU reactors. Moltex plans to produce the fuel for the SSR-W through the WATSS process using spent fuel from the Point Lepreau Nuclear Generating Station in New Brunswick, Canada.

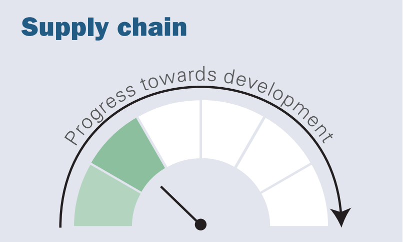
MoltexFLEX – FLEX

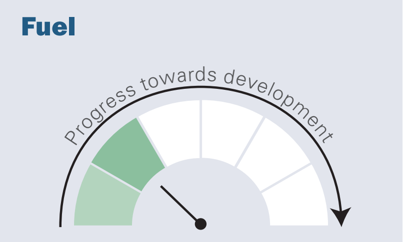












Reactor description: High-temperature graphite moderated molten salt reactor using separate molten salts as the fuel and coolant.

Thermal power (MWth)	60
Outlet temperature (°C)	700
Spectrum (thermal/fast)	Thermal
Fuel type	Molten salt
Fuel (LEU/HALEU/HEU)	LEU

Assessment of FLEX's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

In February 2023, MoltexFLEX received a grant from the Henry Royce Institute to work with the University of Manchester's Nuclear Graphite Research Group to study the interactions between molten coolant salt and graphite.

Supply chain

In 2020, MoltexFLEX selected Jacobs, an American engineering, procurement and construction company, to develop experimental capabilities at Jacob's Birchwood Park facility in Warrington, Cheshire (United Kingdom), to test thermal transfer behaviours of fuel and coolant molten salts. In 2023, the test rig for the FLEX in Warrington became operational with instruments supplied by manufacturer Anton Paar. The Hydrock engineering consultancy is developing the safety case and business strategy for the FLEX reactor. MoltexFLEX is also collaborating with the University of Manchester's Nuclear Graphite Research Group to advance research on the FLEX reactor's graphite moderator.

Engagement

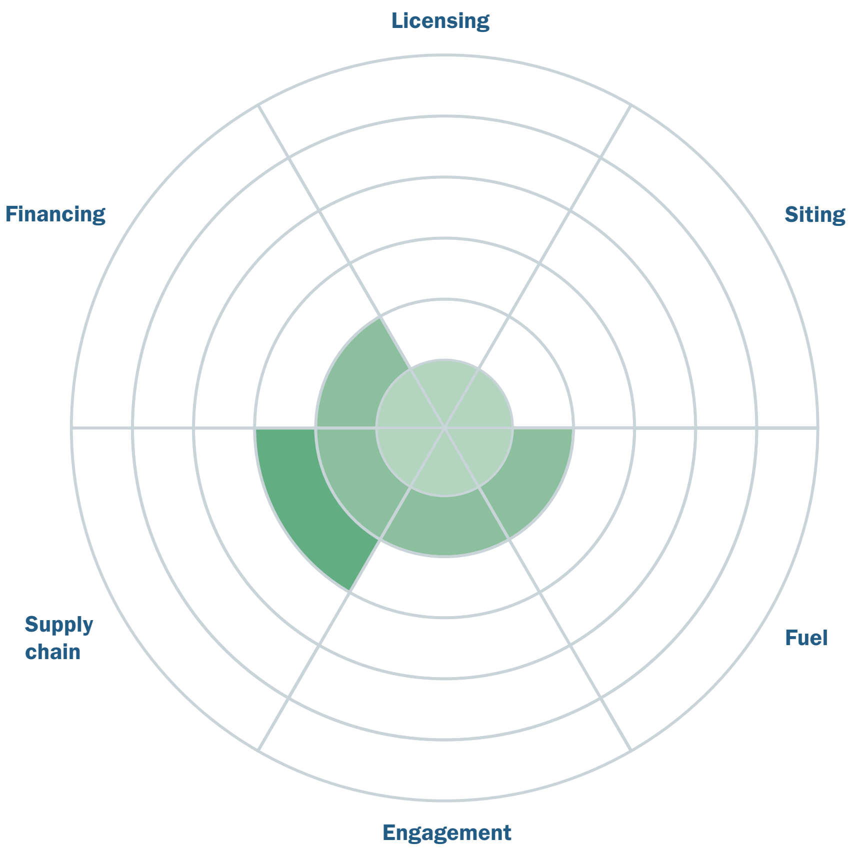
Since 2021, MoltexFLEX has hosted tours of its facility in Birchwood for Grant Shapps, the former UK Secretary of State for Energy Security and Net Zero, and UK Members of Parliament. In 2023, MoltexFLEX engaged the UK Parliament on nuclear energy by providing oral and written evidence to the Energy Security and Net Zero Committee, and through the All-Party Parliamentary Group on Small Modular Reactors. MoltexFLEX won the UK government's Green Builder of Tomorrow competition in 2023, and was selected to join a programme of events in Dubai and Abu Dhabi to promote the FLEX technology abroad. MoltexFLEX has also advanced public outreach through a BBC Radio 4 Today programme and BBC podcast: *New Nuclear*, and was recognised by the BBC as one of 39 ways to save the planet in October 2022.

Fuel

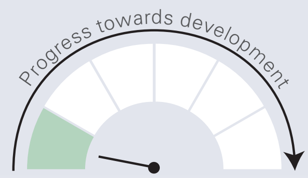
The FLEX reactor proposes to use a mixture of low-enriched uranium fluoride and sodium fluoride salts as a fuel, and a separate fluoride salt as a coolant. In 2023, MoltexFLEX was awarded GBP 1.3 million (USD 1.6 million) as a part of the UK government's Nuclear Fuel Fund to develop capabilities to produce molten salt fuel for the FLEX SMR and secured equipment to support research on molten salt fuel properties.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, GBP 0.811 equals USD 1.000.

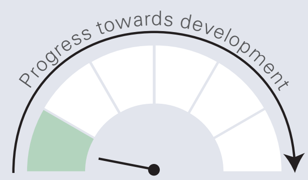
NAAREA – XAMR



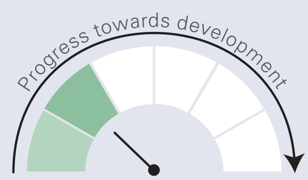
Licensing



Siting

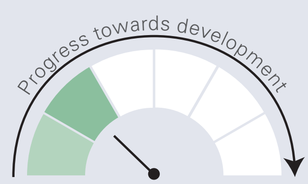


Financing

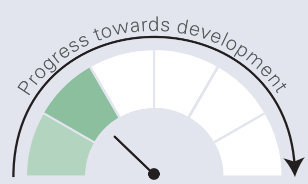


Supply chain

Engagement



Fuel



Reactor description: Transportable fast spectrum chloride molten salt reactor.

Thermal power (MWth)	80
Outlet temperature (°C)	625
Spectrum (thermal/fast)	Fast
Fuel type	Molten salt
Fuel (LEU/HALEU/HEU)	Undisclosed

Assessment of XAMR's progress to deployment

Licensing

NAAREA has met with the Autorité de sûreté nucléaire (French Nuclear Safety Authority, or ASN) and the Institut de radioprotection et de sûreté nucléaire (Institute for Radiation Protection and Nuclear Safety, or IRSN) to discuss its molten salt reactor project. At the time of assessment, there was no additional information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

In June 2023, NAAREA was awarded EUR 10 million (USD 10.53 million) as part of the France 2030 initiative to advance research and development activities for its XAMR design. NAAREA was also one of the awardees for the first edition of the French Tech 2030 programme, a government-sponsored startup incubator.

Supply chain

In 2021, NAAREA signed a co-operation agreement with Assystem, a European nuclear engineering company, to develop a digital twin of NAAREA's XAMR design and support the development of a prototype at scale. In August 2023, NAAREA operated the first silicon carbide molten salt loop in the world, which it developed in collaboration with Mersen Group, an international materials manufacturer, and ICAR-CM2T, a French materials engineering laboratory.

Engagement

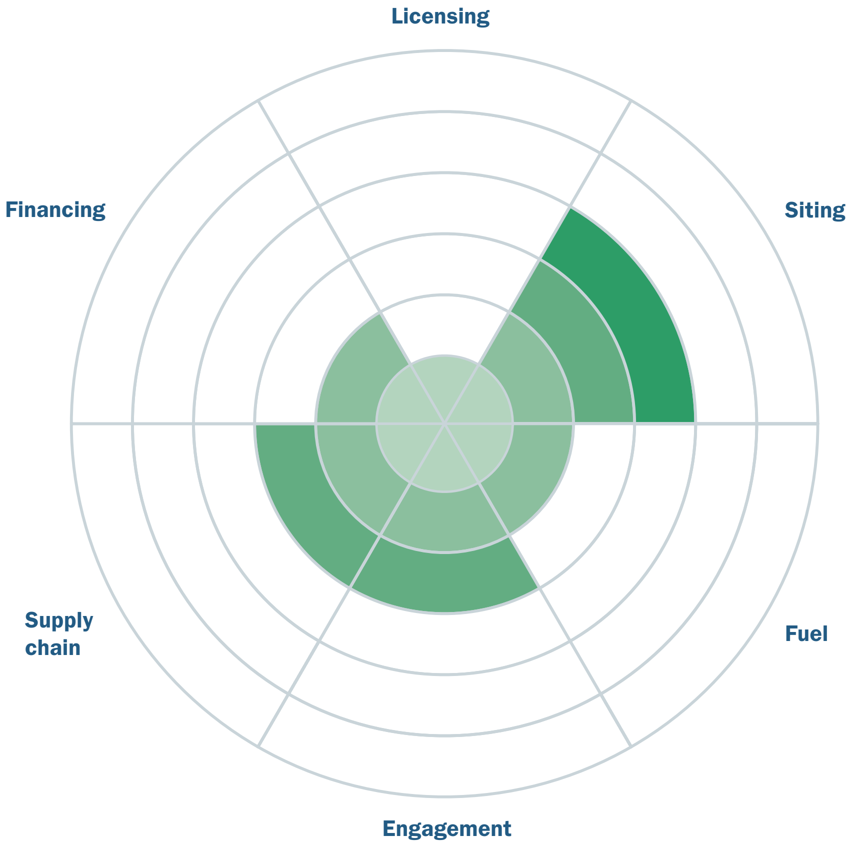
Throughout 2023, NAAREA invited several French Members of Parliament, including Maud Bregeon, Paul Midy, Antoine Armand and Raphael Schellenberger, to visit their office and present NAAREA's XAMR. Jean-Luc Alexandre, NAAREA's Chief Executive Officer, also gave interviews on SMRs and the XAMR to mainstream media outlets, including L'Opinion, Sciences et Avenir and Europe 1.

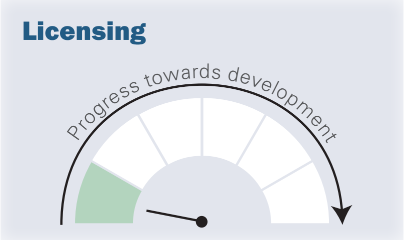
Fuel

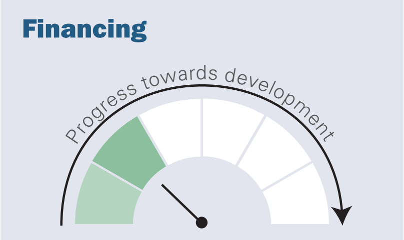
In 2023, NAAREA and ROBATEL, a nuclear equipment manufacturer, announced a collaboration to conduct feasibility studies for XAMR's fuel management.

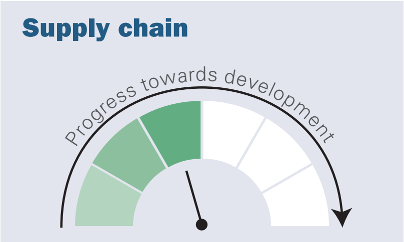
Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, EUR 0.950 equals USD 1.000.

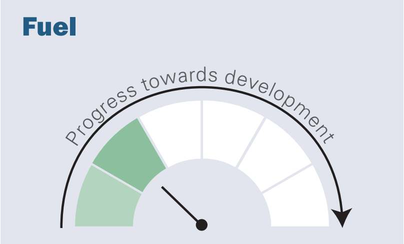
NCBJ (National Centre for Nuclear Research) – HTGR-POLA











Reactor description: Gas-cooled high temperature demonstration reactor.

Thermal power (MWth)	30
Outlet temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of HTGR-POLA's progress to deployment

Licensing

In 2019, the Ministry of Energy and the National Centre for Research and Development (NCBiR) launched the GoHTR project to support HTGR development in Poland, which included the pre-conceptual design for the HTGR-POLA reactor and worked on a methodology for HTGR safety assessments. In 2021, the National Centre for Nuclear Research (NCBJ) signed a contract with the Ministry of Education and Science (MEiN) for the conceptual and basic designs and a Preliminary Safety Report for the HTGR-POLA. The conceptual design was completed in 2022, and the main elements of the basic design and Preliminary Safety Report are planned to be completed in 2024. At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

NCBJ plans to build an HTGR-POLA reactor at the site it owns in Świerk, a district of Otwock, Poland, where NCBJ's research pool type reactor MARIA is currently operating.

Financing

In 2019, the NCBiR committed PLN 18 million (USD 4 million) in public funding to the GoHTR project to support the HTGR-POLA pre-conceptual design development. In 2021, the MEiN committed PLN 60 million (USD 13.4 million) over 3.5 years for the HTGR-POLA conceptual and basic design development.

Supply chain

In 2019 and 2022, NCBJ signed an Implementation Arrangement with Japan Atomic Energy Agency (JAEA) for co-operation on research and development (R&D) in the field of HTGR technology, including the preparation of a basic design of HTGR-POLA. Under the arrangement, two contracts were signed for JAEA to provide technical information to NCBJ on HTGR technologies from JAEA's experience with the High Temperature Test Reactor (HTTR) in Oarai, Japan. In 2023, NCBJ announced that Energoprojekt-Katowice, a Polish engineering, procurement and construction company, was selected as the designer of the conventional island of the HTGR-POLA.

Engagement

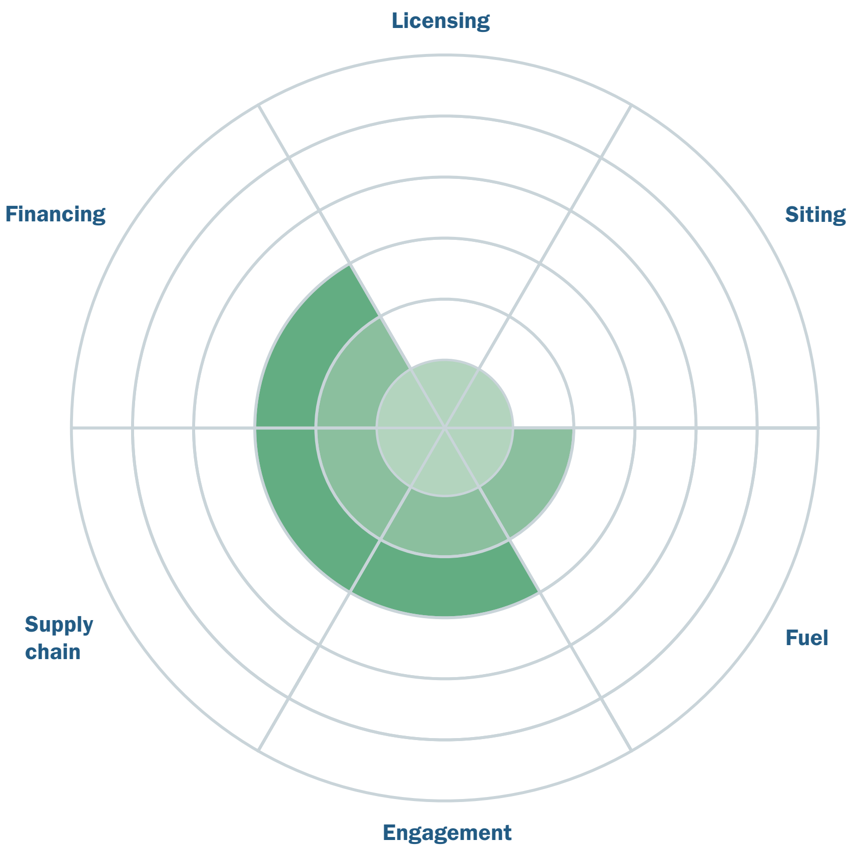
In 2022, NCBJ and the Institute of Economic Diplomacy, a private Polish think-tank, held a webinar to raise awareness on nuclear energy, including SMRs and HTGRs, in Poland. NCBJ also engages students on HTGR through lectures in schools and the general public with YouTube videos and a board game.

Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. HTGR-POLA plans to use the same fuel that has already been qualified and demonstrated by JAEA in the HTTR reactor it operates in Oarai, Japan. The HTGR-POLA project will benefit from JAEA's knowledge and expertise under NCBJ's research collaboration contract with JAEA.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, PLN 4.458 equals USD 1.000.

newcleo – LFR-AS-200

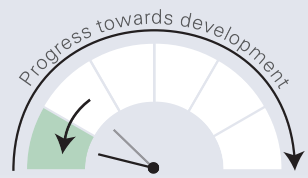


Δ Indicates change since 2023.

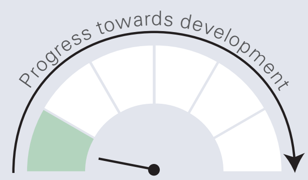
Reactor description: Fast spectrum, lead-cooled reactor using mixed plutonium-uranium oxide (MOX) fuel.

Thermal power (MWth)	480
Outlet temperature (°C)	530
Spectrum (thermal/fast)	Fast
Fuel type	MOX
Fuel (LEU/HALEU/HEU)	Uranium oxide and plutonium

Licensing Δ



Siting

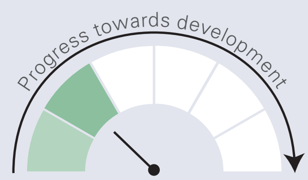


Financing

Supply chain Δ

Engagement Δ

Fuel



Assessment of LFR-AS-200's progress to deployment

Licensing

*New*cleo proposes a three-step approach for the deployment of its LFR-AS-200 SMR, beginning with constructions of test facilities, including an electrical prototype in Italy, followed by a 30 MWe LFR demonstrator, called the LFR-AS-30, in France, before deploying the larger commercial version, called the LFR-AS-200. In January 2023, *new*cleo submitted an application to the UK Office of Nuclear Regulation to enter the Generic Design Assessment (GDA) process. As of November 2023, the LFR-AS-200 had not yet started the GDA process. *New*cleo has also met with the Autorité de sûreté nucléaire (French Nuclear Safety Authority, or ASN) and the Institut de radioprotection et de sûreté nucléaire (Institute for Radiation Protection and Nuclear Safety, or IRSN) to discuss the design and fuel cycle.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

By mid-2022 *new*cleo had raised EUR 300 million (USD 315.8 million), with the first EUR 100 million (USD 105.3 million) secured as initial capital in 2021 alongside its acquisition of Hydromine Nuclear Energy. In March 2023, *new*cleo launched a financing round with the objective to raise up to EUR 1 billion (USD 1.05 billion) in equity. In June 2023, the French government selected *new*cleo's LFR-AS-30 as one of two SMRs to be awarded funding for advancing research and development activities as part of the "Réacteurs nucléaires innovants" programme. As of October 2023, the company had hired more than 400 employees, mainly nuclear physicists and engineers.

Supply chain

In 2023, *new*cleo completed the acquisition of Servizi Ricerche e Sviluppo and Fucina Italia, two Italian engineering companies with lead fast reactor experience, and announced its acquisition of a nuclear pumps manufacturer, Rütschi Group. In 2023, *new*cleo signed a work for equity investment agreement with the Tosto Group to advance the industrialisation of *new*cleo's reactors. *New*cleo is also engaged with the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) to develop an electrical prototype to study its thermo-dynamic and mechanical performance. *New*cleo collaborates with the Italian energy group Enel, which is sharing its expertise on advanced nuclear technologies in exchange for an option to invest in *new*cleo's first nuclear power plant.

Engagement

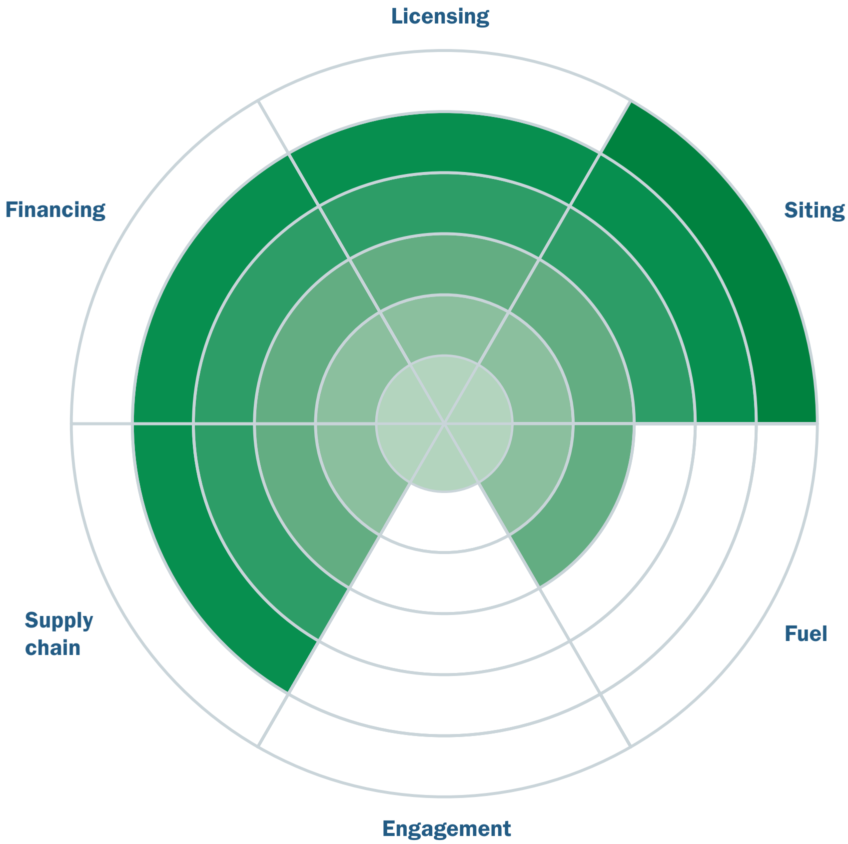
In October 2023, Elisabeth Rizzotti, co-founder of *new*cleo, participated in a public meeting in Castiglione dei Pepoli, Italy, to discuss *new*cleo's investment plan in the Bologna region and its partnership with ENEA. *New*cleo is engaging with students including through participation in a seminar at the Ecole des Mines d'Alès in France, participation in a university fair at the University of Glasgow, United Kingdom, and a presentation at the University of Turin, Italy. *New*cleo is also engaging with the general public through podcasts and media interviews.

Fuel

*New*cleo will use MOX fuel. MOX fuel is a technically proven fuel type; however, there are presently limited suppliers in particular for fast reactors. *New*cleo plans to design its own MOX production facility. In June 2022, *new*cleo announced it had contracted Orano for feasibility studies on the establishment of a MOX production plant. In September 2023, *new*cleo signed a Memorandum of Understanding with the United Kingdom National Nuclear Laboratory to advance LFR research, including MOX fuel development and reprocessing techniques.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, EUR 0.950 equals USD 1.000.

NIKIET (N.A. Dollezhal Research and Design Institute of Power Engineering) – BREST-OD-300



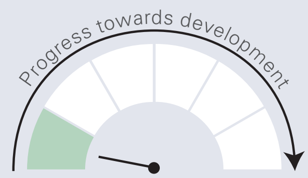
Licensing

Siting

Financing

Supply chain

Engagement



Fuel

Reactor description: Lead-cooled fast spectrum demonstration reactor using mixed uranium-plutonium nitride fuel (MNUP fuel).

Thermal power (MWth)	700
Outlet temperature (°C)	535
Spectrum (thermal/fast)	Fast
Fuel type	MNUP fuel
Fuel (LEU/HALEU/HEU)	Natural or depleted uranium and plutonium

Assessment of BREST-OD-300's progress to deployment

Licensing

The Brest-OD-300 lead-cooled fast reactor is a demonstration unit of one of the technologies that ROSATOM has selected for its "Waste-free Atom" strategy, which seeks to deploy a mix of thermal and fast spectrum reactors to close the nuclear fuel cycle. The Brest-OD-300 demonstration will support future efforts to develop the 1200 MWe BR-1200 technology, a larger design with the same fuel cycle. A licence to construct the BREST-OD-300 was issued by the Russian nuclear regulator Rostechnadzor in February 2021. In expectation of the reactor's startup, the Russian nuclear regulator and its Technical Support Organisation (TSO) are working on developing specific operational regulations for this type of lead-cooled fast reactor.

Siting

Construction of the BREST-OD-300 started in 2021 at the Siberian Chemical Combine site in Seversk, Russia. The BREST-OD-300 demonstration reactor is part of a larger project called the Proryv Project, which includes a fuel fabrication plant, the BREST Reactor, and a fuel reprocessing plant. These will form the pilot-demonstration energy complex (PDEC), focused on demonstrating new technologies for the production and recycling of nuclear fuel and owned by the Siberian Chemical Combine. The full PDEC is expected to be commissioned in 2030. The goal of Proryv is to close the fuel cycle by collocating thermal and fast spectrum reactors to expand the nuclear sector's raw material base while reducing the volumes of waste generated by the industry.

Financing

In 2010, the government of Russia announced RUB 110 billion (USD 1.6 billion) over 10 years for advanced nuclear technology development, which included RUB 60 billion (USD 876 million) for fast spectrum reactors such as BREST-OD-300. In 2021, the Russian government approved a project cost of RUB 506 billion (USD 7.4 billion) for new nuclear technologies by 2030, including the construction of BREST-OD-300 in Seversk. In 2022, the Russian government announced that it would invest RUB 100 billion (USD 1.5 billion) in new nuclear technologies, including BREST-OD-300. The government has approved RUB 64.2 billion (USD 937 million) for the Proryv project, which includes BREST-OD-300.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, RUB 68.485 equals USD 1.000.

Supply chain

Construction of the BREST-OD-300 reactor began in June 2021. The Siberian Chemical Combine (SCC), a subsidiary of ROSATOM's fuel company TVEL, is responsible for building the pilot demonstration power complex. The SCC contracted the Concern Titan-2 engineering company for RUB 26.3 billion (USD 384 million) to undertake construction and installation works. TsKBM (part of ROSATOM's mechanical engineering division Atomenergomash) started assembling a prototype of the main circulation pump unit. ZiO-Podolsk (part of ROSATOM's machine-building unit) will provide and install the steam generators for the reactor facility. Prototyping and qualification of the main circulation pumps by TsKBM and steam generators by ZiO-Podolsk is ongoing.

Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

The BREST-OD-300 proposes to use novel, specially developed mixed uranium-plutonium nitride fuel (MNUP). In 2021, the SCC was making test batches of MNUP. To support fuel qualification, samples are currently being irradiated in the sodium-cooled fast reactor BN600 at the Beloyarsk nuclear power plant in Russia. A MNUP fabrication and refabrication module complements BREST-OD-300 as part of the Proryv Project. Commissioning tests with inert samples are ongoing and the facility is expected to be operational in 2024. In 2024 construction of an irradiated fuel reprocessing module is planned to start on the same site. SCC also signed a contract with CKBM (part of the machine-building unit of ROSATOM) for the manufacturing and supply of equipment for the refuelling complex.

NuScale Power – VOYGR

★ Active in multiple jurisdictions or countries.

Reactor description: Integral multi-module pressurised water reactor.	
Thermal power (MWth)	250
Outlet temperature (°C)	321
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Licensing ★

Siting ★

Financing

Supply chain

Engagement

Fuel

Assessment of VOYGR's progress to deployment

Licensing ✯

VOYGR power plants can be configured with 4, 6 or 12 NuScale Power Modules (NPM) of 77 MWe each, providing 308 MWe (VOYGR-4), 462 MWe (VOYGR-6), or 924 MWe (VOYGR-12), respectively. In 2020, the US Nuclear Regulatory Commission (NRC) issued a Standard Design Approval (SDA) for the 50 MWe NuScale Power Module (NPM) in a VOYGR-12 configuration and issued its final rule in January 2023. In 2023, the NRC docketed for review the SDA application from NuScale Power (NuScale) for the 77 MWe NPM in a VOYGR-6 configuration, with a mutually agreed 24-month review period. The NRC review of the 77 MWe NPM is expected to be informed by earlier work on the 50 MWe NPM. NuScale is also conducting pre-licensing activities in additional jurisdictions, including Ukraine, Poland, Romania, Canada and Indonesia.

Siting ✯

In 2023: Standard Power announced plans for VOYGR SMRs at two data centres in the United States; the Utah Associated Municipal Power Systems and NuScale announced an agreement to terminate the Carbon Free Power Project (CFPP) at Idaho National Laboratory. NuScale continues to progress in Romania: RoPower, a joint venture of Nuclearelectrica and Nova Power & Gas, has a contract with NuScale for engineering and site evaluation for deployment of VOYGR-6 at the Doicesti site; in 2023, the National Commission for Nuclear Activities Control approved the Licensing Basis Document for VOYGR's deployment in Doicesti. NuScale is also shortlisted by the UK's Great British Nuclear and has a Memorandum of Understanding with nuclear operator ČEZ for possible deployment in Czechia.

Financing

In 2013, the US Department of Energy (DOE) announced up to USD 226 million in matching funds for NuScale to support design certification. In 2020, the DOE approved a cost-share award of USD 1.355 billion over 10 years for the CFPP. NuScale became a publicly traded company in May 2022. In 2023, the United States, Japan, Korea, and the United Arab Emirates announced up to USD 275 million of new financing and the US Export-Import Bank and Development Finance Corporation issued Letters of Interest for up to USD 4 billion to support deployment in Romania. In 2023, the Export-Import Bank of Korea signed an MoU with Doosan Enerbility and NuScale to support NuScale deployment.

Supply chain

NuScale has developed a mature supply chain through agreements and contracts with Framatome, Ultra Electronics, Sarens, Samsung, Doosan Enerbility, PaR Systems, Concurrent Technologies Corp. NuScale has made progress in testing, engineering and review capabilities, and engineering and review assistance through agreements and contracts including with SIET, the US Reactor Forging Consortium, Oregon State University, Sargent and Lundy, Enercon, and BWXT. It has made progress in deployment assistance, in particular through its strategic alliance with project developer ENTRA1 that aims to offer a one-stop-shop partnership structure for the development, ownership and operation of VOYGR plants. In 2023, Doosan said it had started forging upper reactor pressure vessels for NuScale.

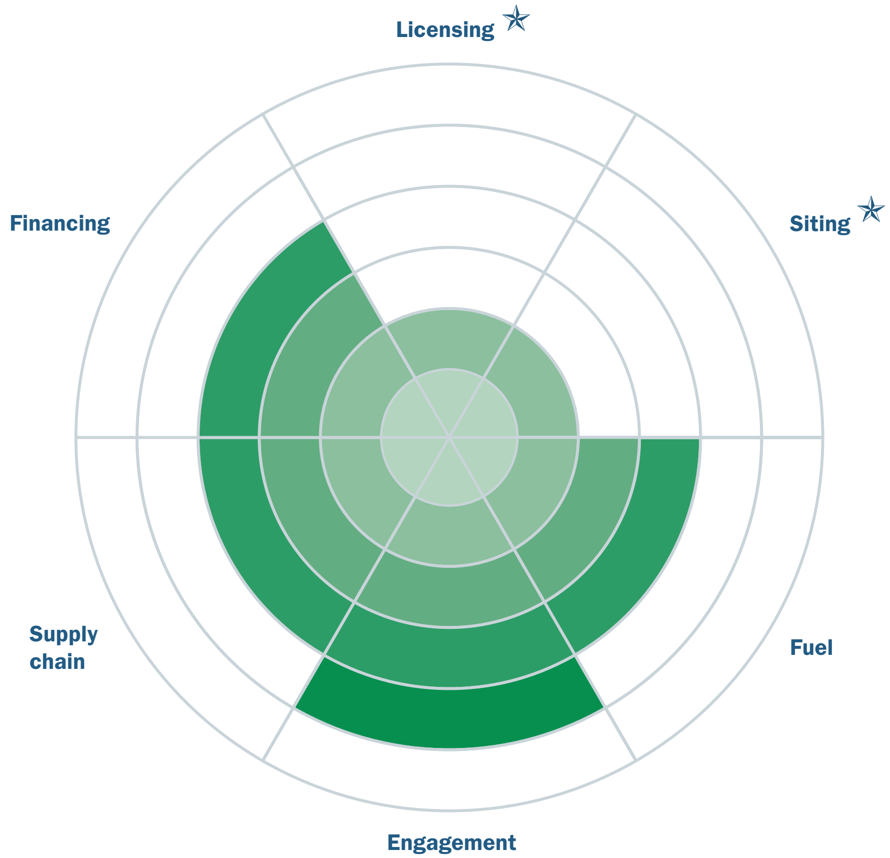
Engagement

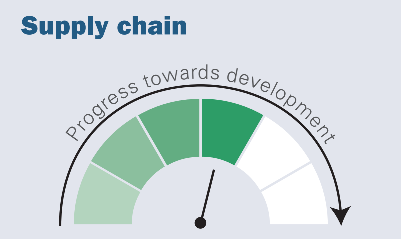
NuScale has deployed six Energy Exploration Centers (E2 Centers) at universities in the United States, Romania and South Korea as an educational tool in the use of modular reactors. NuScale has also engaged communities through town hall meetings. In 2023, the Polish Ministry of Climate and Environment issued a Decision-In-Principle to support VOYGR deployment for KGHM in Poland. NuScale joined the United Nations 24/7 Carbon-free Energy Compact, a group of stakeholders committed to carbon-free energy solutions. In Korea, GS Energy and the Uljin County signed an MoU to conduct feasibility studies of using NuScale VOYGR for hydrogen production.

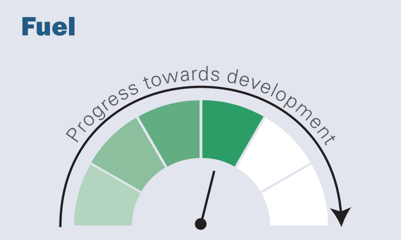
Fuel

In 2016, NuScale included its NuFuel-HTP2 fuel in its application to the NRC for design certification of the 50 MWe NPM in a VOYGR-12 configuration. In 2020, the NRC issued an SDA for the 50 MWe NPM in a VOYGR-12 configuration and issued its final rule in January 2023, approving by incorporation by reference the use of the NuFuel-HTP2 fuel. NuScale's fuel design can be fabricated at Framatome's fabrication facilities in the United States and Europe. The fuel design uses proven Framatome components with extensive operating history. 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.

NUWARD – NUWARD SMR







★ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: Integrated pressurised water-cooled SMR providing 340 MWe from two 170 MWe reactors.

Thermal power (MWth)	1 080 (plant deployed with two modules of 540 MWth)
Outlet temperature (°C)	307
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of NUWARD SMR's progress to deployment

Licensing ☆

Électricité de France (EDF), NUWARD's holding company, submitted the safety option file, or *Dossier d'Option de Sureté*, for the NUWARD SMR to the French Autorité de sûreté nucléaire (Nuclear Safety Authority, or ASN) in July 2023. The ASN as well as Finland's Radiation and Nuclear Safety Authority (STUK) and Czechia's State Office for Nuclear Safety (SUJB) released the closure report for the first phase of their joint pre-licensing review of NUWARD SMR in September 2023. Poland's National Atomic Energy Agency (PAA), Sweden's Radiation Safety Authority (SSM) and the Netherlands' Authority for Nuclear Safety and Radiation Protection (ANVS) have expressed interest in joining the group of regulators for the next phase of the joint pre-licensing review.

Siting ☆

EDF owns 18 licenced nuclear sites in France that could be suitable for the NUWARD first-of-a-kind (FOAK) and has committed to start construction, with the first concrete poured by 2030. EDF also has a Memorandum of Understanding (MoU) with the nuclear operator ČEZ to evaluate the feasibility of deploying the NUWARD SMR at the ČEZ-owned nuclear power plant site in Temelin, Czechia. In 2023, EDF signed an exclusive co-operation agreement with Respect Energy, a Polish electricity trading company, to conduct siting studies for NUWARD in Poland. In addition, the NUWARD SMR was shortlisted with five other SMRs by Great British Nuclear to move to the next phase of the United Kingdom's innovative nuclear technology competition for potential deployment in the country.

Financing

The French government has provided more than EUR 500 million (USD 526 million) in funding for NUWARD development.

Supply chain

NUWARD is in a partnership with: Commissariat à l'énergie atomique et aux énergies alternatives (the French Alternative Energies and Atomic Energy Commission, or CEA) for research and qualification; EDF for systems integration and operation; Naval Group for structures and modular experience; TechnicAtome for compact reactor design; Framatome for reactor core and fuel design; and Tractebel for the conventional island and the balance of plant. EDF and NUWARD signed a co-operation agreement with Tractebel in 2023 for nuclear engineering. EDF also signed co-operation agreements with 5 Polish companies – Uniserv, Telefonika Kable, Polimex Mostostal, Sefako, and Zakłady Remontowe Energetyki (ZRE) Katowice – in 2022, as well as two Italian companies – Ansaldo Energia and Ansaldo Nucleare – in 2023.

Engagement

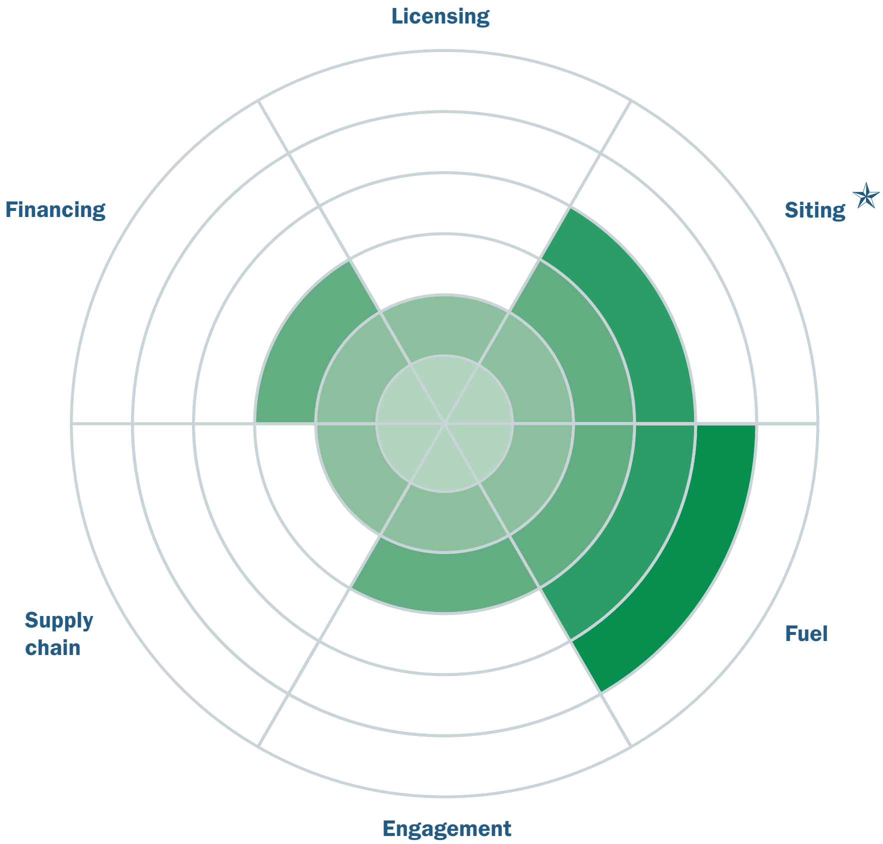
In 2021, the NUWARD International Advisory Board was created to provide advice on subjects including public acceptance. In 2022, the French President stated public support. Since 2022, EDF has advanced various engagements, including through co-operation agreements and letters of intent for feasibility studies and to explore the possible deployment of the NUWARD SMR in Brazil, Czechia, Finland, Italy, Poland, Slovakia and Sweden.

Fuel

The NUWARD SMR uses 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 currency exchange rate applied is the relevant average for the year 2022. In this case, EUR 0.95 equals USD 1.000.

Oklo – Aurora Powerhouse



★ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: Liquid metal-cooled, metal-fuelled fast reactor for heat and cogeneration, using fresh or recycled fuel.

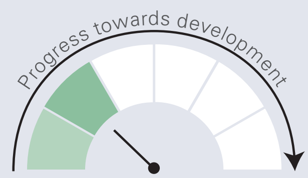
Thermal power (MWth)	40
Outlet temperature (°C)	500
Spectrum (thermal/fast)	Fast
Fuel type	Metallic U-Zr Alloy
Fuel (LEU/HALEU/HEU)	HALEU

Licensing

Siting ★

Financing

Supply chain



Engagement Δ

Fuel

Assessment of Aurora Powerhouse's progress to deployment

Licensing

Oklo has been engaged in pre-licensing activities with the US Nuclear Regulatory Commission (NRC) since 2016. In 2020, the NRC reviewed and approved Oklo's Quality Assurance Program Description and safeguards information protection and handling plan. Since January 2022, Oklo has met with the NRC on a variety of topics, and has docketed multiple reports, licensing project plans and white papers with the NRC on topics related to the design and safety of the Aurora Powerhouse. Oklo is expected to benefit from previous activities related to the licensing of the Aurora SMR with the NRC, including through the submission of a Combined License Application (COLA) in March 2020, which was denied without prejudice in 2022 following considerable NRC engagement.

Siting ☆

In 2019, Oklo received a permit from the US Department of Energy (DOE) to build a first-of-a-kind Aurora reactor at the Idaho National Laboratory (INL). The company still needs to meet insurance, permitting and other requirements before construction can begin. In 2023, Oklo initiated a collaboration with the Southern Ohio Diversification Initiative (SODI) towards the deployment of two Aurora Powerhouses on the decommissioned Portsmouth plant for uranium enrichment in Piketon, Ohio. In 2023, Oklo also signed a Memorandum of Understanding (MoU) with Centrus to supply power from these Aurora Powerhouses to the Centrus Piketon HALEU production facility.

Financing

Oklo has benefited from more than five sources of funding, including cost-share awards from the DOE Advanced Research Projects Agency – Energy (ARPA-E) programmes and the Technology Commercialization Fund. In July 2023, the company announced its plan to take Oklo public in 2024 via a merger with AltC Acquisition Corp., a special purpose company co-founded by Sam Altman, the CEO of OpenAI, and Churchill Capital.

Supply chain

Oklo was granted vouchers under the Gateway for Accelerated Innovation in Nuclear (GAIN) programme to access some US national laboratory capabilities. The company has also signed an agreement with Argonne National Laboratory to work towards commercialisation of advanced fuel recycling technology. In 2023, Oklo and Centrus Energy Corp signed an MoU to collaborate on the possible manufacturing of components for the Aurora Powerhouse at the Centrus manufacturing facilities in Piketon, Ohio, and Oak Ridge, Tennessee.

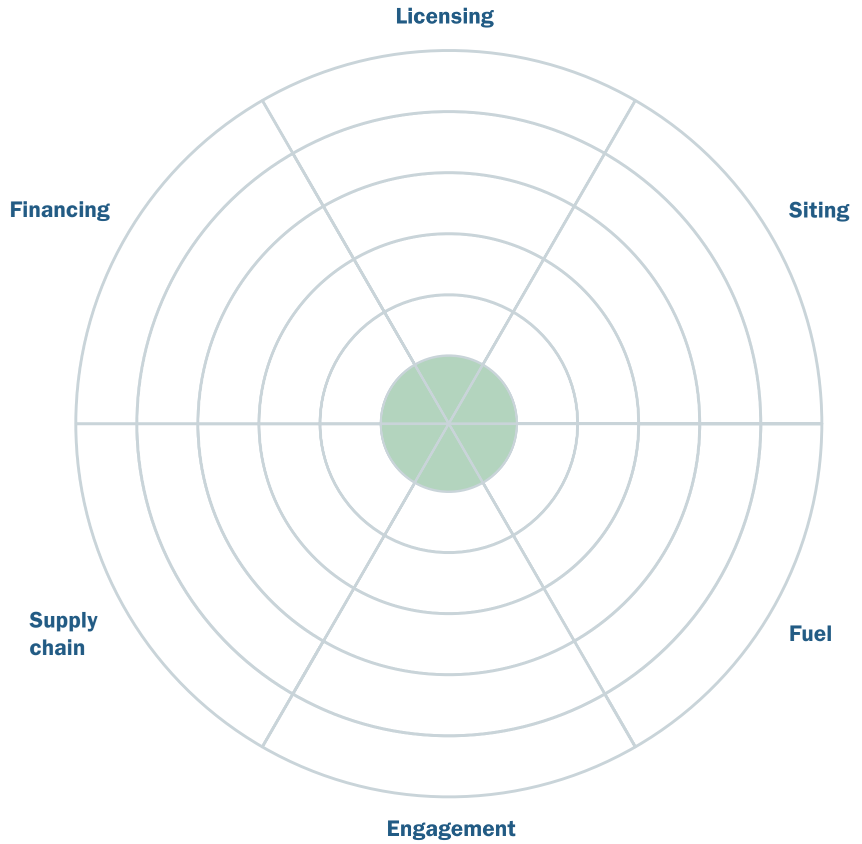
Engagement

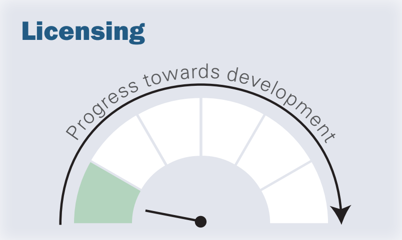
The Aurora Powerhouse team has engaged with community leaders in the region of Piketon, Ohio, including through a community event organised by SODI in 2023 with more than 70 community leaders and officials from federal, state and local governments. In September 2023, Oklo met with officials of the US Air Force and stakeholders in Alaska related to the opportunity to construct a microreactor facility on the Eielson Air Force Base Alaska. The Aurora Powerhouse was also selected as one of TIME's 200 Best Inventions of 2023 in the category of Reuse and Recycle technologies.

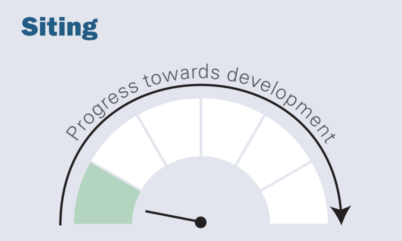
Fuel

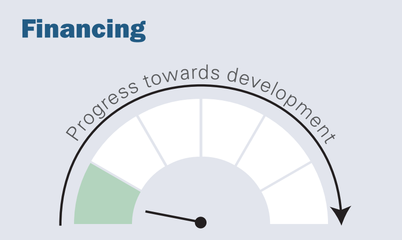
HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. Oklo fabricated and demonstrated prototypes of its metallic fuel with the INL in 2019. In 2020, the INL selected Oklo through a competitive process to receive HALEU for their first-of-a-kind Aurora Powerhouse by processing and treating used fuel from the Experimental Breeder Reactor-II. In 2021, the company signed a non-binding letter of intent with Centrus to co-operate in the deployment of a HALEU facility. Oklo and Centrus extended their collaboration through a new MoU signed in 2023 to explore, among other topics, the possibility for Oklo to purchase HALEU produced by Centrus.

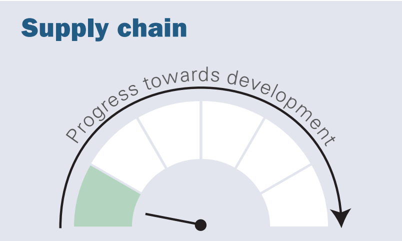
Otrera Nuclear Energy – Otrera 300

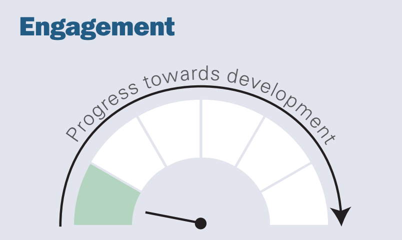


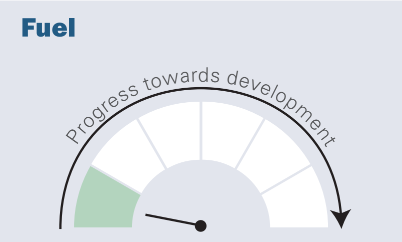












Reactor description: Sodium-cooled fast reactor for cogeneration and low-level heat (<150°C) with option for minor actinide burning.

Thermal power (MWth)	300
Outlet temperature (°C)	550
Spectrum (thermal/fast)	Fast
Fuel type	MOX
Fuel (LEU/HALEU/HEU)	MOX

Assessment of Otrera 300's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

At the time of assessment, no information about financing was readily available from verifiable public sources.

Supply chain

Otrera is one of five SMR projects selected in mid-2023 by the French Commissariat à l'énergie atomique et aux énergies alternatives (the Alternative Energies and Atomic Energy Commission, or CEA) under CEA's French Atomic Sustainable Technologies (FAST) programme, aimed at advancing commercialisation of projects from R&D. Otrera is expected to benefit from CEA's history of experience in designing, building and operating sodium-cooled fast reactors.

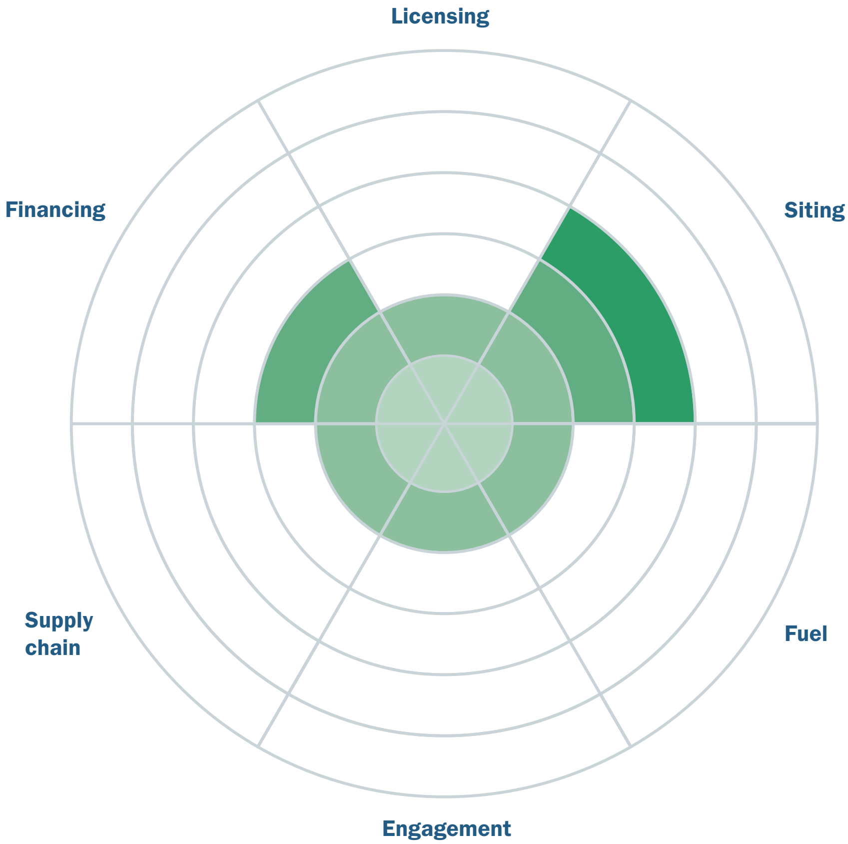
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

Otrera plans to use mixed plutonium-uranium oxide fuel (MOX) with two zones (17.3% Pu and 15.6% Pu). MOX fuel is a technically proven fuel type; however, there are presently limited suppliers, in particular for fast reactors. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

Radiant Industries – Kaleidos



Δ Indicates change since 2023.

Reactor description: Compact, portable high temperature gas microreactor designed to replace diesel generators.

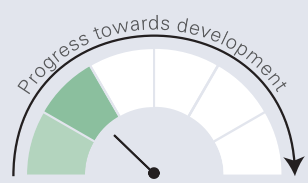
Thermal power (MWth)	1.9
Outlet temperature (°C)	700
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Licensing Δ

Siting Δ

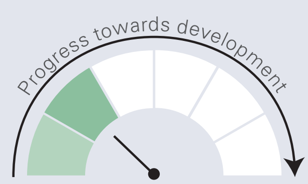
Financing Δ

Supply chain



Engagement Δ

Fuel



Assessment of Kaleidos' progress to deployment

Licensing

Radiant Industries engaged the US Nuclear Regulatory Commission (NRC) on the Kaleidos SMR through a public meeting on 17 February 2023. Radiant Industries has also engaged the NRC on their business and licensing plans. As part of the 2023 US Congressional Budget Justification, the NRC indicated that they expect to review the licence application for the Radiant Industries demonstration microreactor during the 2024 fiscal year.

Siting

National Reactor Innovation Center (NRIC), a US Department of Energy (DOE) programme led by Idaho National Laboratory (INL), has selected Kaleidos to be demonstrated at one of the sites in INL's Demonstration and Operation of Microreactor Experiments (DOME) facility in Idaho, United States, where testing in DOME could start as early as 2026.

Financing

Radiant has secured public and private sector financing in support of the Kaleidos microreactor. This includes more than USD 50 million in private financing and two awards through the US Small Business Innovation Research programme totalling approximately USD 250 000 to support modelling and simulation capabilities. Through the NRIC FEEED process, Radiant was awarded up to USD 1.5 million to progress towards deployment of the Kaleidos at the DOME facility.

Supply chain

Radiant has been awarded two vouchers under the US DOE Gateway for Accelerated Innovation in Nuclear (GAIN) initiative to advance modelling capabilities for their proposed reactor concept in partnership with the INL and Argonne National Laboratory.

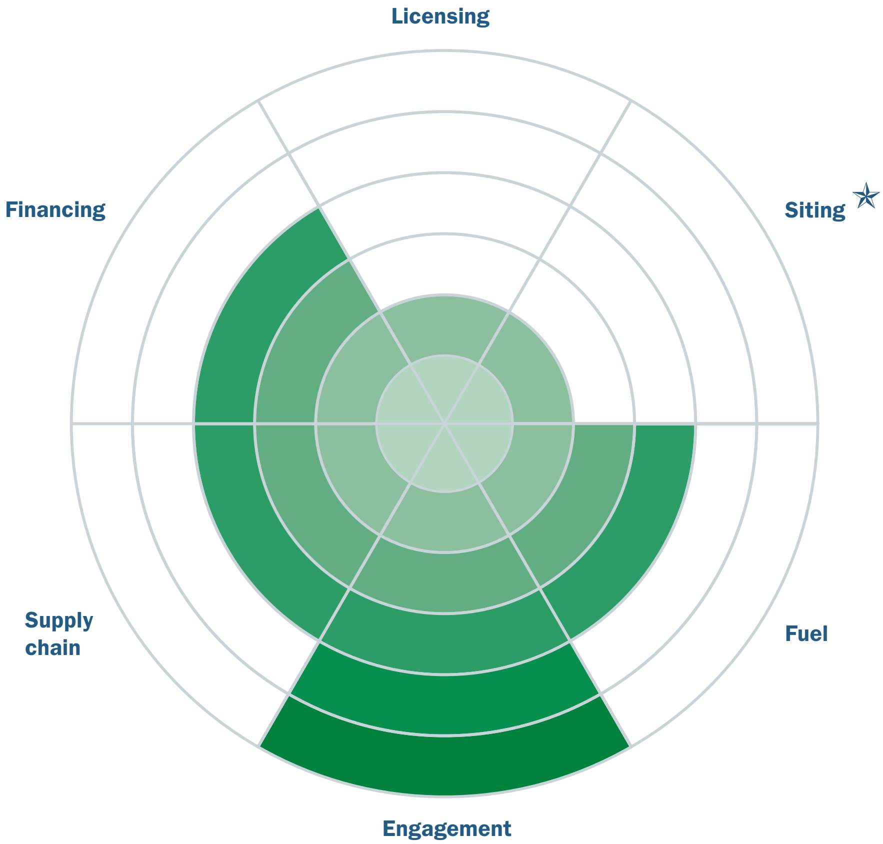
Engagement

Radiant Industries has engaged the public on the potential benefits and sustainability of the Kaleidos SMR, including through the 2023 Forbes Sustainability Leaders Summit on 20 September 2023.

Fuel

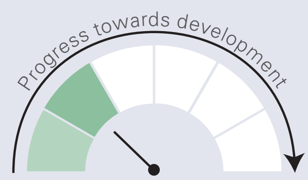
HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. In 2022, Radiant Industries launched a Request for Proposals for fuel fabricators to produce TRISO fuel, and in 2023 the company entered an agreement with Centrus Energy to work towards identifying a path to provide a future supply of HALEU for up to 20 Kaleidos microreactors.

Rolls-Royce SMR – RR SMR



Licensing

Siting ★



Financing

Supply chain

Engagement Δ

Fuel

★ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: Close-coupled, three-loop pressurised water reactor using low enriched uranium fuel.

Thermal power (MWth)	1 358
Outlet temperature (°C)	325
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of RR SMR's progress to deployment

Licensing

The design certification application for the Rolls-Royce SMR (RR SMR) has been submitted to the UK Office for Nuclear Regulation (ONR) for review, and the design has entered Step 2 of the ONR Generic Design Assessment 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 RR SMR. The RR SMR was also selected as the preferred technology by the Solway Community Power Company, which intends to deploy an SMR in West Cumbria, United Kingdom. Rolls-Royce SMR also has a Memorandum of Understanding (MoU) with the nuclear operator ČEZ to evaluate the feasibility of deploying the RR SMR at the ČEZ-owned nuclear power plant site in Temelin, Czechia. In 2023, Great British Nuclear selected the RR SMR along with five other SMRs to progress to the next phase of the United Kingdom's innovative nuclear technology competition for potential deployment in the country.

Financing

Rolls-Royce SMR has attracted more than GBP 500 million (USD 616 million) in combined public and private sector funding to support its development and deployment. The UK government has supported the RR SMR, including with GBP 210 million (USD 259 million) in funding through the UK Research and Innovation funding. In the private sector, partners in the Rolls-Royce SMR business have made equity investments. Specifically, Rolls-Royce Group, BNF Resources, Constellation, and the Qatar Investment Authority have raised nearly GBP 300 million (USD 370 million) in combined funding for the RR SMR.

Supply chain

The RR SMR is supported by a Rolls-Royce-led consortium that includes the UK National Nuclear Laboratory as well as the British engineering companies BAM Nuttall, Laing O'Rourke, Jacobs, Nuclear AMRC, Assystem and The Welding Institute. Rolls-Royce SMR aims to develop and own factories to build the SMR modules and to establish turnkey engineering, manufacturing and assembly for RR SMR power plants. Rolls-Royce SMR is working to select a site for its first factory, and has several agreements in place for products and services to develop the SMR. AtkinsRéalis's UK team is supporting work related to the design and delivery aspects of the SMR. Rolls-Royce SMR also has contracts in place for specific materials, including with Sheffield Forgemasters.

Engagement

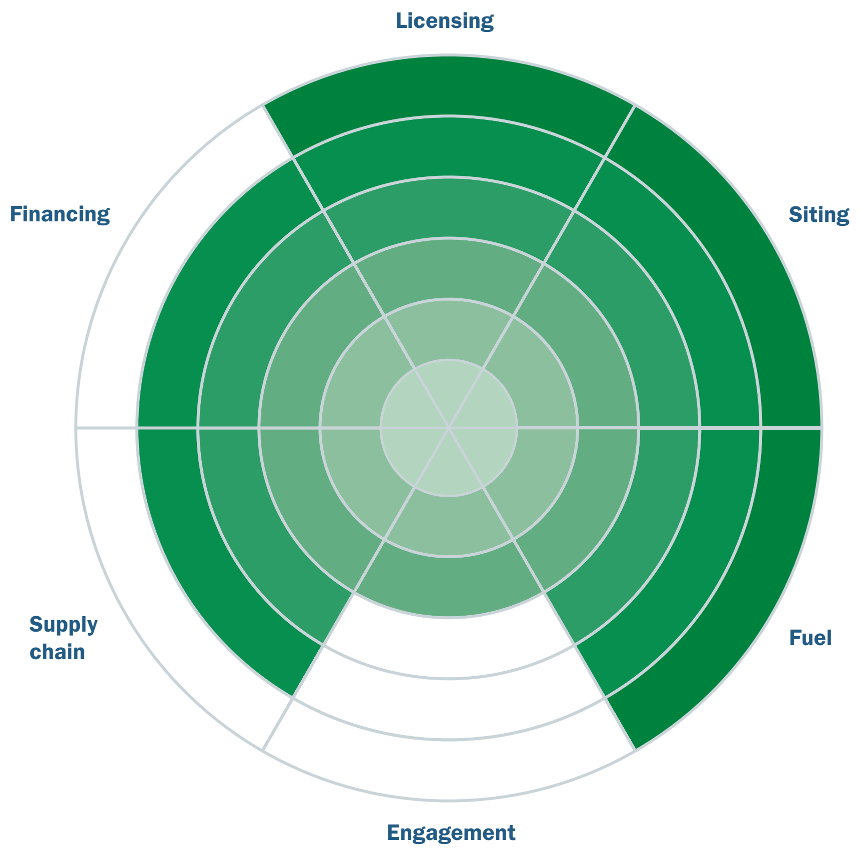
Rolls-Royce SMR has received endorsements from officials in the UK government and from the Greater Manchester Investment Authority. Rolls-Royce SMR is working with stakeholders in local jurisdictions to explore sites for a factory to build SMR modules. Rolls-Royce SMR has MoU with ČEZ in Czechia, ULC-Energy in the Netherlands, the Jordan Atomic Energy Commission in Jordan, Fortum in Finland, and Energoatom in Ukraine. Rolls-Royce SMR also has a MoU as well as a Memorandum of Intent with the Polish industrial group Industria to develop plans towards deploying Rolls-Royce SMRs to decarbonise Industria's activities in Poland, including through the production of clean hydrogen.

Fuel

The RR 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. In 2023, Rolls-Royce SMR signed an agreement with Westinghouse Electric Company to develop and advance work on the design of the RR SMR nuclear fuel.

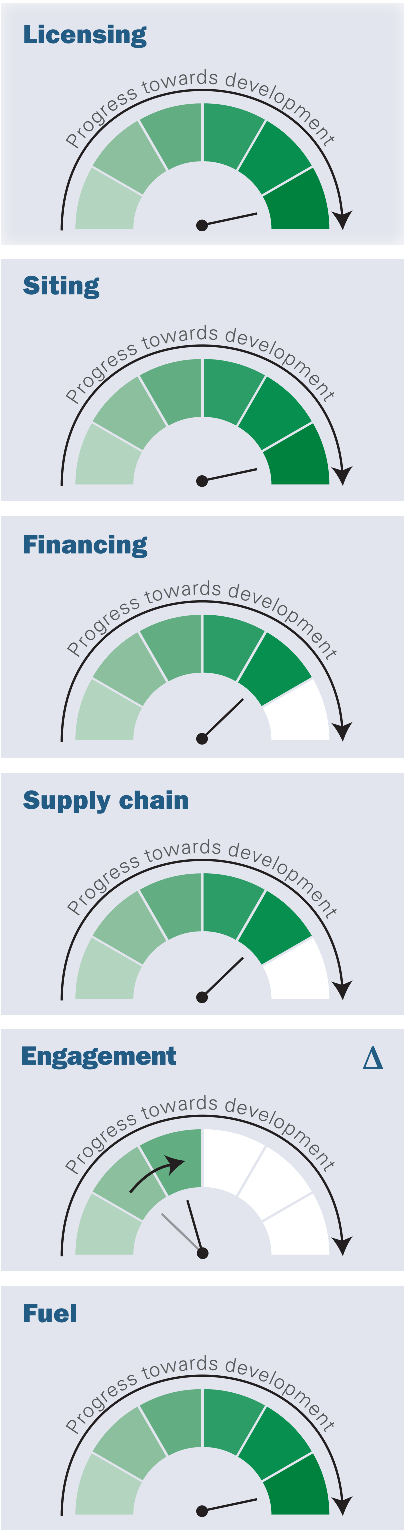
Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, GBP 0.811 equals USD 1.000.

ROSATOM – KLT-40S



Δ Indicates change since 2023.

Reactor description: Pressurised water reactor for the floating nuclear power unit *Akademik Lomonosov*.	
Thermal power (MWth)	300 (plant deployed with two modules of 150 MWth)
Outlet temperature (°C)	316
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	HALEU



Assessment of KLT-40S's progress to deployment

Licensing

The Akademik Lomonosov floating nuclear power unit 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 units back in 2010, and has been operating in the city of Pevek since May 2020.

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 currently used to power icebreakers. Several organisations have contributed to the construction of the Akademik Lomonosov floating nuclear power unit and its KLT-40S reactor units: Rosenergoatom as owner and operator; Afrikantov OKB Mechanical Engineering as chief designer; the Kurchatov Institute as scientific supervisor of the reactor design; TsKB "Iceberg" as general designer; the Krylov Shipbuilding Research Institute as scientific supervisor; Baltiysky Zavod as builder of the floating nuclear power unit; 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

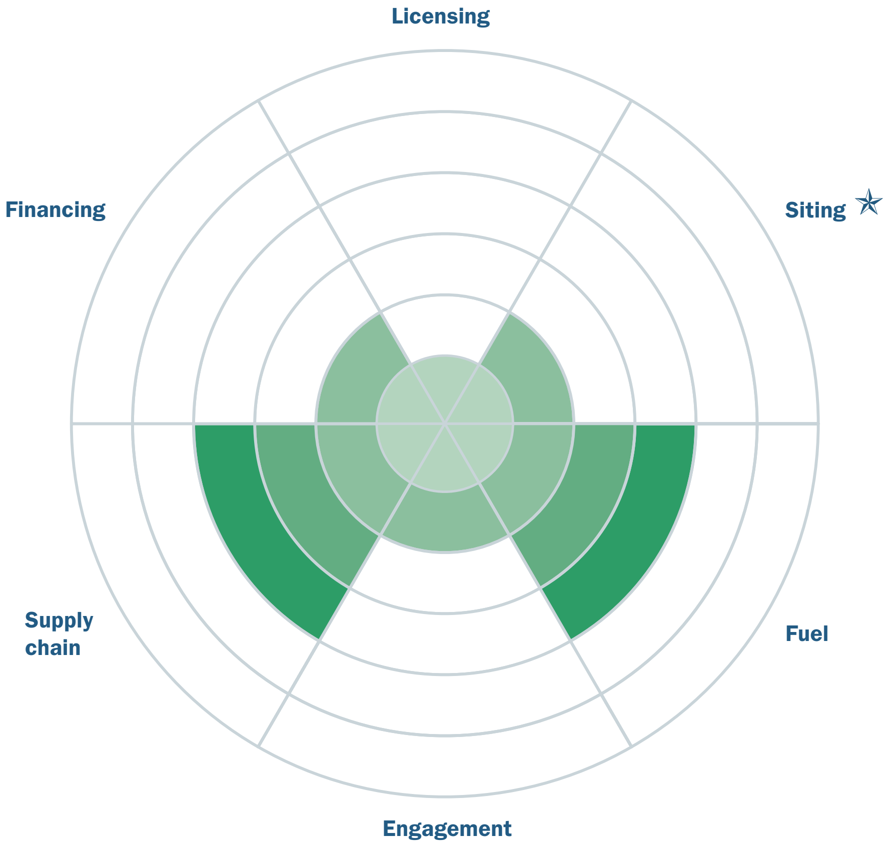
Rosenergoatom has organised public tours on the Akademik Lomonosov barge to showcase the KLT-40S power station and highlight the attractiveness of working in nuclear energy. In 2022, 111 people visited the Akademik Lomonosov of which a significant portion were school-age children. Public hearings were led by Rosenergoatom at Pevek, and Rosenergoatom is engaged with the city of Pevek to leverage the Academic Lomnosov to support the development of social infrastructure within the city. In 2022 Rosenergoatom donated more than RUB 200 million (USD 2.9 million) to support urban infrastructure development within the city of Pevek.

Fuel

The KLT-40S design is based on the existing KLT-40M technology which is currently used to power icebreakers, 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.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, RUB 68.485 equals USD 1.000.

ROSATOM – RITM-200M

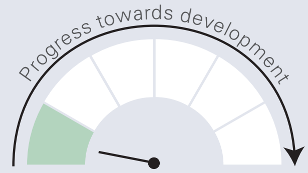


✯ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

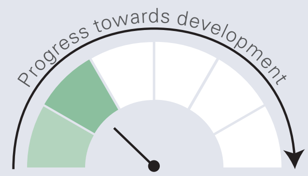
Reactor description: Pressurised water reactor for the floating nuclear power units for export markets.	
Thermal power (MWth)	396 (plant deployed with two modules of 198 MWth)
Outlet temperature (°C)	318
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	HALEU

Licensing



Siting ✯

Financing



Supply chain

Engagement Δ

Fuel

Assessment of RITM-200M's progress to deployment

Licensing

The RITM-200M SMR designed by ROSATOM, Russia's State Atomic Energy Corporation, is a floating SMR in the RITM200 series designed for export markets. Six RITM-200 units are already licensed and in operation on dual-draft icebreakers – two each on the icebreaker ships Arktika, Sibir and Ural. Licensing for the floating RITM-200M will benefit from ROSATOM's prior experience in licensing and operating the RITM-200 SMRs on icebreakers. At the time of assessment, there was no additional information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting ✯

In 2019, ROSATOM signed a Memorandum of Intent with the Ministry of Energy in the Philippines to conduct a preliminary feasibility study on the possible deployment of an RITM-200M. In 2023 the Director General of ROSATOM indicated that ROSATOM is working in co-operation with the government of Myanmar on the possible deployment of an RITM-200M in Myanmar. In 2023, Russia and Myanmar signed an intergovernmental agreement on co-operation in peaceful nuclear power, which included RITM SMRs.

Financing

In 2021, the Russian government approved a project cost of RUB 506 billion (USD 7.4 billion) for new nuclear technologies by 2030, which includes the RITM-200M. In 2022, the Russian government announced that the government would invest RUB 100 billion (USD 1.5 billion) in new nuclear technologies, including the RITM-200M.

Supply chain

ROSATOM has significant experience and capabilities in nuclear power development, engineering, procurement and construction, including with the deployment of several RITM-200 units for icebreakers. As RITM-200M is a floating SMR within the RITM-200 series, it is expected that the RITM-200M supply chain will benefit significantly from the work on the other RITM-200 series SMRs. ROSATOM has created a joint venture with TSS Group, an oil and gas construction and engineering company, to construct and export a series of RITM-200M floating power units targeting markets in the Middle East, southeast Asia and Africa as early as 2029.

Engagement

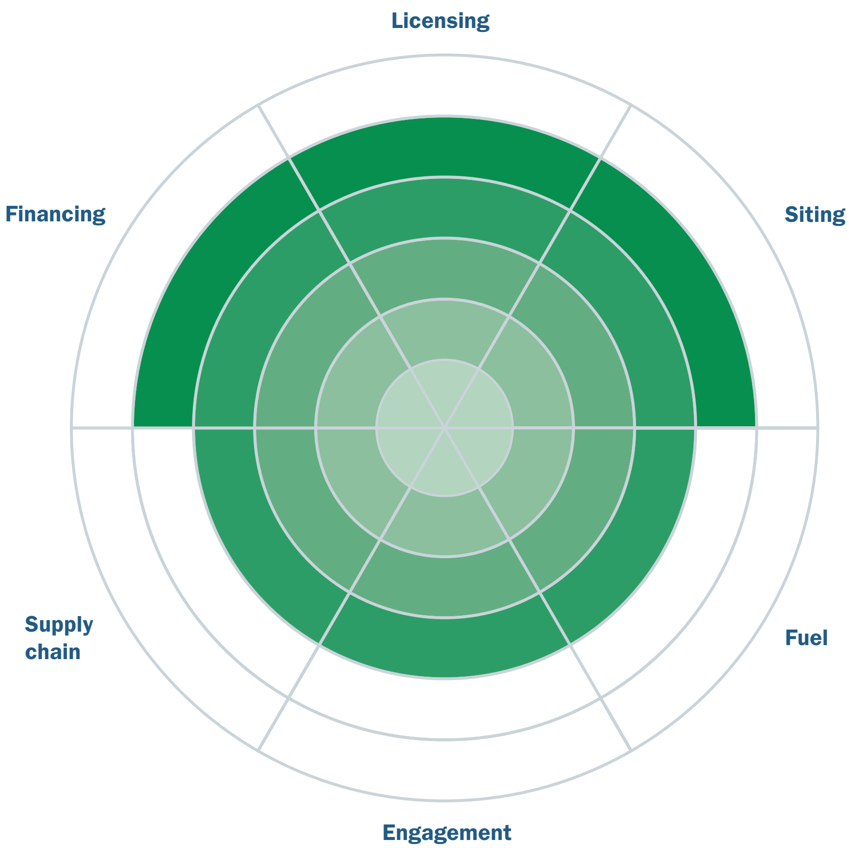
On 28 July 2023, ROSATOM participated in the Economic and Humanitarian Russia-Africa Forum and presented and discussed the potential role for ROSATOM to sell electricity from a fleet of RITM-200M floating power units in Africa.

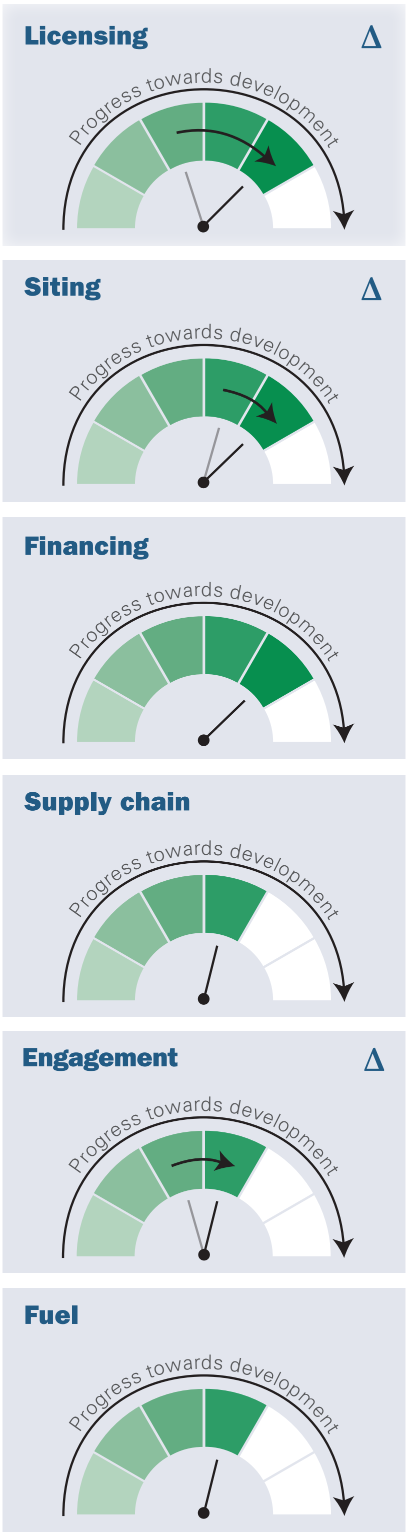
Fuel

The RITM-200M is designed to use HALEU fuel enriched to less than 20%. Russia has existing capabilities to produce HALEU fuel on a commercial scale. The floating RITM-200M shares aspects of the fuel design for the RITM-200 series SMRs and is expected to leverage the same fuel supply chain. Compared to the RITM-200S, which requires refuelling every five years, the RITM-200M requires refuelling over a period of up to ten years. Fuel elements for the RITM-200 series reactors have been designed and developed by specialists at the Bochvar Research Institute of Inorganic Materials, part of the Russian fuel manufacturer TVEL, which supplies nuclear fuel to all Russian nuclear power plants, including marine-based reactors.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, RUB 68.485 equals USD 1.000.

ROSATOM – RITM-200N





Δ Indicates change since 2023.

Reactor description: Pressurised water reactor for small land-based nuclear power plants.

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

Licensing for the land-based RITM-200N will benefit from past experience from the licensing and operation of the RITM-200 SMRs on icebreakers. The Federal Environmental, Industrial and Nuclear Supervision Service of Russia (Rostechnadzor) reviewed more than 82 Safety Justification documents for the RITM-200N SMR, and on 21 April 2023 issued a licence to construct the RITM-200N in the Ust-Yansky District of the Republic of Sakha (Yakutia) in northern Russia. The project is expected to be completed in 2028. Rostechnadzor is developing draft amendments to Federal Rules and Regulations to add considerations on the specifics of the RITM-200N SMR. The amendments relate to design and material standardisation for technologies previously used on ship installations.

Siting

In 2019, the Republic of Sakha and ROSATOM signed an agreement of intent to build the first land-based RITM-200N SMR in Yakutia. In 2020, the two parties reached a formal agreement to proceed with the construction. The license to construct was issued by Rostechnadzor in April 2023, and construction has begun. In August 2023, the government of the Republic of Sakha (Yakutia) announced that a temporary village has been constructed in the Arctic region of Yakutia to accommodate more than 1 000 construction workers. The start of work to construct the RITM-200N is scheduled for 2024.

Financing

In 2021, the Russian government approved a project cost of RUB 506 billion (USD 7.4 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 1.5 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 icebreakers. 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. Pre-construction work is already underway in the area of the village of Ust-Kuyga and the start of work is scheduled for 2024. More than 2 000 tonnes of cargo have been delivered to the site, and a temporary village for construction workers has been constructed to accommodate more than 1 000 people.

Engagement

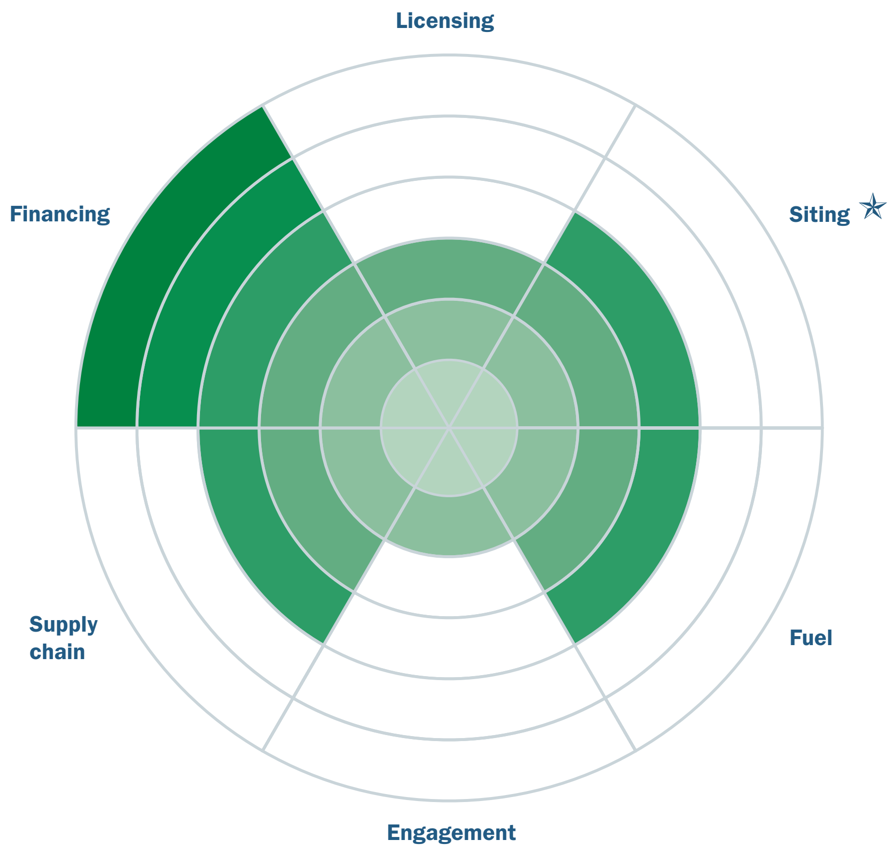
In 2021 and 2023, public discussions were held about the land-based RITM-200N project in Yakutia. The Ministry for the Development of the Russian Far East has created a working group to oversee the implementation of the project, with representatives from: Rusatom Overseas; the Ministry of Economic Development; the Ministry of Energy; and Joint Stock Company VEB Infrastructure. ROSATOM has signed a memorandum of co-operation with Kyrgyzstan on the construction of RITM-200N reactors in the country. In September 2023, Seligdar PJSC signed an agreement of intent with ROSATOM, the Ministry of the Russian Federation for the Development of the Russian Far East and Arctic, and the Government of the Republic of Sakha (Yakutia) to use the RITM-200N to develop deposits in the Arctic.

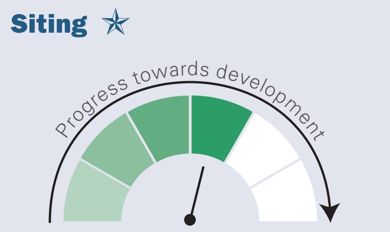
Fuel

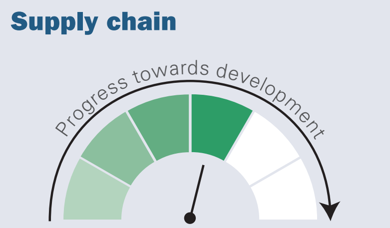
The land-based RITM-200N shares some aspects of the fuel supply chain of the RITM-200 design, which is already operational on the Arktika, Sibir and Ural icebreakers. Regarding the RITM-200N fuel design, the Elemash Machine-building plant, a fabrication facility of Russian fuel manufacturer TVEL, produced 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.

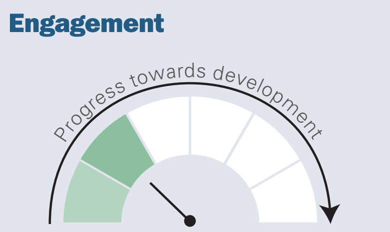
Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, RUB 68.485 equals USD 1.000.

ROSATOM – RITM-200S









★ Active in multiple jurisdictions or countries.

Reactor description: Pressurised water reactor for floating nuclear power units.

Thermal power (MWth)	396 (plant deployed with two modules of 198 MWth)
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 designed for domestic deployment in Russia. Six RITM-200 units are already licensed and in operation on dual-draft icebreakers – two on the Arktika icebreaker ship, two on Sibir, and two on Ural. Licensing for the marine-based RITM-200S will benefit from past experience in the licensing and operation of the RITM-200 SMRs on icebreakers. A licence to construct the RITM-200S for deployment in Cape Nagleynyn in north-eastern Russia is under consideration.

Siting ☆

In 2021, following a competitive selection process, the Russian government selected four floating units, with two RITM-200S SMRs per unit, to supply heat and power to the Baimskaya copper mine and mineral processing facility in Cape Nagleynyn. The first unit is expected by 2027, and the remainder by 2031. FSUE Atomflot, ROSATOM's floating nuclear power unit owner-operator, and Baimskaya mine operator, signed a preliminary agreement for RITM-200S SMRs to supply power to Baimskaya. In 2023, ROSATOM also announced that it is considering up to 15 additional floating units in the Arctic by 2042. Kommersant, a Russian news outlet, has reported that natural gas company Gazprom is considering RITM-200S units for the Kirinskoye and Yuzhno-Kirinskoye gas condensate fields in the Sakhalin region.

Financing

In 2021, the Russian government approved a project cost of RUB 506 billion (USD 7.4 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 1.5 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 unit project, which is valued at RUB 190.2 billion (USD 2.8 billion).

Supply chain

Substantial supply chain capabilities for the RITM-200S SMR have been developed with the construction of several RITM-200 units for icebreakers. Atomenergomash, a machinery construction division of ROSATOM, and OKBM Afrikantov JSC, an engineering subsidiary of ROSATOM, started construction of the RITM-200S off-site 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. In March 2023, the Russian government announced over RUB 27.5 billion (USD 401 million) over 4 years for the construction of a marine terminal in the port of Pevek that could support a fleet of floating nuclear power units with RITM-200S SMRs.

Engagement

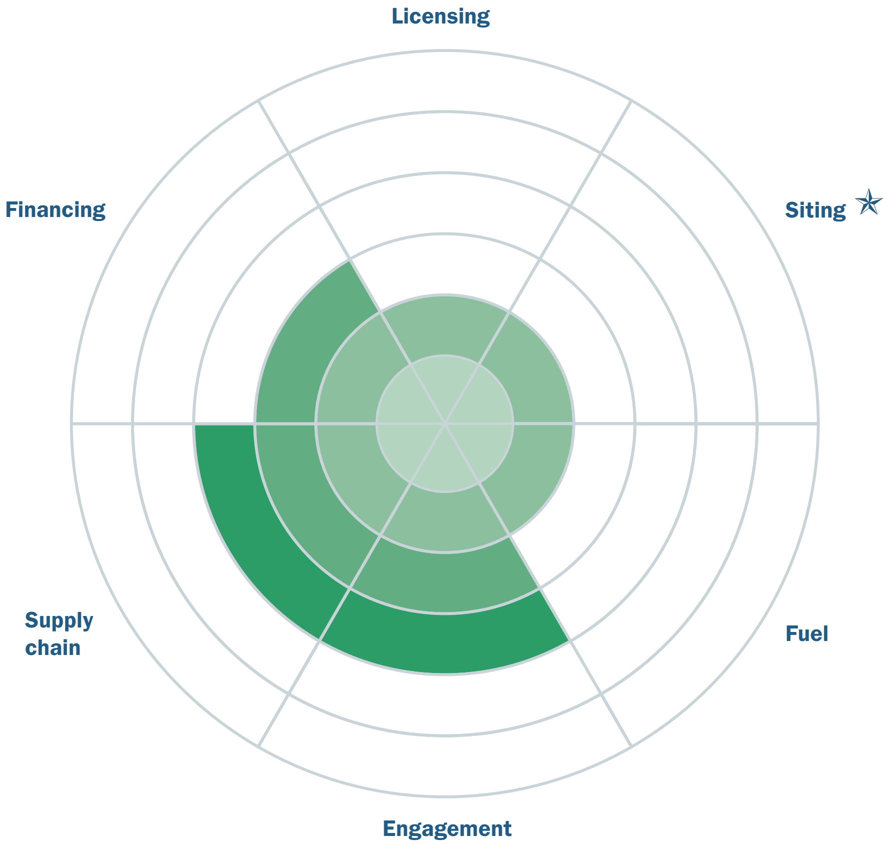
The local district administration of Cape Nagleynyn announced the start of public consultations for the marine-based RITM-200S floating nuclear power unit project in 2022.

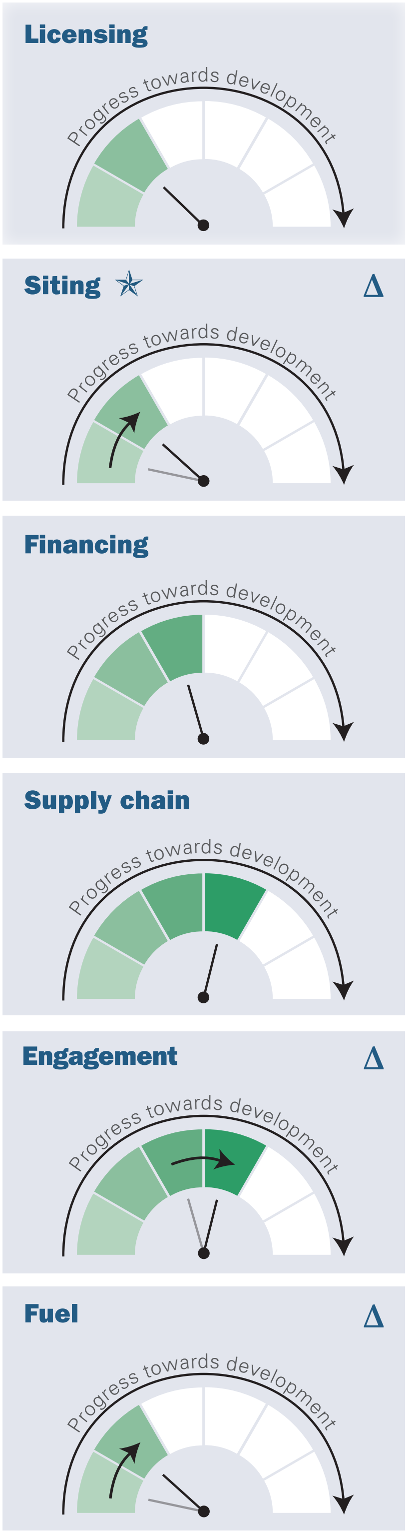
Fuel

The marine-based RITM-200S shares some aspects of the fuel supply chain of the RITM-200 design, which is already operational on the Arktika, Sibir and Ural icebreakers. Regarding the RITM-200S fuel design, JSC Afrikantov OKBM designed the core, absorbing elements and emergency protection rods, and JSC VNIINM designed the fuel elements, burnable absorber rods, and starting neutron source. The core is being produced at the Machine-Building Plant in Elektrostal, which is part of the Russian fuel manufacturer TVEL.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, RUB 68.485 equals USD 1.000.

Seaborg Technologies
– Compact Molten Salt Reactor (CMSR)





✯ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: Multi-module, graphite moderated, liquid fluoride fuelled, molten salt reactor on a power barge.

Thermal power (MWth)	250
Outlet temperature (°C)	670
Spectrum (thermal/fast)	Thermal
Fuel type	Molten salt
Fuel (LEU/HALEU/HEU)	LEU

Assessment of CMSR's progress to deployment

Licensing

Seaborg has been advancing qualification activities with respect to the international maritime legal framework. The American Bureau of Shipping (ABS) evaluated the CMSR through its New Technology Qualification process and in 2020 found that it satisfied the Feasibility Stage, the first of five phases. In 2022, ABS issued an Approval in Principle to South Korean shipbuilder Samsung Heavy Industries for the use of the CMSR on a power barge. The CMSR will require separate licensing from a nuclear safety regulator. At the time of assessment, there was no information readily available from verifiable public sources related to engagement with nuclear safety regulators.

Siting ☆

In 2023, Seaborg signed a Memorandum of Understanding (MoU) with the Indonesian power company Pertamina NRE and a letter of intent with Norsk Kjernekraft (Norwegian Nuclear Power) to investigate the possible deployment of CMSR in Indonesia and in Norway. In 2022, Seaborg conducted a joint study with Siemens Energy and Vietnamese power engineering consultancy PECC2 to explore the requirements for deploying floating nuclear power plants in Viet Nam, which included the preparation of a Strategic Environmental Assessment and the identification of potential sites to deploy an CMSR power barge. In 2022, Seaborg announced a draft MoU with the Philippines Nuclear Research Institute related to the potential deployment of the CMSR in the Philippines.

Financing

Seaborg Technologies has received private and public sector funding to advance its CMSR and related technologies. In 2018, Seaborg raised DKK 11.5 million (USD 1.63 million) in venture financing, including from PreSeed Ventures – whose shares were later acquired by Heartland. In 2020, the company secured two loans from the Danish state investment fund Vaekstfonden, and announced that they had secured USD 24 million in private funding from a range of investors to accelerate the deployment of its CMSR technology. In 2022, the European Innovation Council (EIC) provided a EUR 2.5 million (USD 2.6 million) grant and committed EUR 15 million (USD 15.8 million) in equity through the 2022 EIC Accelerator programme.

Supply chain

In April 2023, Seaborg joined a consortium with Korea Hydro & Nuclear Power and Samsung Heavy Industries (SHI). SHI completed the conceptual design for the CMSR Power Barge in January 2023. Seaborg is working with the Technical University of Denmark (DTU) to explore corrosion induced by molten sodium hydroxide. Seaborg is also advancing research with the ISIS Neutron and Muon Source near Oxford in the United Kingdom and the European Spallation Source research centre in Sweden. Through the European Commission ERA-LEARN programme, Seaborg is working with DTU, the Chalmers University of Technology in Sweden, and others to develop multi-physics software. In May 2022, Seaborg signed an MoU with Best Engineering in Energy Solutions Inc. for regulatory support services.

Engagement

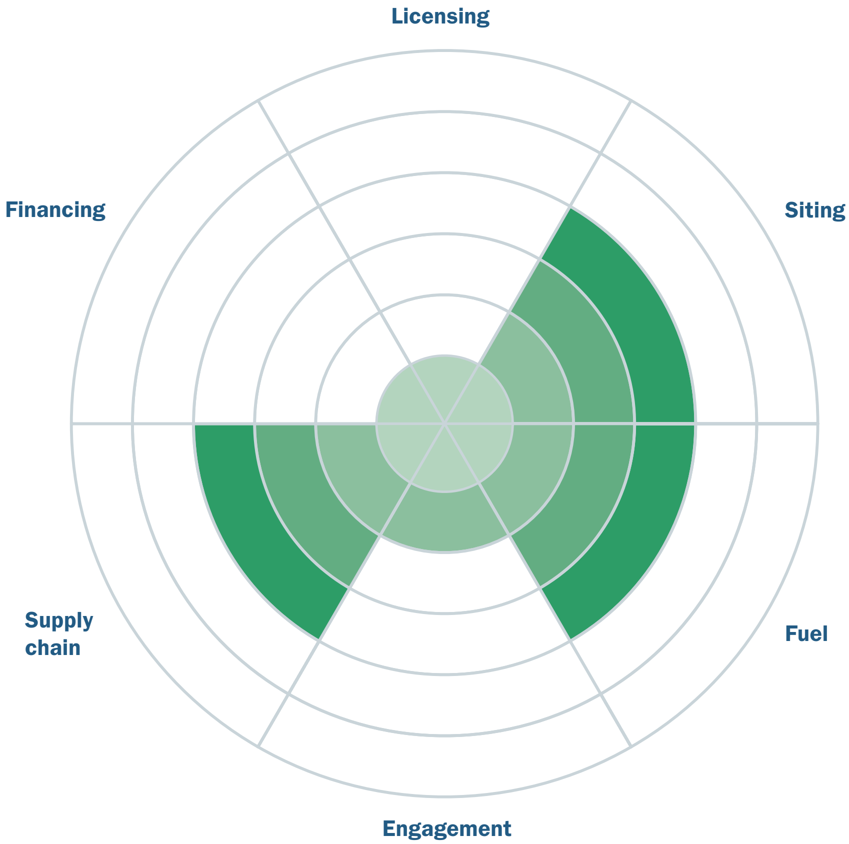
Seaborg has joined the coal-to-nuclear REPOWER initiative led by NGO TerraPraxis. Seaborg founders have also taken steps to reach public audiences beyond the nuclear sector, for example through interviews in a podcast hosted by the *Harvard Business Review* in March 2022, with Azeem Azhar, Korea's Arirang News media outlet, as well as a TEDx presentation in 2019. In 2023, Seaborg held an open-door event inviting the public to meet Seaborg scientists and learn about the Seaborg CSMR as part of the Copenhagen Culture Night programme called Kulturenatten.

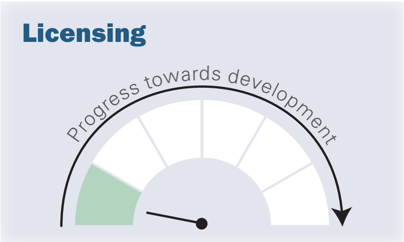
Fuel

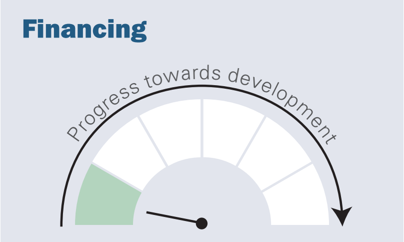
The CMSR proposes to use LEU in a molten salt, which will be a blend of UF_4 LEU with sodium and potassium fluoride salts. In 2023, Kepco Nuclear Fuel, GS Engineering & Construction and Seaborg signed an MoU for fuel salt production, and announced a collaboration to investigate the feasibility of developing a LEU fuel salt production facility in South Korea. Also in 2023, Badan Riset dan Inovasi Nasional (BRIN), the Indonesian National Research and Innovation Agency, announced it received a visit from Seaborg Technologies and discussed potential collaboration on nuclear fuel and radioactive waste management R&D.

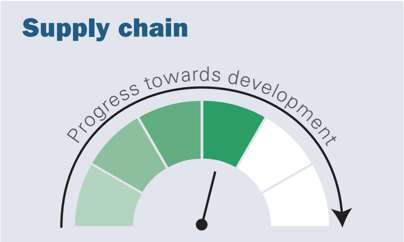
Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, DKK 7.076 and EUR 0.950 equal USD 1.000.

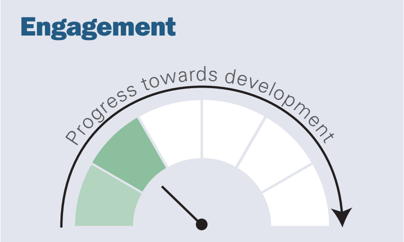
SPIC (State Power Investment Corporation) – HAPPY200











Reactor description: Low-temperature, low-pressure light water reactor.

Thermal power (MWth)	200
Outlet temperature (°C)	120
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of HAPPY200's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to ongoing licensing or pre-licensing activities.

Siting

In 2019, the HAPPY200 was selected for the Nuclear Energy Heating Demonstration Project in Baishan in Jilin province of the People's Republic of China (China), which could provide heating for an area over 80 square kilometres. This technology selection decision builds on a co-operation agreement that was signed earlier in 2019 between China's State Power Investment Corporation (SPIC) and the municipal government of the city of Baishan to explore the deployment of the HAPPY200 in Baishan. The site for the Baishan Nuclear Energy Heating Project was selected in September 2018.

Financing

At the time of assessment, no information about financing was readily available from verifiable public sources.

Supply chain

In 2015 China Power Investment Corporation and the State Nuclear Power Technology Corporation merged to form SPIC. SPIC is an integrated energy organisation and performs nuclear supply chain roles associated with the development of the HAPPY200 SMR. This includes research, design and manufacturing of nuclear power components and equipment, as well as construction, operation and management activities. The State Power Investment Corporation signed a general contracting framework agreement with the Shanghai Nuclear Engineering Institute to support the Nuclear Energy Heating Demonstration Project in Baishan. The HAPPY200 reactor is expected to benefit from existing light water reactor supply chains.

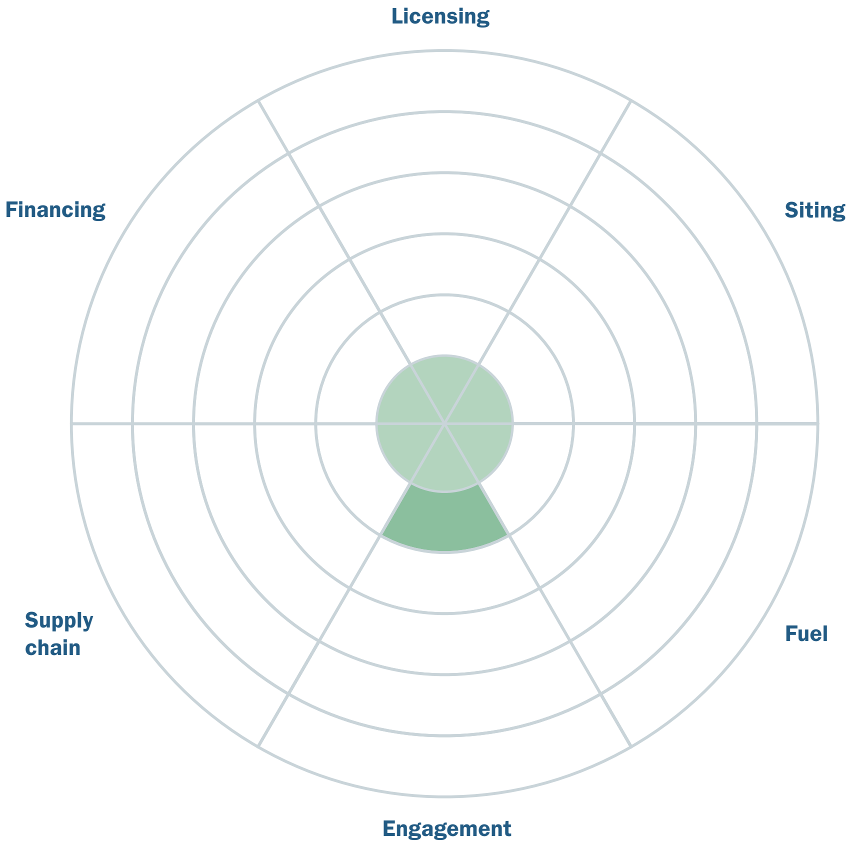
Engagement

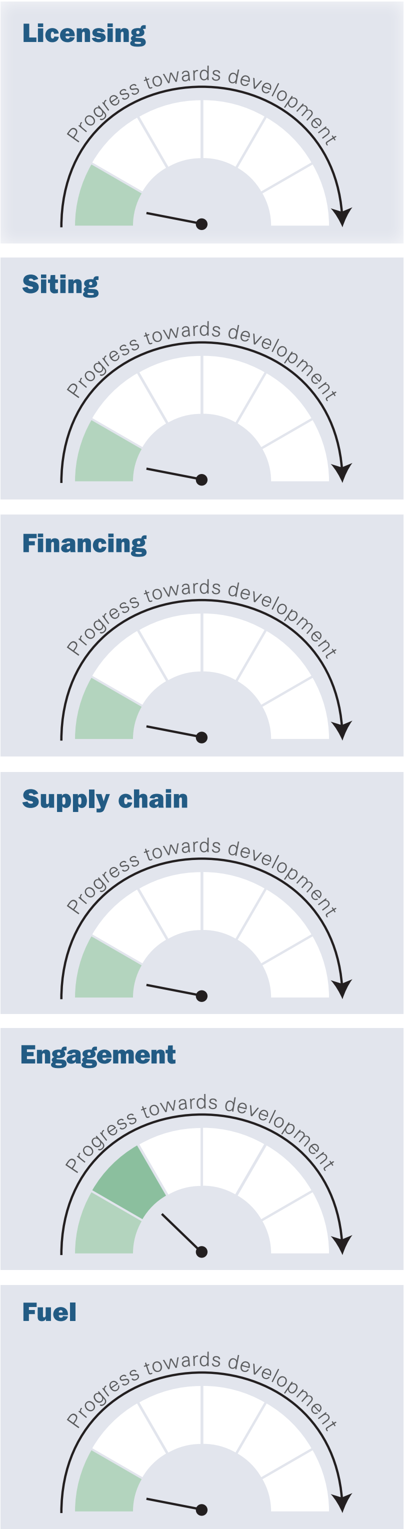
In 2019 the State Power Investment Corporation signed a co-operation agreement with the municipal government of the city of Baishan in the Jilin province, China, for the Baishan Nuclear Energy Heating Demonstration Project, with the aim of exploring the HAPPY200 SMR's ability, among other nuclear heating solutions, to meet local heating demand in the Jilin province.

Fuel

The HAPPY200 utilises fuel that is the current industry standard for water-cooled reactor technologies and therefore relies on well-established supply chains.

Stratek Global – HTMR-100





Reactor description: High temperature gas-cooled TRISO pebble bed reactor coupled with a steam turbine to produce electricity.

Thermal power (MWth)	100
Outlet temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO pebble
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of HTMR-100's progress to deployment

Licensing

The HTMR-100 SMR is based on the South African Pebble Bed Modular Reactor (PBMR) research initiative that has been in a state of "care and maintenance" since 2010. At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

At the time of assessment, no information about financing was readily available from verifiable public sources.

Supply chain

At the time of assessment, no information about supply chain readiness was readily available from verifiable public sources.

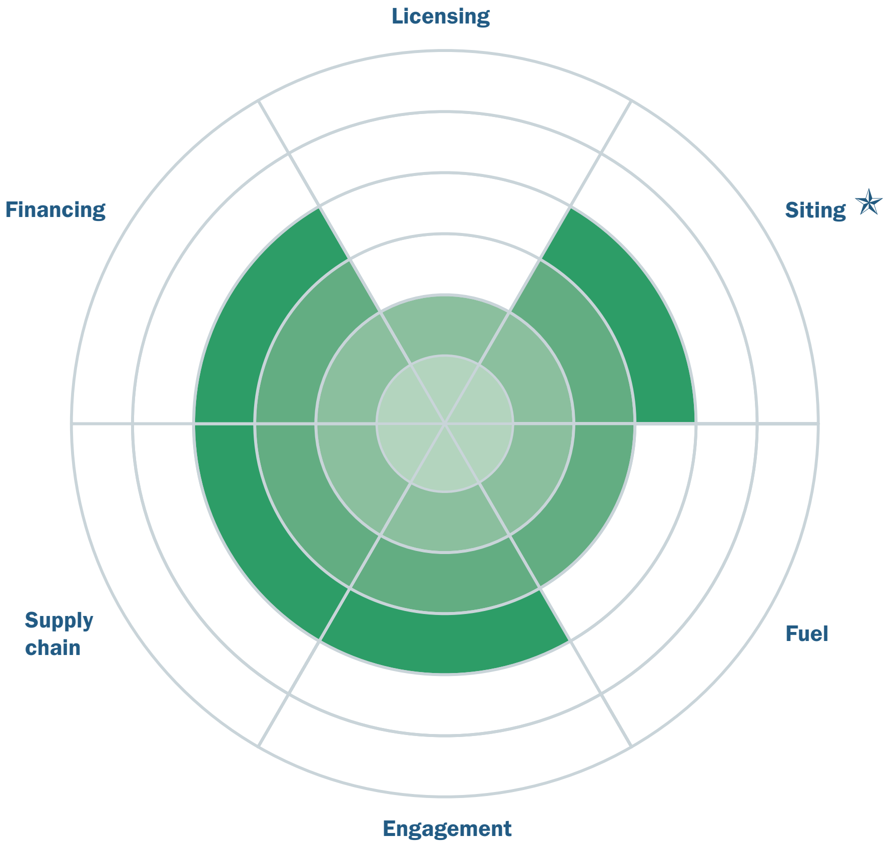
Engagement

Dr Kelvin Kemm, the Chair and CEO of Stratek Global, has taken steps to reach public audiences beyond the nuclear sector, for example through contributions to the ESI Africa, an African industrial journal, as well as an interview on the Tom Nelson Podcast, a platform focused on discussions about climate and energy.

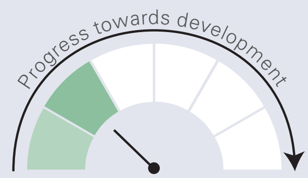
Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. In the 2000s, as part of the PBMR programme, TRISO particles were produced in South Africa and later sent to Idaho National Laboratory, United States, for irradiation tests. The South African Nuclear Energy Corporation (NECSA) has a TRISO pebble fuel manufacturing laboratory in Pretoria, South Africa, which has been in care and maintenance since 2010. In 2017, NECSA announced that it is working to restart this facility. At the time of assessment, no additional information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

TerraPower – Natrium Reactor Plant



Licensing



Siting ✯

Financing

Supply chain

Engagement Δ

Fuel

✯ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: Sodium fast reactor coupled with a molten salt energy storage system designed to provide dispatchable power.

Thermal power (MWth)	840
Outlet temperature (°C)	500
Spectrum (thermal/fast)	Fast
Fuel type	Metallic U-Zr alloy
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of Natrium's progress to deployment

Licensing

The Natrium Reactor Plant is undergoing pre-licensing activities with the US Nuclear Regulatory Commission. Several white papers and topical reports that support TerraPower's SMR safety case have already received regulatory feedback.

Siting ☆

PacifiCorp has selected the Natrium Reactor Plant to replace the retiring coal-fired Naughton Power Plant in Kemmerer, Wyoming. PacifiCorp has also launched feasibility studies to potentially deploy up to five additional Natrium Reactor Plants at multiple sites in its service territory by 2035. In August 2023, TerraPower announced it purchased the land in Kemmerer where the Natrium Reactor Plant demonstration project is planned. TerraPower 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 Reactor Plant 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 raised over USD 830 million in additional funding for the Natrium Reactor Plant through one of the largest private capital raises in the advanced nuclear industry.

Supply chain

TerraPower has partnerships with engineering, procurement and construction companies such as Bechtel, academia including North Carolina State, Oregon State and the University of Wisconsin, as well as Idaho and Argonne National Laboratories. In 2023, TerraPower signed a partnership agreement with Energy Northwest, a collaboration agreement with SK and KHNP, and selected Western Service Corporation (WSC), James Fisher Technologies, BWXT Canada, and Curtiss-Wright Flow Control Service for engineering services for its demonstration project in Kemmerer. In 2023, TerraPower expanded its Memoranda of Understanding with the Japan Atomic Energy Agency, Mitsubishi Heavy Industries and Mitsubishi fast breeder reactor (FBR) Systems, and South Korea SK Group.

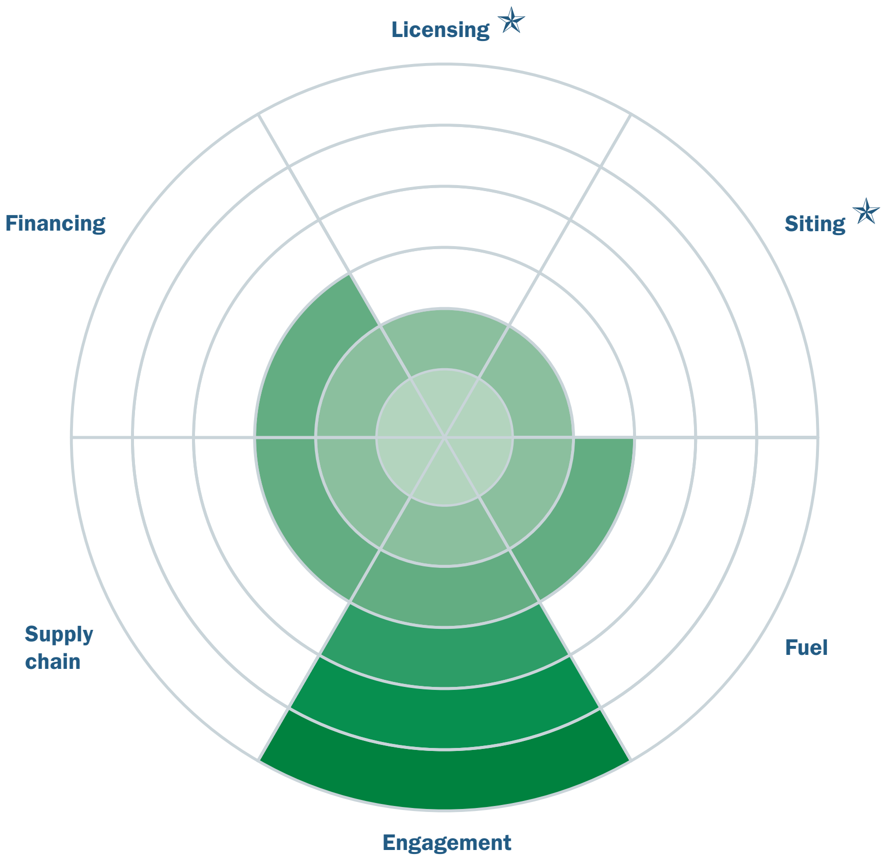
Engagement

TerraPower has formed an advisory board comprising representatives from around ten US utilities. 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, and advance engagement activities with local populations in Kemmerer, including through public webinars and town hall meetings.

Fuel

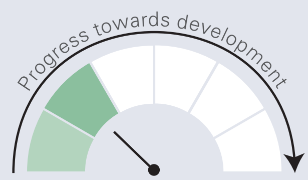
HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. Global Nuclear Fuel-Americas (GNF-A), a GE-led joint venture, and TerraPower have announced a binding agreement to build a fuel fabrication facility at the site of GNF-A's existing plant near Wilmington, North Carolina. In July 2023, TerraPower signed a Memorandum of Understanding with Centrus Energy to work towards securing HALEU supply for the Natrium Reactor Plant demonstration to meet the project's 2030 operation date.

Terrestrial Energy – Integral Molten Salt Reactor (IMSR)



Licensing ✯

Siting ✯



Financing

Supply chain

Engagement

Fuel Δ

✯ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: Fluoride molten salt fuelled, graphite moderated reactor using low enriched uranium.

Thermal power (MWth)	884
Outlet temperature (°C)	700
Spectrum (thermal/fast)	Thermal
Fuel type	Molten salt
Fuel (LEU/HALEU/HEU)	LEU

Assessment of IMSR's progress to deployment

Licensing ✯

Terrestrial Energy (TE) has completed Phase 2 of the Canadian Nuclear Safety Commission (CSNC) Vendor Design Review (VDR) pre-licensing process for its Integral Molten Salt Reactor (IMSR) and is also engaged in pre-application activities with the US Nuclear Regulatory Commission (NRC). The CNSC and NRC are collaboratively reviewing the IMSR technology and aim to issue a common report providing feedback on the IMSR design. In its VDR report of the IMSR the CNSC did not identify any fundamental barriers to licensing.

Siting ✯

TE 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 to be operated by Canadian Nuclear Laboratories (CNL). The IMSR completed the prequalification phase in 2019, which is the first of four stages that could eventually result in the technology being selected for deployment at a CNL-operated facility. In 2018, TE signed a Memorandum of Understanding (MoU) with US utility Energy Northwest to explore the possible siting, construction and operation of an IMSR at an Idaho National Laboratory site.

Financing

TE has raised more than USD 35 million in public and private sector financing in support of commercialising the IMSR. This includes more than CAD 15 million (USD 11.5 million) in Series A financing, support from the US federal government for advancing R&D and pre-licensing activities with the NRC, and CAD 25.7 million (USD 19.7 million) in Canadian federal funding through Sustainable Development Technology Canada and Canada's Strategic Innovation Fund.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, CAD 1.302 equals USD 1.000.

Supply chain

TE has contracts with Aecon Group to confirm construction costs and timelines, Hatch for engineering, procurement, and project management, and Siemens Energy Canada to supply steam turbines and other equipment. TE also has contracts with BWXT, L3Harris Technologies, and KSB Pumps, as well as an MoU with Energy Northwest. R&D is being advanced with universities, CNL, Oak Ridge National Laboratory, and the Nuclear Research and Consultancy Group in the Netherlands. TE has received three vouchers under the US Gateway for Accelerated Innovation in Nuclear initiative. Frazer-Nash, an engineering consultancy in the United Kingdom, has been contracted for graphite moderator fabrication engineering services.

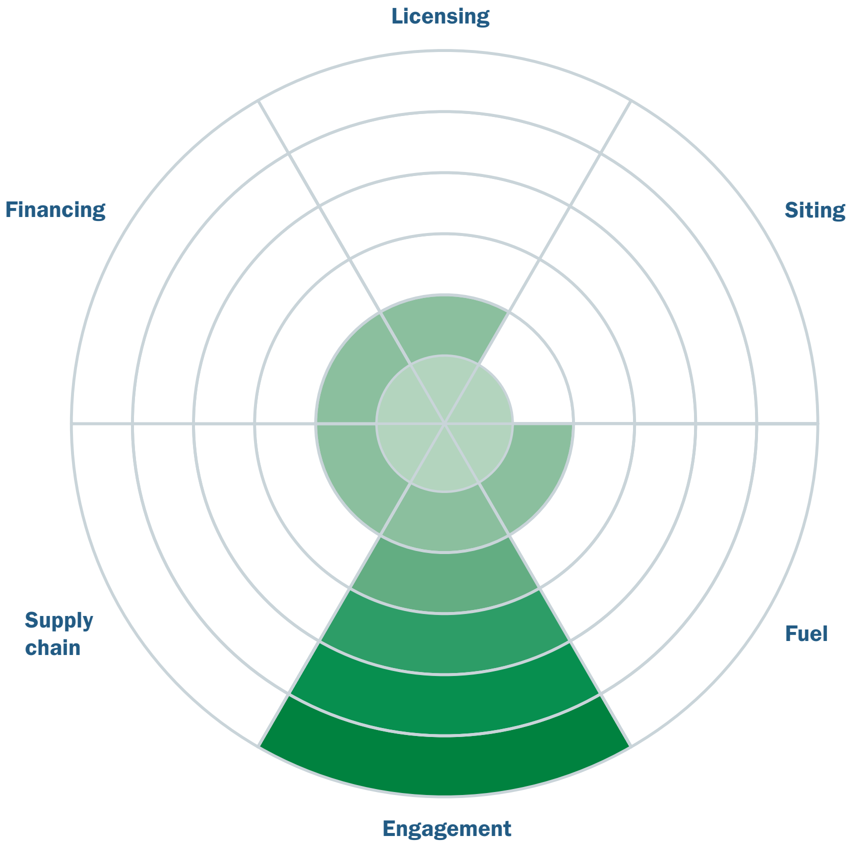
Engagement

TE has signed a Letter of Intent with NGO TerraPraxis and joined the Fuel Cell & Hydrogen Energy Association. TE is a member of the First Nations Power Authority and has signed an MoU with Invest Alberta, Canada. TE's advisors include a former Canadian Prime Minister, a former US Secretary of Energy, a former UK Climate Change Minister, a former TVA COO, a former Lockheed Martin CTO of, a former BP CEO, a former CNSC President, a former NRC Commissioner, the Climate Change Capital founder, the Bright New World Executive Director, and a former Head of Risk at Goldman Sachs. The TE President has advanced public outreach since 2017 through such media as the New York Times, Mother Jones, The Globe and Mail, the Canadian Broadcasting Corporation, and the Edmonton Journal.

Fuel

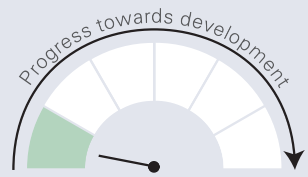
TE plans to use low-enriched uranium in molten salt in a once-through fuel cycle. The concept is based on the Molten Salt Reactor Experiment, which operated at Oak Ridge National Laboratory in 1965-1969. TE is advancing research to develop molten salt for the IMSR, including with ENGIE Laborelec, Belgium, Canadian Nuclear Laboratories, the Joint Research Centre, Germany, and Argonne National Laboratory, United States. TE has been working to transition from laboratory to commercial scale, including through contracts with Orano and MoUs with Centrus Energy and Cameco for fuel and uranium supply, respectively. In 2023, TE also signed a contract with Springfields Fuels Limited, a subsidiary of Westinghouse, to design and construct a pilot fuel plant for the IMSR in the United Kingdom.

ThorCon International – ThorCon 500

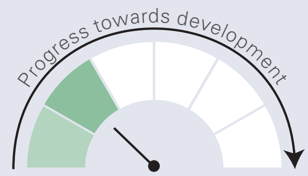


Licensing

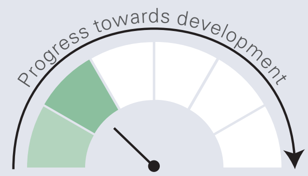
Siting



Financing

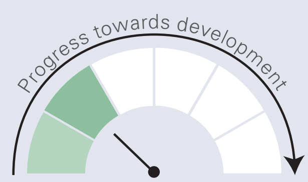


Supply chain



Engagement Δ

Fuel



Δ Indicates change since 2023.

Reactor description: Molten salt reactor on a floating hull, designed for two power modules, ballasted to the seabed or shore.

Thermal power (MWth)	1 100 (plant deployed with two modules of 557 MWth)
Outlet temperature (°C)	704
Spectrum (thermal/fast)	Thermal
Fuel type	Molten salt
Fuel (LEU/HALEU/HEU)	LEU

Assessment of ThorCon 500's progress to deployment

Licensing

In March 2023, ThorCon submitted a consultation paper for its ThorCon 500 to the Badan Pengawas Tenaga Nuklir (Indonesian Nuclear Energy Regulatory Agency, or BAPETEN), to initiate the pre-licensing process in Indonesia.

Siting

ThorCon has reported their interest to demonstrate and site ThorCon's ThorCon 500 on Gelasa (Kelasa) Island in Bangka Belitung (Babel) Islands Province. At the time of assessment, no information related to siting was readily available from any site owners.

Financing

ThorCon has created a Singapore-based special purpose company, supported by private investors, for the purpose of financing the ThorCon 500 project in Indonesia. ThorCon has prepared an investment fund of RP 17 trillion (USD 1.14 billion) for the construction of the ThorCon 500 on Gelasa Island. ThorCon has indicated that the funds will not be dispersed until the project is approved.

Supply chain

In 2017, ThorCon began feasibility studies with the Indonesia Thorium Consortium of state-owned companies in Indonesia. ThorCon is also collaborating with partners, including Badan Riset dan Inovasi Nasional, Universitas Sebelas Maret (UNS), Universitas Bangka Belitung (UBB), Institut Teknologi Bandung (ITB), and University of California Berkeley on R&D. In 2019, ThorCon signed Memorandum of Understandings (MoUs) with Daewoo Shipyard & Marine Engineering in South Korea and PT PAL Indonesia. In 2022, ThorCon signed collaboration agreements with the Spanish firm Empresarios Agrupados and with the Universitas Gadjah Mada for safety assessments of the ThorCon 500 design. ThorCon has also signed an agreement with Bureau Veritas, a conformity assessment body, to work on project certifications.

Engagement

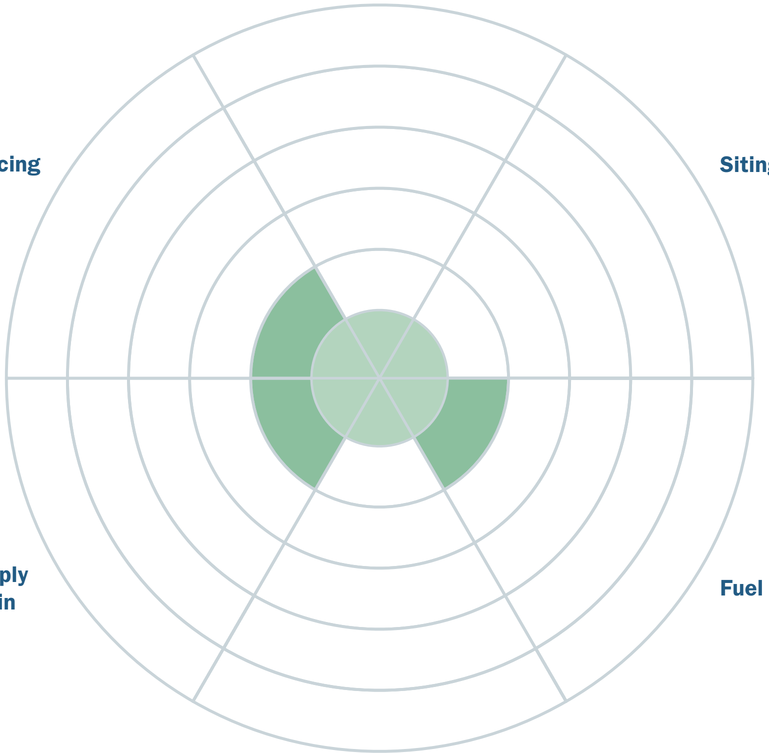
In the fall of 2023, engaging at the national level, ThorCon presented its latest progress and met with the National Energy Council of the Republic of Indonesia. At the local level, ThorCon participated in two meetings organised by BAPETEN. ThorCon met with communities and representatives of the Central Bangka Regency, a province of the Bangka Belitung Islands. ThorCon also met with the acting governor of the Bangka Belitung Islands. Under ThorCon's three MoUs with UNS, UBB, and ITB universities, it participates in research and education programmes on nuclear energy in Indonesia. In addition, ThorCon organised one seminar and one webinar to raise awareness of the impacts of the deployment of its ThorCon 500 SMR.

Fuel

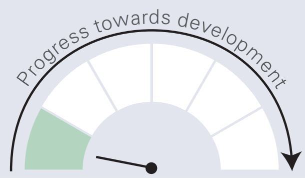
ThorCon intends to use low-enriched uranium (<5% LEU) as a source of fuel for its ThorCon 500 design. ThorCon has been awarded a voucher under the United States Department of Energy Gateway for Accelerated Innovation in Nuclear (GAIN) initiative in partnership with Argonne National Laboratory (ANL) to work on sodium fluoride and beryllium fluoride salt properties for liquid fuelled fluoride molten salt reactors. ThorCon is also advancing R&D activities with the ITB university on its molten salt fuel.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, RP 14 849.854 equals USD 1.000.

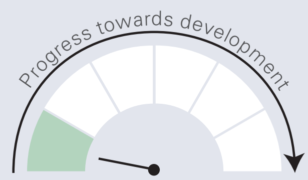
Thorizon – Thorizon One



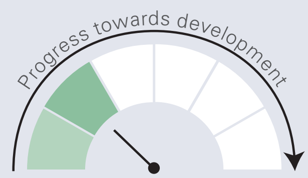
Licensing



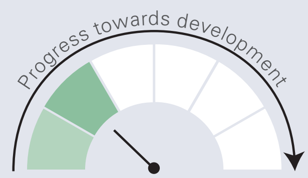
Siting



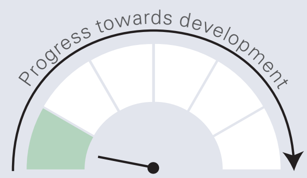
Financing



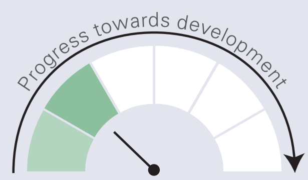
Supply chain



Engagement



Fuel



Reactor description: Cartridge core molten salt reactor using spent fuel and thorium with option for thermal or fast spectrum.

Thermal power (MWth)	250
Outlet temperature (°C)	550
Spectrum (thermal/fast)	Thermal or fast
Fuel type	Molten salt
Fuel (LEU/HALEU/HEU)	SNF and thorium

Assessment of Thorizon One's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

Thorizon announced it is working with EPZ, a Dutch nuclear power plant operator, to assess the feasibility of deploying a demonstration reactor at the Borssele nuclear plant site, in the province of Zeeland, Netherlands. At the time of assessment, no information related to siting was readily available from any site owners.

Financing

In August 2022, Thorizon raised EUR 12.5 million (USD 13.2 million) from private investors, including Positron Ventures and Huisman, and public investors, including Invest-NL, the Participation Fund Sustainable Economy North Holland (PDENH), and Impuls Zeeland, to perform essential tests and research to complete the design of a prototype.

Supply chain

Thorizon is part of a consortium with the Nuclear Research and Consultancy Group (NRG), Delft University of Technology, and the Dutch Institute for Fundamental Energy Research, that advances research and development activities on the molten salt reactor technology. Thorizon is also a member of the Nuclear Valley network, a group of more than 400 companies involved in the French nuclear supply chain.

Engagement

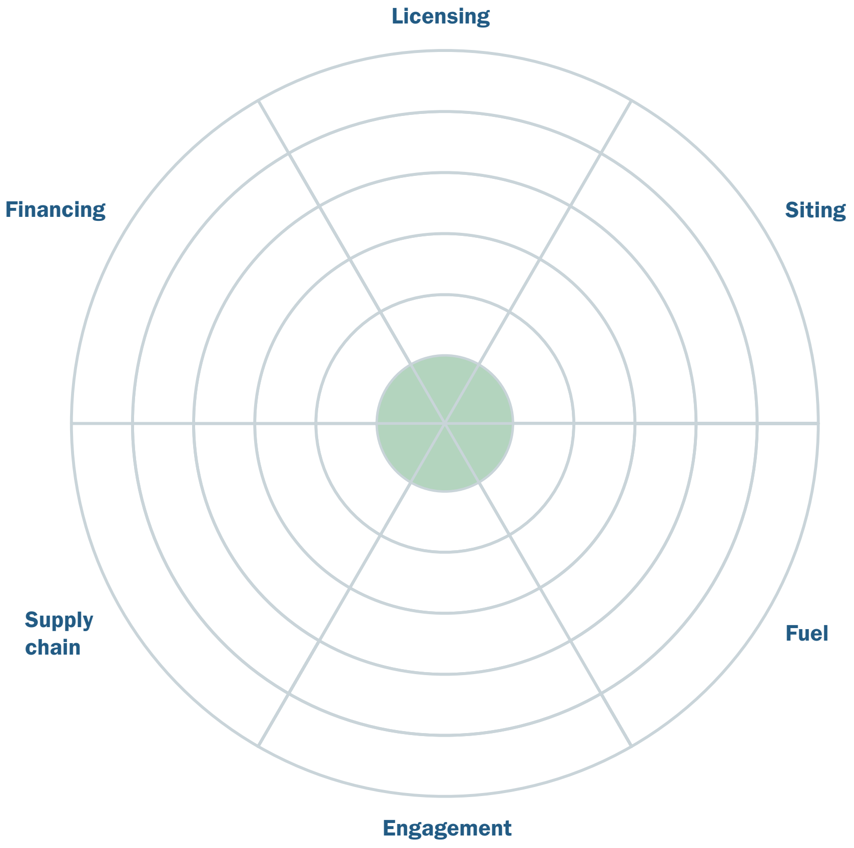
At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

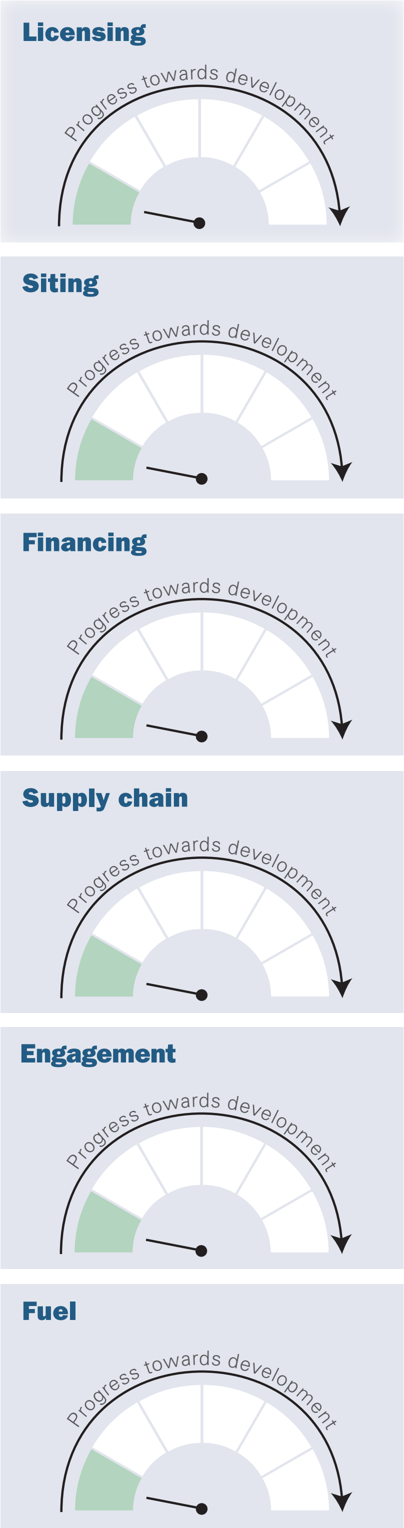
Fuel

Thorizon proposes to use a chloride molten fuel salt mixture of uranium, plutonium from spent nuclear fuel, and thorium. The molten salt fuel and the molten salt coolant are separated. The fuel is contained in cartridges. Several cartridges are inserted into the Thorizon SMR, which contains the molten salt coolant. Thorizon is a member of MIMOSA (MultI-recycling strategies of LWR SNF focusing on MOlten SAlt technology), a consortium of 14 parties with Orano, EDF, Delft University and NRG. MIMOSA has a budget of EUR 5.75 million (USD 6.05 million) from the Euratom HORIZON fund to work on multi-recycling of spent nuclear fuel from light water reactors.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, EUR 0.95 equals USD 1.000.

Toshiba Energy Systems & Solutions Corporation – MoveluX





Reactor description: Heat-pipe-cooled calcium-hydride moderated microreactor.

Thermal power (MWth)	10
Outlet temperature (°C)	680
Spectrum (thermal/fast)	Thermal
Fuel type	Uranium silicide
Fuel (LEU/HALEU/HEU)	LEU

Assessment of MoveluX's progress to deployment

Licensing

The MoveluX is in the conceptual design phase. At the time of assessment, there was no information readily available from verifiable public sources related to licensing and pre-licensing activities.

Siting

At the time of assessment, no information related to siting was readily available from any site owners.

Financing

At the time of assessment, no information about financing was readily available from verifiable public sources.

Supply chain

At the time of assessment, no information about supply chain readiness was readily available from verifiable public sources.

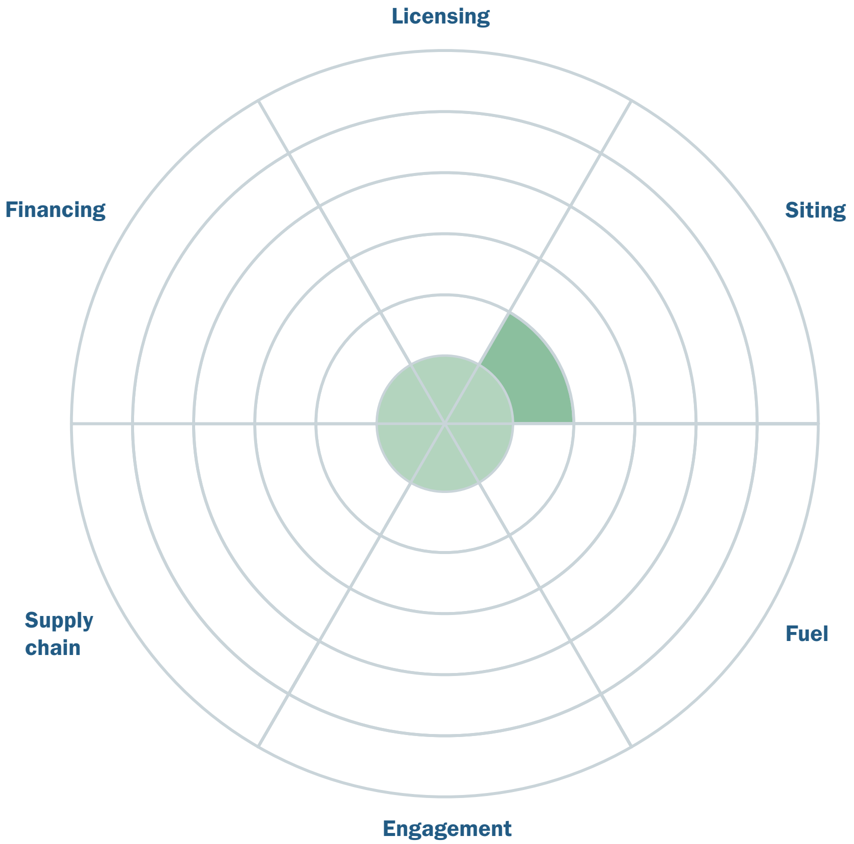
Engagement

At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

The MoveluX proposes to use a hexagonal uranium silicide (U_3Si_2) fuel assembly with a uranium enrichment of less than 5%. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

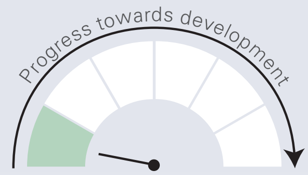
Toshiba Energy Systems & Solutions Corporation – 4S



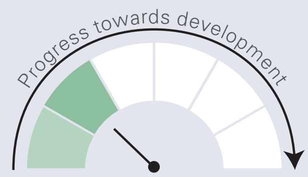
Reactor description: Sodium-cooled fast reactor intended for remote areas.

Thermal power (MWth)	30 and 135
Outlet temperature (°C)	510
Spectrum (thermal/fast)	Fast
Fuel type	Metallic U-Zr alloy
Fuel (LEU/HALEU/HEU)	HALEU

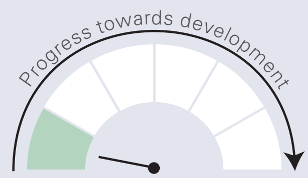
Licensing



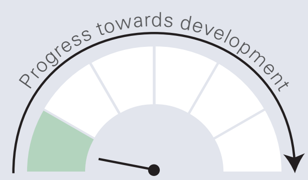
Siting



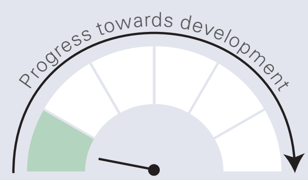
Financing



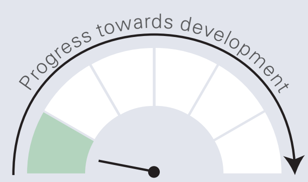
Supply chain



Engagement



Fuel



Assessment of 4S's progress to deployment

Licensing

The 4S reactor has two options: 30 MWth and 135 MWth. Toshiba had engaged with the US Nuclear Regulatory Commission (NRC) for the 30 MWth 4S reactor. In 2007 Toshiba first began engagement with the US NRC through a pre-application review for design approval of the 4S. In 2012, Toshiba submitted Technical Reports to the NRC related to safety design criteria for the 4S to support this pre-application review. These materials have since been archived by the NRC. At the time of assessment, there was no additional information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

In 2007, the Alaska Electric Light and Power Company and the City of Nome both wrote to the NRC indicating their interest in the 4S SMR for replacing diesel generators in remote areas of Alaska.

Financing

At the time of assessment, no information about financing was readily available from verifiable public sources.

Supply chain

At the time of assessment, no information about supply chain readiness was readily available from verifiable public sources.

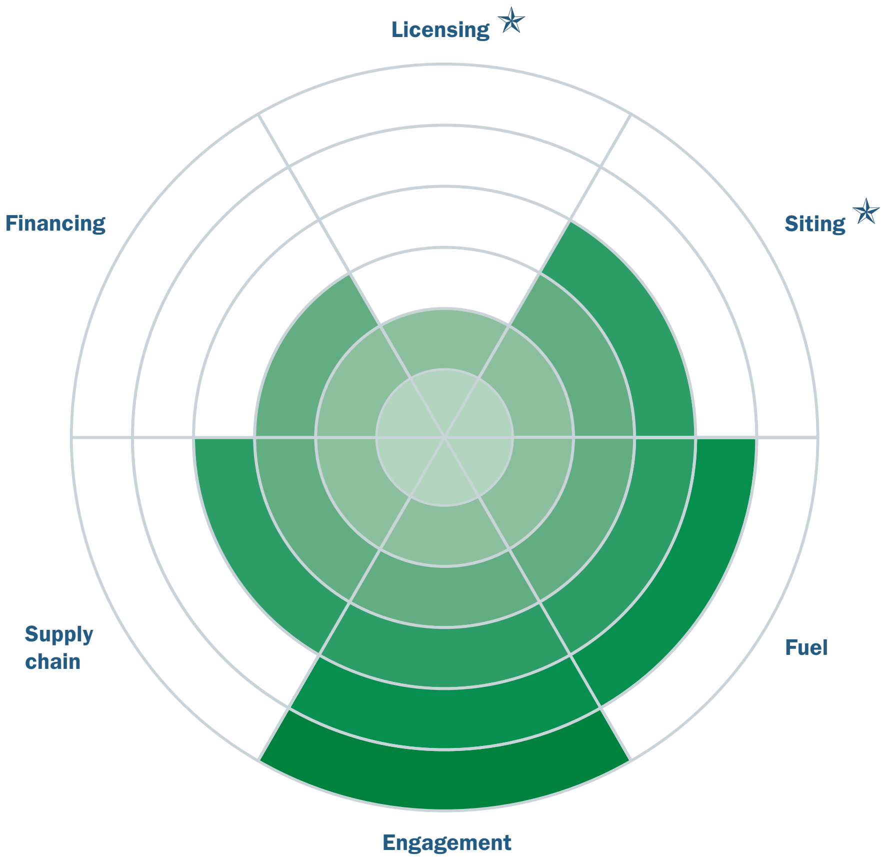
Engagement

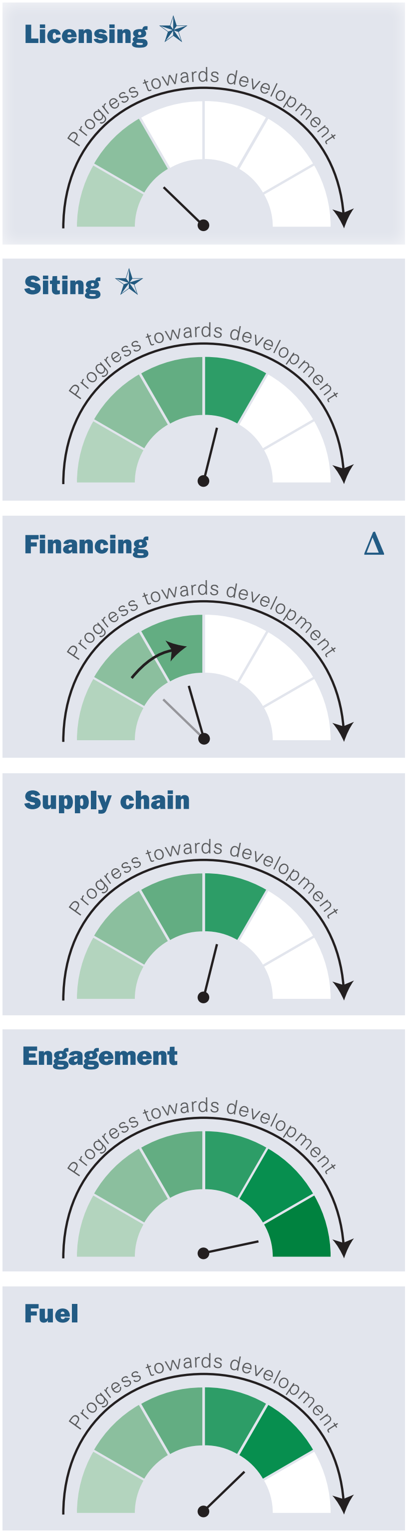
At the time of assessment, no recent information was readily available from verifiable public sources related to engagement activities.

Fuel

The 4S proposes to use HALEU fuel. HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. At the time of assessment, no information was readily available from verifiable public sources to assess progress towards the commercial supply of qualified fuel.

Ultra Safe Nuclear Corporation (USNC) – Micro-Modular Reactor (MMR)





★ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: High-temperature gas-cooled reactor using TRISO fabricated into fully ceramic microencapsulated fuel pellets.

Thermal power (MWth)	10 to 50
Outlet temperature (°C)	660
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of MMR's progress to deployment

Licensing ✯

In Canada, USNC has completed Phase 1 of the Canadian Safety Nuclear Commission's (CNSC) Pre-Licensing Vendor Design Review process, and the Phase 2 assessment is underway. Global First Power (GFP), a joint venture between USNC and Ontario Power Generation (OPG), has submitted an application to CNSC for a licence 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 and submitted a regulatory engagement plan and topical reports to the US Nuclear Regulatory Commission (NRC). In the United Kingdom, under the Advanced Modular Reactor Research, Development and Demonstration (AMR RD&D) Programme Phase B, USNC will have regulatory sessions with the Office for Nuclear Regulation.

Siting ✯

In Canada, Canadian Nuclear Laboratories has signed a project host agreement with GFP and selected a site at Chalk River Laboratories to deploy the USNC MMR. GFP and USNC are working 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 to construct the MMR at the University of Illinois Urbana-Champaign (UIUC). USNC has signed an agreement with Manila Electric Company for the potential deployment of the MMR in the Philippines and is working with Polish chemicals producer Grupa Azoty Police and the West Pomeranian University of Technology to build a research facility in Poland based on the MMR.

Financing

In the United Kingdom, USNC received a GBP 22.5 million (USD 27.7 million) grant, and a financial award, from the UK government through the UK AMR RD&D Programme. In Canada, Portland Holdings, a private investment firm, signed a Memorandum of Understanding (MoU) to invest up to USD 350 million in USNC to expand the deployment of the MMR in the Middle East, North Africa and the Caribbean regions. The MMR at Chalk River in Canada is pursuing deployment through a joint venture owned equally by USNC and OPG, where OPG is a provincial Crown corporation supported and wholly owned by the government of Ontario. USNC has also attracted investment from Hyundai Engineering, who agreed to invest in USNC for certain rights to engineering, procurement and construction business related to the MMR.

Supply chain

Hyundai Engineering has an equity investment in USNC, and is the preferred engineering, procurement and construction company for the MMR. USNC has secured contracts for specific services and materials in support of the MMR demonstration projects and has selected Jacobs to support front-end engineering design in the United Kingdom. In the United States, USNC selected a site for a manufacturing and testing plant for non-radiological modules for the MMR. Through a joint venture with Ontario Power Generation, GFP will own and operate the MMR at the Chalk River Laboratories site in Canada. USNC is also progressing advanced manufacturing techniques, exploring hydrogen production technologies, and working with a polish chemical company to develop a training and research facility based on the MMR.

Engagement

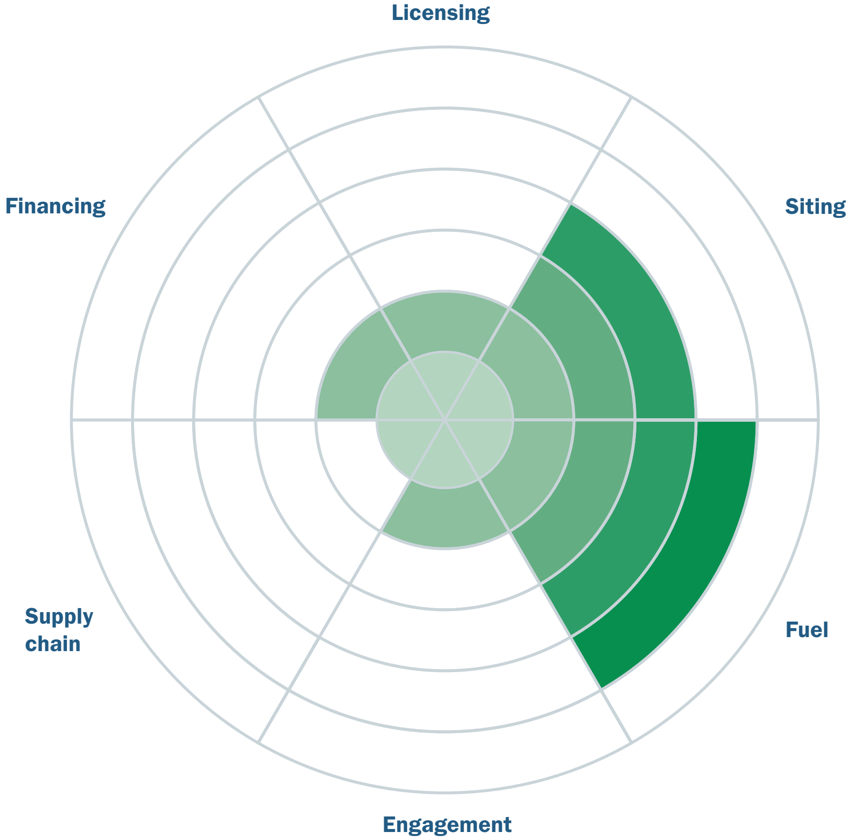
GFP has engaged the public about the MMR in Canada through town halls, open houses, webinars, and testimony before the House of Commons. Regarding the MMR project at UIUC in the United States, professors and students have discussed the MMR project on local news outlets, radio stations, podcasts, and through monthly public meetings. The Illinois Institute for Sustainability, Energy, & Environment also held a community event in 2020 where they discussed the opportunity for the MMR to support campus carbon neutrality. Throughout 2022 and 2023, USNC has been engaging the Alaska State Legislature Senate Community and Regional Affairs Standing Committee, provided public project updates, and held multiple engagement sessions on the potential use of microreactors in Alaska.

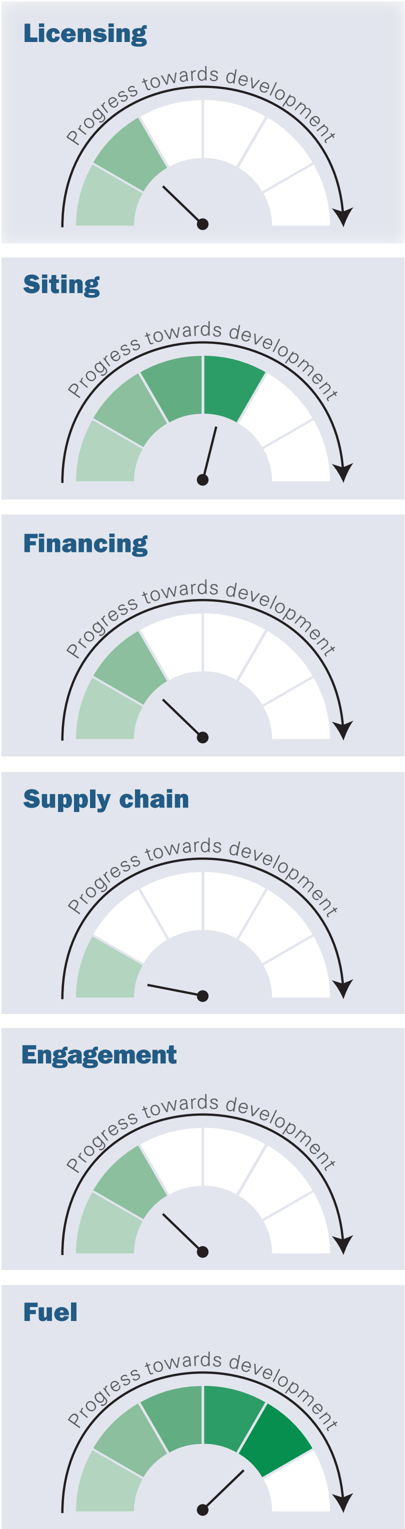
Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. UIUC announced that it will source fuel from the US Research Reactor Infrastructure Program. In 2023, USNC signed an agreement with Urenco for supply of enriched uranium, with the first batch slated for delivery in 2025. USNC plans to manufacture the fuel for the MMR. USNC's Pilot Fuel Manufacturing facility in Oak Ridge will produce fuel for testing and qualification and has supplied TRISO to NASA in 2023. Through a joint venture with Framatome, USNC intends to build a factory to scale up TRISO fuel fabrication commercially starting in 2025.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, GBP 0.811 equals USD 1.000.

Ultra Safe Nuclear Corporation (USNC) – Pylon D1





Reactor description: Transportable high-temperature gas-cooled reactor for off-grid applications and space.

Thermal power (MWth)	1
Outlet temperature (°C)	727
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO prismatic
Fuel (LEU/HALEU/HEU)	HALEU

Assessment of Pylon D1's progress to deployment

Licensing

The National Reactor Innovation Center (NRIC), a US Department of Energy (DOE) programme led by Idaho National Laboratory (INL), has selected Ultra Safe Nuclear Corporation (USNC) as a partner to begin a Front-End Engineering and Experiment Design (FEEED) study, which will include the preparation of safety documents and NEPA-compliance documentation for the Pylon D1 SMR. NRIC has been supporting regulatory engagement activities with the NRC, the DOE, and reactor demonstrators including USNC to determine an appropriate regulatory strategy for the deployment and testing of microreactors, including the Pylon D1, at the Demonstration and Operation of Microreactor Experiments facility at INL.

Siting

NRIC has selected Pylon D1 to be demonstrated at one of the sites in INL's Demonstration and Operation of Microreactor Experiments (DOME) facility in Idaho, United States, where testing in DOME could start as early as 2026.

Financing

Through the NRIC FEEED process, USNC was awarded up to USD 1.5 million to progress towards to deployment of the Pylon D1 at the DOME facility. USNC has also received USD 5 million in funding from NASA to develop nuclear thermal propulsion systems.

Supply chain

Through the NRIC FEEED process, USNC will develop an experimental programme plan for the Pylon D1, Class 4 cost estimates, and the contract for the work to be performed at INL. At the time of assessment, no information about supply chain readiness was readily available from verifiable public sources.

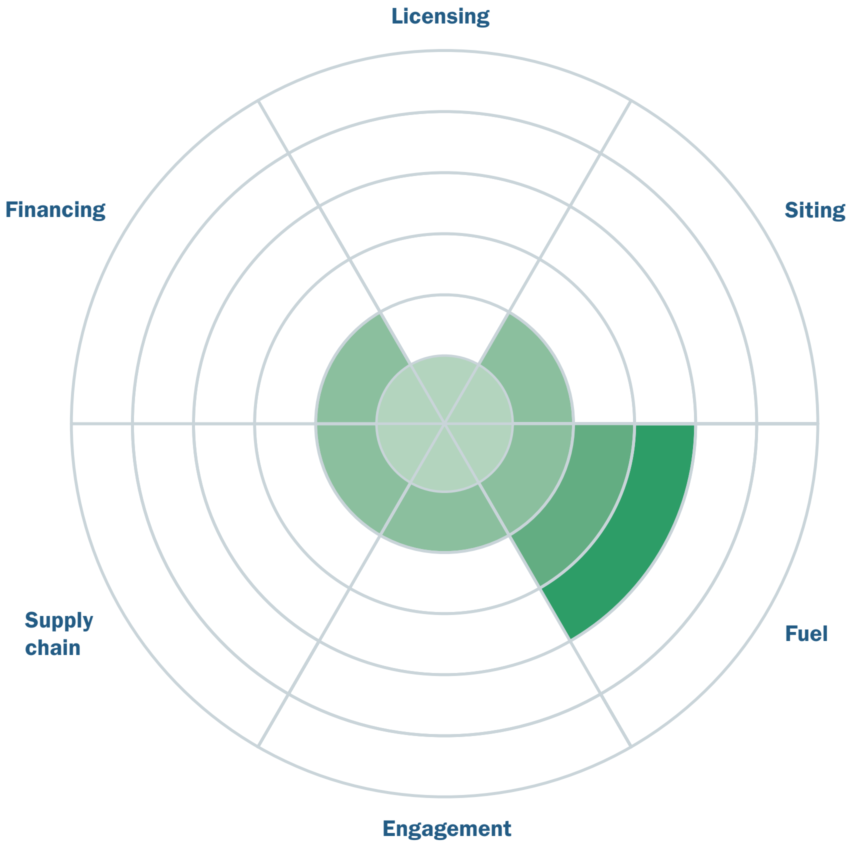
Engagement

The Pylon D1 concept was presented and discussed as part of the Space Technology Industry-Government-University Roundtable on 4 October 2023, which convened senior representatives to explore research issues and options for public-private partnerships for space technologies.

Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. In 2023, USNC signed an agreement with Urenco for supply of enriched uranium, with the first batch slated for delivery in 2025. USNC will manufacture all fuel for the Pylon D1 at its fuel manufacturing facilities. USNC's Pilot Fuel Manufacturing facility in Oak Ridge will produce fuel for testing and qualification, and has supplied TRISO to NASA in 2023. Through a joint venture with Framatome, USNC intends to build a factory to scale up TRISO fuel fabrication commercially starting in 2025.

UWB and CIIRC CTU (University of West Bohemia and Czech Technical University in Prague) – TEPLATOR

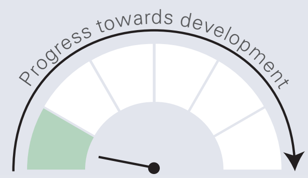


Δ Indicates change since 2023.

Reactor description: Low temperature, low pressure and low power density heavy water reactor for district heating.

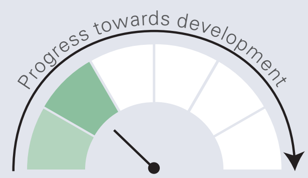
Thermal power (MWth)	170
Outlet temperature (°C)	180
Spectrum (thermal/fast)	Thermal
Fuel type	SNF assemblies from VVER, BWR or PWR reactors or natural uranium
Fuel (LEU/HALEU/HEU)	SNF or natural uranium

Licensing

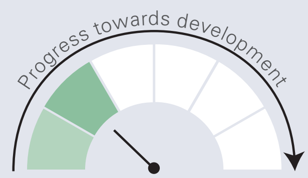


Siting Δ

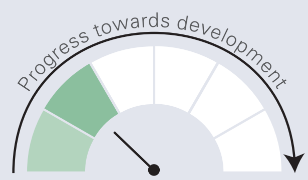
Financing



Supply chain



Engagement



Fuel

Assessment of TEPLATOR's progress to deployment

Licensing

At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting

In 2023, a tripartite agreement was signed between World ThermoExport, a company created in early 2023 to commercialise the TEPLATOR reactor, Teploatom Service LCC, the company that supports the development of TEPLATOR in Ukraine, and the Ukrainian city of Slavutych, to explore the possible deployment of a TEPLATOR reactor in Slavutych, in northern Ukraine.

Financing

Invest & Property Consulting (IPC), based in Czechia, is the primary investor in TEPLATOR.

Supply chain

The TEPLATOR is being advanced in a partnership with the Czech Technical University in Prague and the University of West Bohemia in Pilsen, Czechia.

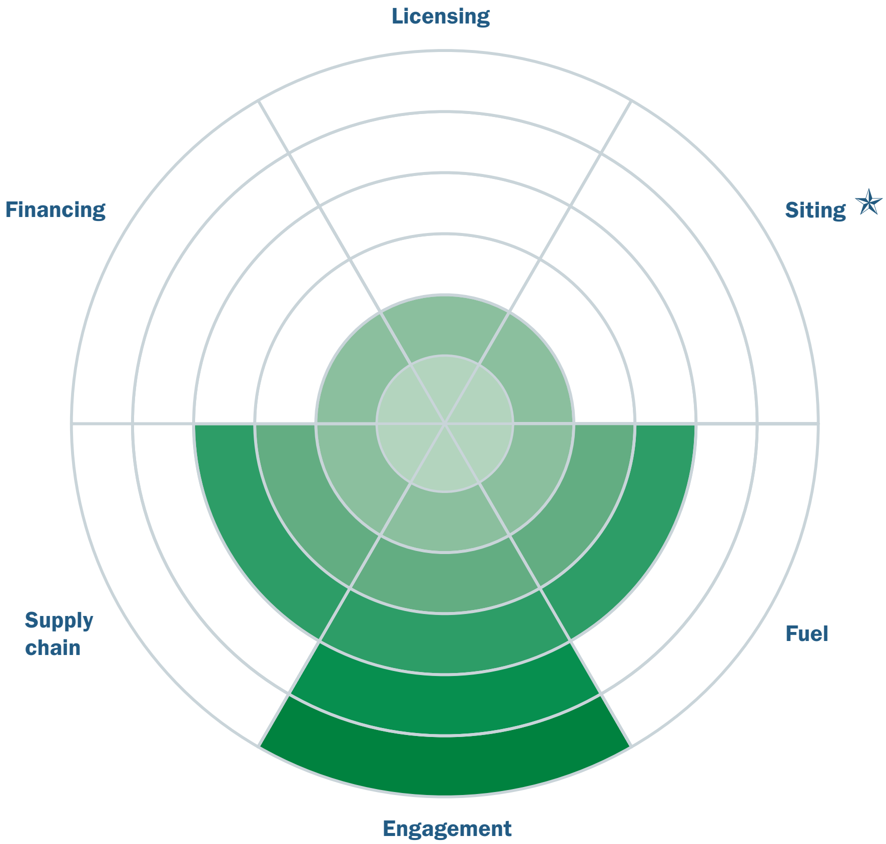
Engagement

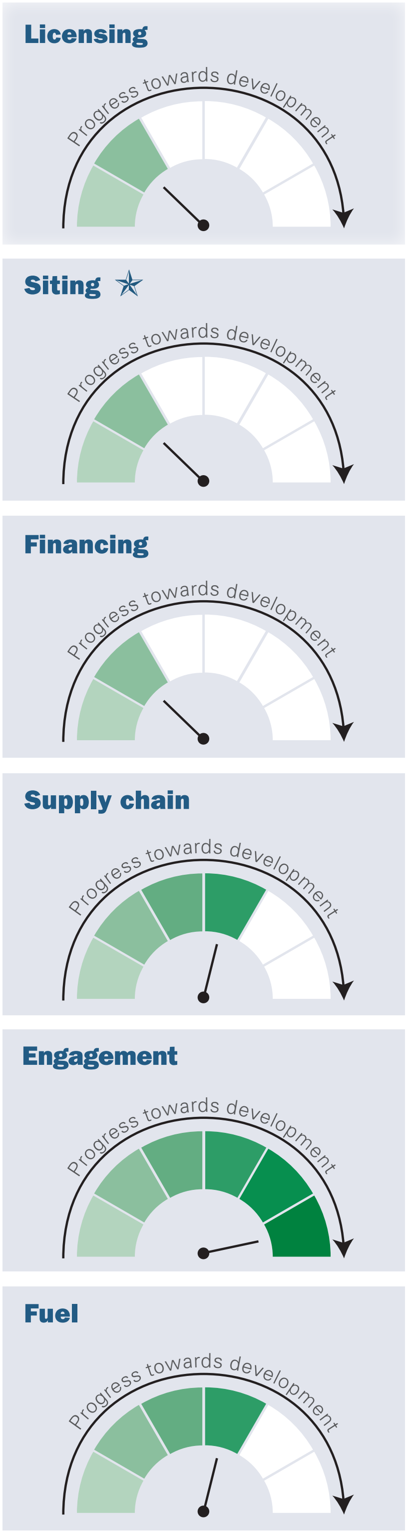
Development of the TEPLATOR design is taking place in partnership with the Czech Technical University in Prague and the University of West Bohemia in Pilsen, which creates opportunities for engagement with students. In September 2023, Teplatom LLC participated in the Spent Nuclear Fuel Management Workshop organised by the International Conference on Nuclear Decommissioning and Environmental Recovery in the Slavutych City Council meeting hall to present the TEPLATOR technology in the presence of the mayor of Slavutych.

Fuel

TEPLATOR proposes to use spent nuclear fuel assemblies from VVER, BWR or PWR reactors as fuel or natural uranium. While contracts have not been signed to procure the spent fuel assemblies, the current fleets of operating reactors could provide the supply of fuel required for the TEPLATOR.

Westinghouse Electric Company – AP300™ SMR





★ Active in multiple jurisdictions or countries.

Reactor description: One-loop pressurised light water reactor based on the proven AP1000 design.

Thermal power (MWth)	990
Outlet temperature (°C)	325
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

Assessment of AP300™ SMR's progress to deployment

Licensing

In May 2023, Westinghouse Electric Company (Westinghouse) submitted a Pre-Application Regulatory Engagement Plan to the US Nuclear Regulatory Commission (NRC) to prepare pre-licensing activities in the United States. This Regulatory Engagement Plan (REP) describes the anticipated pre-application interactions Westinghouse intends to have with the US NRC to support the future licensing of the AP300. In November 2023, the NRC hosted a meeting with public and private sessions where Westinghouse presented its AP300 design.

Siting ☆

Westinghouse signed a memorandum of co-operation with CEZ to evaluate the feasibility of deploying the AP300 SMR at the ČEZ-owned nuclear power plant site in Temelin, Czechia. In October 2023, Great British Nuclear selected the AP300 SMR along with five other SMRs to progress to the next phase of the United Kingdom's innovative nuclear technology competition for potential deployment in the United Kingdom.

Financing

The AP300 SMR is based on the licensed AP1000 pressurised light water technology. Past US DOE funding for the AP1000 programme contributed to the development of the advanced passive safety technology used in the AP300 SMR.

Supply chain

Westinghouse proposes to use identical components to the AP1000, currently deployed and operating in China and the United States, including major equipment, structural elements, safety systems and fuel. The new AP300 system is expected to benefit from the existing and future supply chain capabilities of the AP1000. In 2023, Westinghouse continued to develop its supply chain capabilities for the AP1000 by hosting supplier symposiums in Canada and Czechia and signing Memorandum of Understandings (MoUs) with several industrial companies in Poland and Bulgaria.

Engagement

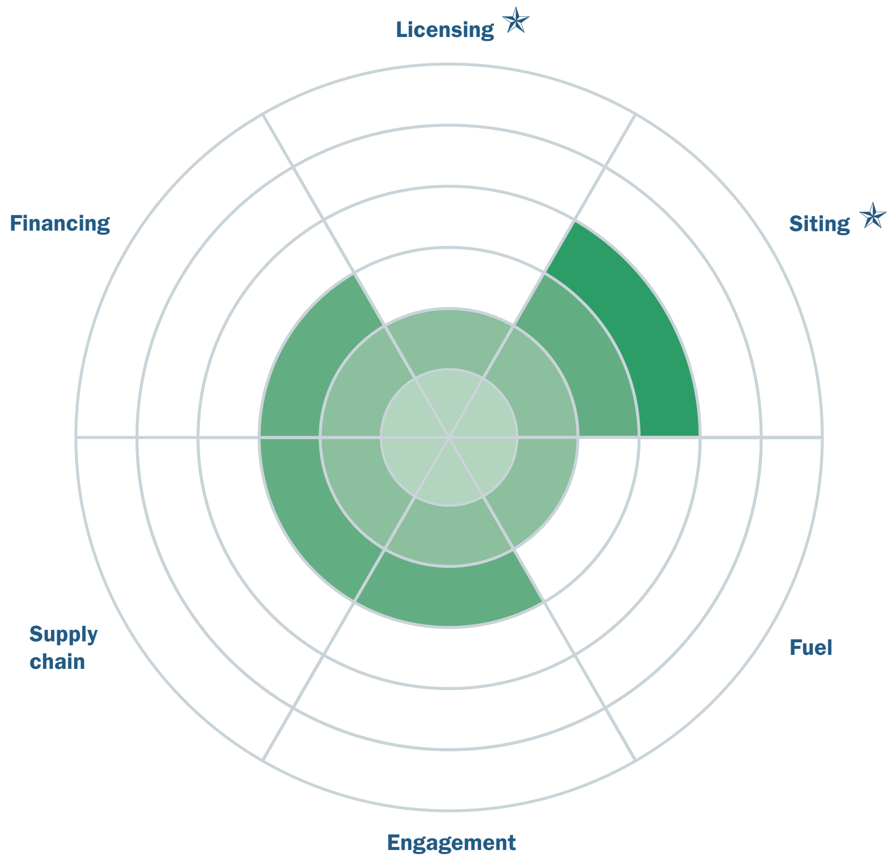
In 2023, Westinghouse engaged community organisations and students, meeting with elected officials, professors and students in Australia, hosting an industry night at the University of Waterloo in Canada, and discussing nuclear energy, including the AP300, with the League of Women Voters of New Mexico, United States. Westinghouse also advances customer engagement through: an MoU with Fortum to explore plans in Finland and Sweden; an MoU with JAVYS in the Slovak Republic; and with Energoatom in Ukraine. Senior executives from Westinghouse have also participated in outreach and engagement activities about the AP300, including presentations to US elected officials, media interviews, YouTube videos, and podcasts for public audiences as well as potential customers for non-electric applications.

Fuel

The AP300 reactor uses proven light water reactor fuel. In July 2023, Westinghouse was awarded GBP 10.5 million (USD 12.9 million) in grants from the UK government's Nuclear Fuel Fund to expand Westinghouse's Springfield fuel fabrication facility in Lancashire, United Kingdom. Part of the funds will be allocated to develop fuel for the AP300 as well as potential production of HALEU. Westinghouse has additional fabrication capabilities in Columbia, South Carolina (United States) and in Vasteras, Sweden.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, GBP 0.811 equals USD 1.000.

Westinghouse Electric Company – eVinci microreactor

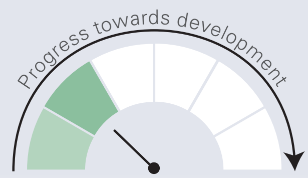


★ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: High temperature sodium heat pipe microreactor using TRISO fuel with a minimum eight-year refuelling period.	
Thermal power (MWth)	15
Outlet temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO
Fuel (LEU/HALEU/HEU)	HALEU

Licensing ★



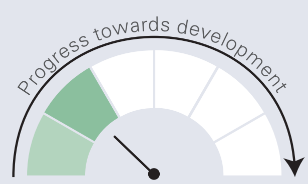
Siting ★ Δ

Financing

Supply chain Δ

Engagement

Fuel



Assessment of eVinci's progress to deployment

Licensing ★

Westinghouse Electric Company (WEC) has applied simultaneously for Phase 1 and 2 of the Canadian Nuclear Safety Commission's (CNSC) Vendor Design Review pre-licencing process for the eVinci microreactor. WEC is also engaged in pre-licensing activities with the US Nuclear Regulatory Commission (NRC) and has submitted various topical reports and white papers in support of the eVinci microreactor. In February 2023, WEC filed a Notice of Intent to submit licensing documentation to both the NRC and CNSC for a joint review of the eVinci microreactor.

Siting ★

National Reactor Innovation Center (NRIC), a US Department of Energy (DOE) programme led by Idaho National Laboratory (INL), has selected the eVinci microreactor to be demonstrated at one of the sites in INL's Demonstration and Operation of Microreactor Experiments (DOME) facility in Idaho, United States, where testing in DOME could start as early as 2026. WEC is also working with the Saskatchewan Research Council to develop a project to deploy the eVinci microreactor in Saskatchewan, Canada, where it would provide heat and power and support the testing of industrial, research and energy use applications. In May 2022, WEC signed a Memorandum of Understanding (MoU) with Pennsylvania State University (PSU) for discussions about possible deployment at PSU's University Park campus.

Financing

WEC has received funding from the US Industry Opportunities for Advanced Nuclear Technology Development programme, Advanced Research Project Agency – Energy (ARPA-E), Advanced Research Development Program (ARDP) Energy Risk Reduction project, and the Modeling Enhanced Innovations Trailblazing Nuclear Energy Reinvigoration programme. WEC was awarded up to USD 1.5 million from NRIC to progress towards deployment of the eVinci microreactor at the DOME facility. For the scaled-down space version of the eVinci microreactor, WEC received funding of almost USD 17 million under the Space Force JETSON project and USD 5 million from INL for the NASA Artemis programme. In Canada, WEC received an investment through the Government of Canada's Strategic Innovation Fund.

Supply chain

In 2023, WEC announced its investment of at least USD 18 million for an eVinci microreactor accelerator hub for engineering, licensing, operations, testing and prototype trials in Etna, Pennsylvania (United States). WEC hosted a Canadian Supplier Symposium in July 2023. WEC has manufactured heat pipes to support a nuclear test reactor and is advancing collaborations with INL, Penn State University, McMaster University, Southern Company Services, and others in Canada related to the commercialisation of the eVinci microreactor, including Canadian Nuclear Laboratories, Hatch and Prodigy Clean Energy. WEC has also signed an MoU with Astrobotic to develop a scaled-down space version of the eVinci microreactor and strengthen the workforce in the United States.

Engagement

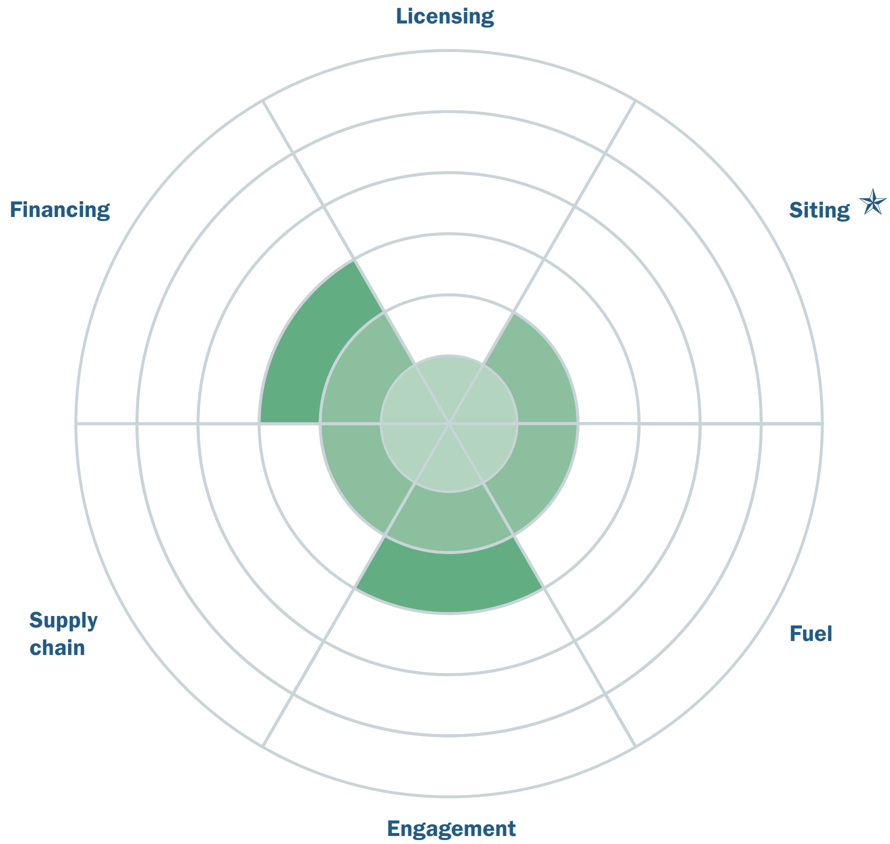
WEC is engaged with research institutions, industry and potential end-users of the eVinci microreactor through the Post-Industrial Midwest and Appalachia Nuclear Alliance, which includes work to advance policy, community engagement and education on nuclear energy technologies. WEC signed an MoU with PSU 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 the eVinci microreactor in a safe and sustainable way. In 2020, WEC signed an MoU with Bruce Power to explore applications of eVinci microreactor in Canada. WEC's eVinci microreactor team is also engaged in Ontario Tech University's Women for STEM Scholarship programme to support women succeed in technical fields.

Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. Through the UK government's Nuclear Fuel Fund, WEC was awarded GBP 10.5 million (USD 12.9 million) in July 2023 to upgrade and expand the Springfields fuel fabrication facility to support the potential production of HALEU fuels. WEC is also collaborating with Urenco on a Pre-Front End Engineering Design study on TRISO fuel.

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, GBP 0.811 equals USD 1.000.

Westinghouse Electric Company – Westinghouse LFR



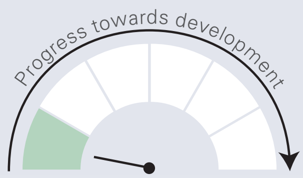
★ Active in multiple jurisdictions or countries.

Δ Indicates change since 2023.

Reactor description: Lead-cooled fast spectrum reactor using uranium oxide or mixed oxide fuel.

Thermal power (MWth)	950
Outlet temperature (°C)	530 (phase 1); 650 (phase 2)
Spectrum (thermal/fast)	Fast
Fuel type	UO_2 pellets or MOX, interchangeably, as near-term fuel; Uranium nitride (UN) pellets as longer-term advanced fuel
Fuel (LEU/HALEU/HEU)	HALEU for UO_2 pellets, otherwise plutonium-uranium oxide for MOX

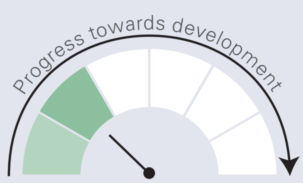
Licensing



Siting ★ Δ

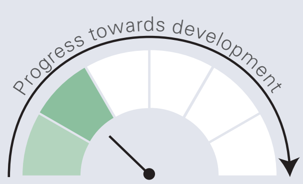
Financing

Supply chain



Engagement Δ

Fuel



Assessment of Westinghouse LFR's progress to deployment

Licensing

Westinghouse Electric Company (Westinghouse) has engaged in discussions with the United Kingdom's Office for Nuclear Regulation (ONR) and the UK Environment Agency (EA) about the Westinghouse LFR since 2018, as part of the UK government Advanced Modular Reactor (AMR) project. In support of the UK AMR project, the ONR completed a three-stage engagement process with Westinghouse to explore regulatory pathways for advanced nuclear technologies and build ONR capacities to license lead-cooled fast reactors, including the Westinghouse LFR. At the time of assessment, there was no information readily available from verifiable public sources related to licensing or pre-licensing activities.

Siting ☆

In November 2023, Westinghouse signed a Memorandum of Understanding (MoU) to work towards forming a consortium that would build a small-scale demonstration of the Westinghouse LFR in Mol, Belgium, followed by a full-scale version in Pitesti, Romania. There are five signatories to the MoU: Westinghouse; SCK CEN; RATEN; Ansaldo Nucleare; and l'Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (the Italian National Agency for New Technologies, Energy and Sustainable Economic Development, or ENEA).

Financing

In 2020, the Westinghouse LFR received GBP 10 million (USD 12.3 million) in public funding as it entered Phase 2 of the UK's government Advanced Modular Reactor programme. In addition, between 2017 and 2022, Westinghouse received a total of USD 1.225 million through four awards from the US Department of Energy Technology Commercialization Fund to advance critical modelling activities in partnership with Argonne National Laboratory (ANL).

Note: The currency exchange rate applied is the relevant average for the year 2022. In this case, GBP 0.811 equals USD 1.000.

Supply chain

Under the UK AMR Research, Development & Demonstration Programme, Westinghouse worked with engineering, procurement and construction companies including Ansaldo Nucleare. R&D was advanced with UK universities as well as national laboratories, including ENEA. Westinghouse has received two vouchers under the United States Department of Energy Gateway for Accelerated Innovation in Nuclear initiative for R&D at ANL and Oak Ridge National Laboratory. In 2022, Westinghouse and Ansaldo Nucleare signed a co-operation agreement on lead-cooled fast reactor development. In November 2023, Westinghouse signed an MoU with Ansaldo Nucleare, SCK CEN, RATEN and ENEA to accelerate development of lead-cooled fast reactor based on the Westinghouse LFR design.

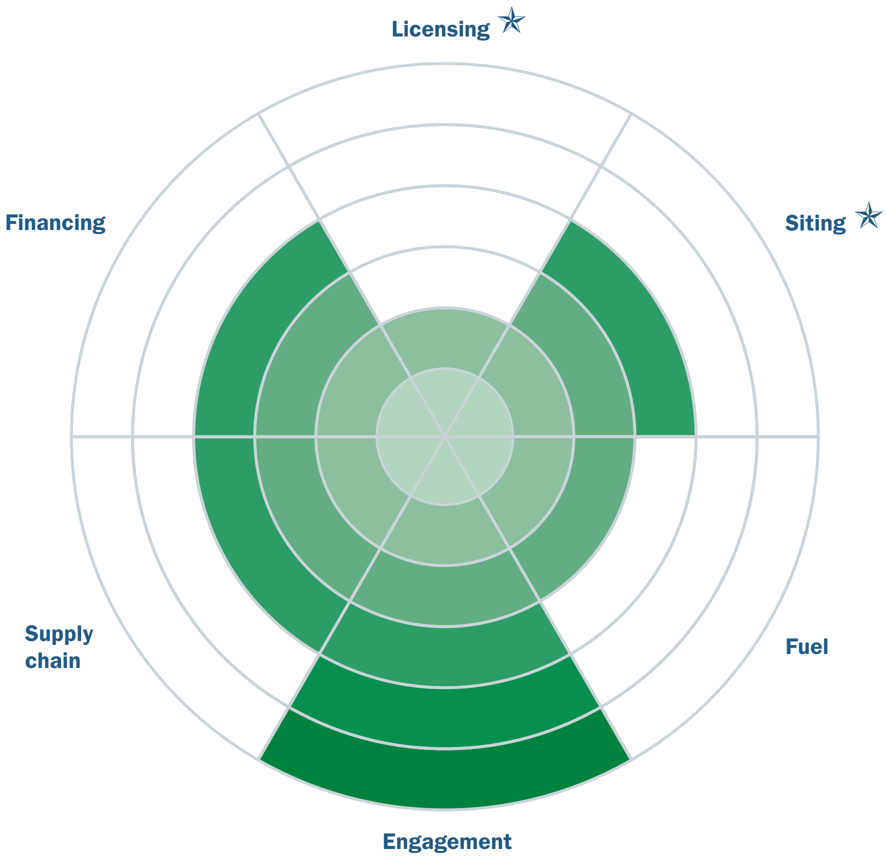
Engagement

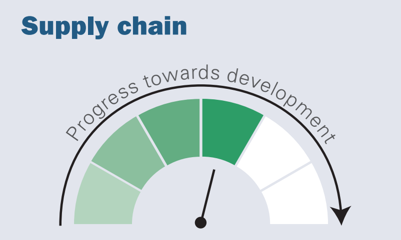
Westinghouse has engaged with students on lead-cooled fast reactor technology through multiple seminars, including at the Ulsan National Institute of Science and Technology (UNIST), Korea, the University of Bristol, United Kingdom, and the University of Florida, United States. In addition, government officials including Alexander De Croo, the Prime Minister of Belgium, and Klaus Iohannis, the President of Romania, expressed support for the MoU that was signed by Westinghouse in November 2023 with Ansaldo Nucleare, SCK CEN, RATEN and ENEA, and aimed at accelerating the commercialisation of lead-cooled fast reactors based on the Westinghouse lead fast reactor design.

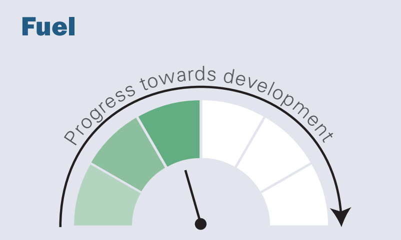
Fuel

For its LFR, Westinghouse plans to use UO_2 pellets or mixed plutonium-uranium oxide fuel. For uranium-based fuel, Westinghouse aims to use HALEU. HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. MOX is also a technically proven fuel type; however, there are presently limited suppliers in particular for fast reactors. Westinghouse is a leading nuclear fuel supplier worldwide. Starting in 2021, under Phase 2 of the UK AMR Research, Development & Demonstration Programme, Westinghouse worked with UK National Nuclear Laboratory and the University of Manchester to advance R&D on the LFR fuel system, including fuel development and testing.

X-energy – Xe-100







★ Active in multiple jurisdictions or countries.
Δ Indicates change since 2023.

Reactor description: High temperature gas-cooled reactor designed for online refuelling using proprietary TRISO-X pebble fuel.

Thermal power (MWth)	200
Outlet temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO-X pebble
Fuel (LEU/HALEU/HEU)	HALEU

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). X-energy has submitted 23 topical reports and white papers to the US NRC, of which 18 have already been reviewed. The NRC and the CNSC co-ordinated a joint review of X-energy's reactor pressure vessel construction code assessment white paper in 2021, under the 2019 NRC-CNSC Memorandum of Cooperation.

Siting ★

Dow Chemical has selected X-energy to provide power and steam using four Xe-100 reactors to its manufacturing facility in Seadrift, Texas (United States). Xe-100 has been shortlisted by Energy Northwest to deploy up to 12 Xe-100 modules at its nuclear-licensed site in Richland, Washington, and has been selected as the SMR of choice by Grant County Public Utility District (PUD). X-energy is also partnered with the Maryland Energy Administration to investigate the feasibility of repowering a current Maryland coal site with a Xe-100 SMR. In 2022, X-energy signed a Framework Agreement with Ontario Power Generation (OPG) to explore potential deployment of Xe-100 in Canada at remote and industrial sites.

Financing

X-energy was selected as one of the two awardees of the US DOE Advanced Reactor Demonstration Program (ARDP) in 2020 and received USD 80 million in initial funding. The ARDP authorised USD 1.23 billion across seven years. The Infrastructure Investment and Job Act officially appropriates funding for the rest of the programme terms. 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. This contract was completed in July 2023. In 2022, Dow announced its intention to take an equity stake in X-Energy. In 2023, Doosan Enerbility and DL E&C invested USD 25 million in X-energy. Between 2021 and early 2023 OPG had invested USD 40 million in X-Energy.

Supply chain

X-energy has selected: Zachry Group as well as a joint venture between Day & Zimmerman and Burns & McDonnell as constructors; Doosan for major components including the steam generator and reactor pressure vessel; Curtiss-Wright in North America for primary components; and Howden in the United Kingdom for Helium circulators. X-energy has agreements with OPG, Cavendish Nuclear, Sheffield Forgemasters, Hatch, and Kinectrics to support deployment. In 2023, X-energy contracted Kinectrics for the design, build and operation of a Helium Test Facility. It also has agreements with Amsted Graphite for nuclear graphite and with SIMSA for supply chain development in Saskatchewan. In 2023, X-energy signed a contract with Mirion Technologies for a detailed design of its Burn-Up Measurement System.

Engagement

In Canada, X-energy has Memoranda of Understanding (MoU) with First Nations Power Authority, Millwright Regional Council of Ontario, Building Trades of Alberta, Invest Alberta Corporation, and OPG. In the United States, X-energy has MoUs with Energy Northwest and the Grant County PUD. X-energy also has an MoU with the Jordan Atomic Energy Commission. These MoUs cover various activities, including public engagement. X-energy is also collaborating with OPG, the Maryland Energy Administration and Frostburg State University to study the potential for supplying heat and power to industrial applications. In 2023, a public meeting was held by the US NRC and X-energy to discuss its fuel fabrication plant plans in Oak Ridge. In 2023, X-energy engaged the local community in a town hall meeting at the Dow site.

Fuel

HALEU is a technically proven fuel type; however, up to and including 2023 there was no commercial supply from OECD countries. Some limited commercial supply is expected to begin in 2024. The Xe-100 reactor is designed to use TRISO-X pebble fuel. X-energy is collaborating with MIT, Sargent & Lundy, Centrus and others to design, produce and license TRISO-X fuel. In 2022, X-energy selected Oak Ridge as the location for its TRISO-X Fuel Fabrication Facility, which is scheduled for startup in 2026, building on X-energy's pilot line of TRISO fuel production at Oak Ridge National Laboratory owned and operated by X-energy since 2017. The NRC is currently reviewing an Xe-100 topical report on TRISO-X Pebble Fuel Qualification Methodology.

Annex 1. The NEA SMR Dashboard assessment criteria definitions

The first edition of the *NEA SMR Dashboard* (NEA, 2023b) introduced and defined six assessment criteria to track the progress towards commercialisation and deployment of respective SMR designs. This second edition applies the same set of criteria to assess progress of 56 SMR designs. Table 11 below summarises the definitions of the criteria applied to assess progress in the areas of: licensing, siting, financing, supply chain, engagement and fuel.

Table 11. ***The NEA SMR Dashboard* assessment 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.

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The NEA Small Modular Reactor Dashboard: Second Edition

A wave of innovation in small modular reactors (SMRs) is advancing quickly with the potential to accelerate pathways to net zero. Looking beyond technical feasibility, the *NEA SMR Dashboard* defines new criteria for assessing progress in six additional dimensions of readiness: licensing, siting, financing, supply chain, engagement and fuel.

For this second edition of the *NEA SMR Dashboard* the NEA's comprehensive global review identified 98 SMR technologies around the world. Fifty-six SMRs are included in this edition of the *NEA SMR Dashboard*. The other 42 include approximately 7 that are under development and requested not to be included in the *SMR Dashboard* at this time but may be included in the future; the remainder include SMR technologies that are not under active development, may be without human or financial resources, or have been cancelled or paused indefinitely. The assessments in this edition of the SMR Dashboard are based on progress up to a cutoff date of 10 November 2023.

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