

# Nuclear Power in the Spotlight: The Role of SMRs in Addressing Rising Electricity Demand and Achieving Decarbonization

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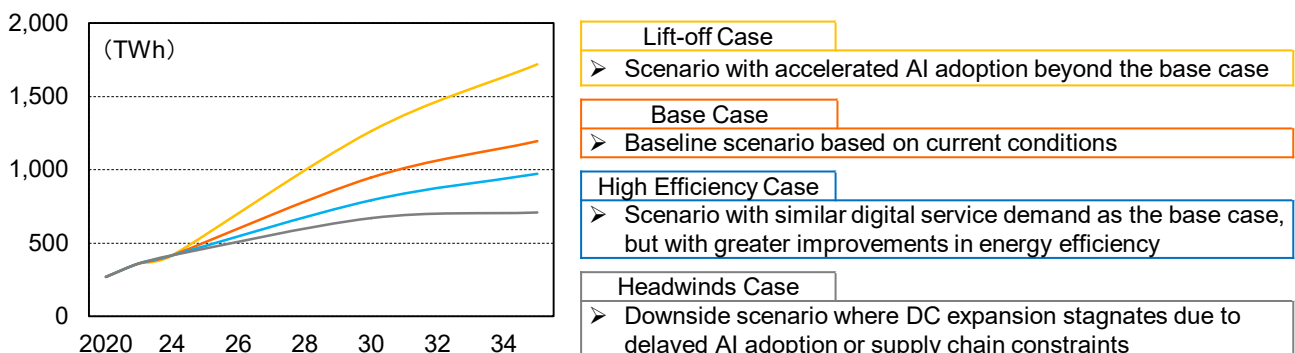
## Executive Summary

- In response to the increase in electricity demand and the goal of realizing decarbonization, the importance of nuclear power generation is being re-evaluated. Efforts toward nuclear power are significant not only for their own electricity systems but also for energy security, as well as industrial competitiveness. Reflecting this, Japan's 7th Strategic Energy Plan clearly states its policy of maximizing the use of nuclear power.
- Next-generation nuclear technologies, including innovative light water reactors, high-temperature gas-cooled reactors, fast reactors, small modular reactors (SMRs), and nuclear fusion, are drawing attention. In the initial stages of deployment, it is essential to address various uncertainties, including (1) the development of supply chains, (2) the rationalization of regulatory and licensing processes, and (3) appropriate risk-sharing among the government, electricity consumers, and other stakeholders.
- Among those technologies, SMRs are considered highly feasible from the perspective of technological maturity and possess features that can overcome the challenges faced by large-scale light water reactors.
- While sincere efforts to address concerns regarding safety and the spent nuclear fuel are a fundamental prerequisite, continuous public and private sector initiatives in the nuclear power field are required as one of the key measures to achieve decarbonization and enhance industrial competitiveness.

### 1. Expectations and Challenges for Nuclear Power

The global electricity system is undergoing a major transformation as it faces the critical challenges of securing sufficient supply capacity to meet the anticipated increase in electricity demand and achieving decarbonization. In particular, the rapid proliferation of data centers (DCs) is a significant factor driving up electricity demand. According to the International Energy Agency (IEA), in its base case scenario, electricity consumption by DCs is projected to reach approximately 945 TWh by 2030, a figure comparable to Japan's total electricity consumption (Figure 1-1).

Figure 1-1: Global DCs' Electricity Consumption Forecast (by Scenario, 2020–2035)



(Note) Created by DBJ based on the International Energy Agency's report "Energy and AI."

Under these circumstances, it is necessary to aim for the construction of a resilient electricity system that does not rely on a single power source. For example, while solar and wind power—key forms of renewable energy—play an important role in decarbonization, their output fluctuates significantly depending on time and weather conditions. As a result, the expansion of renewables introduces various challenges, such as temporal and geographical mismatches between electricity supply and demand (DBJ Research No.429). Therefore, considering the need for stable supply and economic efficiency, there is growing international attention on nuclear power generation in addition to renewables. At COP28, 25 countries, including Japan, announced a declaration to triple the world’s nuclear power generation capacity by 2050. In Japan, the 7th Strategic Energy Plan clearly states the policy of maximizing the use of nuclear power alongside renewables.

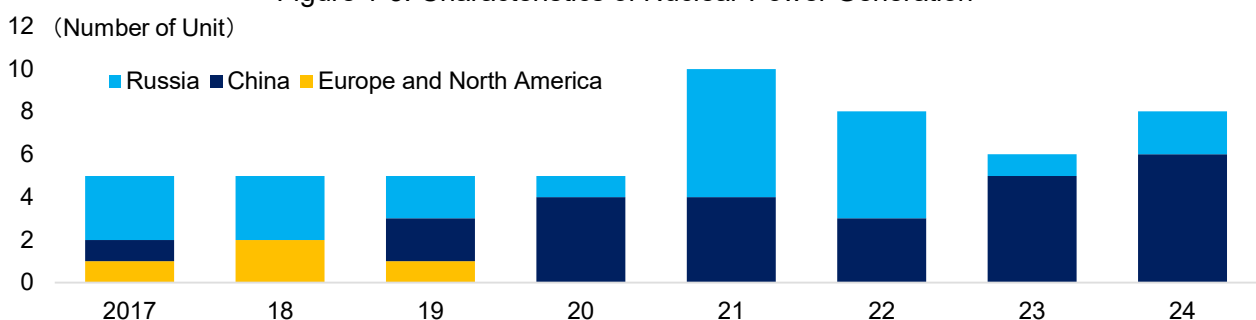
However, the introduction of nuclear power generation faces a variety of challenges, including concerns about safety, the enormous initial investment, and the final disposal of spent nuclear fuel (Figure 1-2). In particular, the Fukushima nuclear accident resulted in a severe meltdown due to the loss of emergency power, causing significant damage to the local community. Furthermore, recent large-scale nuclear power plant construction projects—such as Vogtle Units 3 and 4 in the United States, Flamanville Unit 3 in France, and the Hinkley Point C project in the United Kingdom—have experienced serious cost overruns due to project delays. One contributing factor is the prolonged stagnation of new construction in Europe and North America, which has put the nuclear supply chain, comprising as many as ten million components, at risk of collapse. In contrast to these difficulties in Europe and North America, Russia and China are strategically and continuously strengthening their nuclear supply chains under government leadership, rapidly expanding their international influence in the construction of new nuclear power plants and the nuclear fuel cycle (Figure 1-3).

Figure 1-2: Characteristics of Nuclear Power Generation

Aspects	Advantages	Disadvantages & Risks
Safety	<ul style="list-style-type: none"> <li>➢ Low accident risk due to safety measures based on the concept of multiple barriers</li> </ul>	<ul style="list-style-type: none"> <li>➢ Risk of extensive damage caused by accidents</li> <li>➢ Risks of nuclear proliferation and nuclear security</li> </ul>
Economic Efficiency	<ul style="list-style-type: none"> <li>➢ Low-cost generation, according to estimates</li> <li>➢ Less impact from fuel price fluctuations</li> </ul>	<ul style="list-style-type: none"> <li>➢ Requires enormous initial investment</li> <li>➢ Cost overrun risk from long construction periods</li> </ul>
Energy Security	<ul style="list-style-type: none"> <li>➢ Stable 24-hour power generation, unaffected by weather</li> </ul>	<ul style="list-style-type: none"> <li>➢ Limited output flexibility to demand</li> <li>➢ Geographically concentrated uranium resources</li> </ul>
Environment	<ul style="list-style-type: none"> <li>➢ No CO<sub>2</sub> emissions during power generation</li> <li>➢ Requires little fuel and land area</li> </ul>	<ul style="list-style-type: none"> <li>➢ High-level radioactive waste must be safely managed for thousands of years</li> </ul>

(Note) Created by DBJ.

Figure 1-3: Characteristics of Nuclear Power Generation



(Note) Created by DBJ based on the IEA’s “The Path to a New Era for Nuclear Energy.”

## 2.Next-Generation Nuclear Technologies

To maximize the use of nuclear power, there are high expectations for next-generation nuclear technologies that prioritize safety while overcoming conventional challenges (Figure 2-1). The five main technological options attracting attention are innovative light water reactors (LWRs), high-temperature gas-cooled reactors (HTGRs), fast reactors (FRs), small modular reactors (SMRs), and nuclear fusion. As each of these technologies has its own unique characteristics and strengths, it is necessary to pursue their development and deployment from a medium- to long-term perspective.

Figure 2-1: Classification of Major Nuclear Technologies

	Less than 10 MW	10 MW to less than 300 MW	More than 300 MW
LWR	Light Water Micro Reactor	Light Water SMR	Conventional large reactor, Innovative LWR
Non-LWR	Non-Light Water Micro Reactor	Non-Light Water SMR (mainly HTGRs and FRs)	HTGRs FRs Nuclear Fusion

(Note) Created by DBJ.

### (1) Innovative LWRs

Innovative LWRs are designed to further enhance safety, improve economic efficiency, and strengthen flexibility, based on decades of extensive construction and operational experience with LWRs. Various developments have been made to improve safety, such as reinforcing reactor buildings, strengthening passive safety systems that can cool the reactor without relying on external power sources, and installing core catchers as a countermeasure against meltdowns.

When it comes to replacing existing nuclear power facilities in Japan, innovative LWRs can be considered a relatively low-risk and practical option. Since existing technical knowledge and regulatory experience can be leveraged, earlier social implementation and greater business predictability are expected compared to other technologies with lower maturity.

### (2) HTGRs and FRs

HTGRs are nuclear reactors capable of supplying not only electricity but also high-temperature heat. In Japan, the Japan Atomic Energy Agency (JAEA) and Mitsubishi Heavy Industries (MHI) are advancing their development. The main feature of HTGRs is that the fuel itself has extremely high heat resistance, and helium gas, which is chemically inert, is used as the coolant. As a result, meltdowns are fundamentally unlikely to occur. In addition, since the high-temperature heat can be used for process heat supply to chemical plants, hydrogen production, and seawater desalination, HTGRs are expected to contribute not only to the decarbonization of power sources but also to the decarbonization of industrial sectors that require large amounts of thermal energy.

FRs dramatically improve the utilization efficiency of uranium resources compared to existing LWRs and enable the reduction of high-level radioactive waste volume and the long-term radiotoxicity of such waste. Japan has been engaged in the development of FRs for many years through the experimental reactor “Joyo” and the prototype reactor “Monju.” Building on the valuable experience and lessons learned from Joyo and Monju, the Japanese government is continuing its FR development program, with MHI and Mitsubishi FBR Systems serving as the core companies for demonstration reactor development, aiming to begin operation in the 2040s.

Both HTGRs and FRs are long-term, requiring significant investment and ongoing research and development. HTGRs are expected to contribute to a wide range of industries through the utilization of heat, while FRs can strengthen resource security through more effective use of uranium resources and address the final disposal of high-level radioactive waste. As both technologies contribute to solving fundamental challenges in energy strategy, not only private sector efforts but also strategic government support is expected.

### (3) SMRs

SMRs generally refer to reactors with an output of 300 MW or less and have high potential in terms of safety and siting flexibility. In terms of safety, the adoption of passive safety systems, underground installation, and smaller size can reduce the probability of severe accidents. While local consent is required as with LWRs, the high level of safety may allow the emergency planning zone (EPZ) to be limited to within the plant site boundary. SMRs are also expected to be utilized in various locations where the construction of large reactors is difficult. Specifically, they can supply electricity to remote areas and islands with underdeveloped power grids, provide direct power supply to large electricity-consuming facilities such as DCs and industrial plants, and be used in non-electric applications such as hydrogen production and heat supply (Figure 2-2). On-site power sources that do not rely on the transmission grid are advantageous in that they can avoid the time and transmission charges associated with grid connection.

Figure: 2-2 Features of SMRs and Expected Deployment Sites

	Expected Reason for SMR Deployment in Each Area			
	Small Scale	Fewer Siting Constraints	Shorter Construction Period	Heat/Water Supply (HTGRs, SMRs)
Large consumers (e.g., industrial complexes, DCs)	✓	✓	✓	✓
Off-grid areas (e.g., remote islands, military facilities, mines)	✓	✓		✓
Existing power systems (e.g., replacement for coal-fired power)	✓	✓		

(Note) Created by DBJ.

In addition, SMRs are based on simplified designs, with major components mass-produced as modules in factories and assembled on-site. This approach is expected to significantly shorten construction periods, standardize quality, and reduce construction costs. IEA predicts that, in a scenario where SMR deployment progresses and mass production is achieved, the construction cost of SMRs could fall below that of large reactors by 2040. Furthermore, the smaller investment and shorter construction period enabled by the modular approach offer advantages from a financing perspective.

#### **(4) Nuclear Fusion**

Nuclear fusion is a technology that generates enormous energy by heating and fusing light atomic nuclei into a plasma state at extremely high temperatures. Japan is engaged in R&D through participation in the International Thermonuclear Experimental Reactor (ITER) project, an international collaboration, as well as the JT-60SA, a critical plasma test device jointly operated with the EU. In recent years, private sector initiatives in fusion have also become increasingly active.

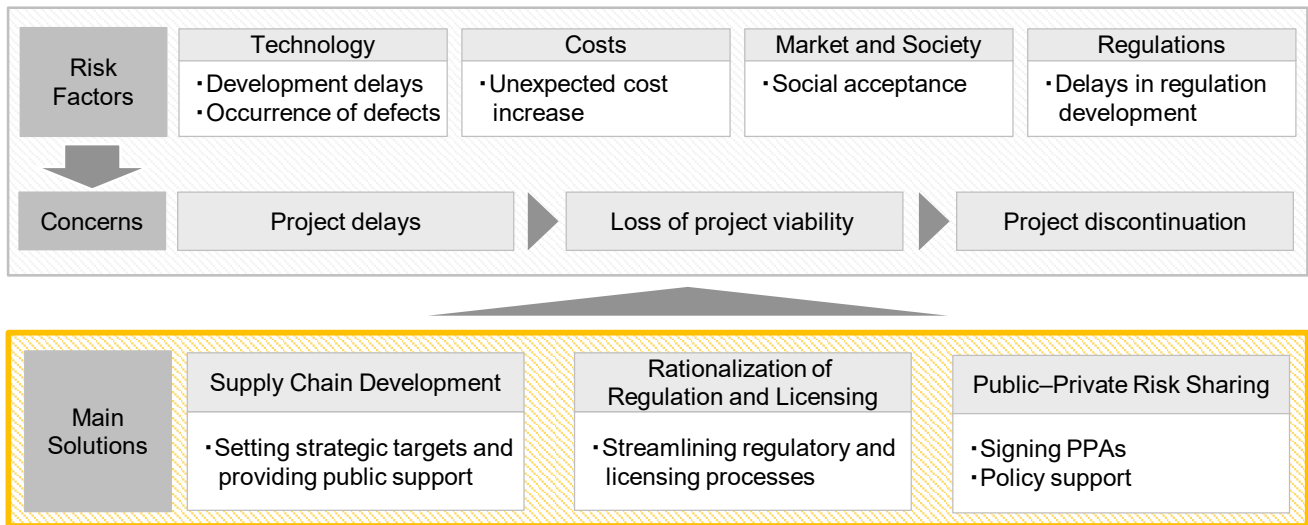
A key feature of nuclear fusion is that its main fuel, deuterium, is abundantly available in seawater, resulting in minimal resource constraints. In addition, unlike nuclear fission, fusion does not involve the risk of runaway chain reactions; the reaction will naturally stop if the fuel supply is cut off, providing inherent safety. Moreover, nuclear fusion does not generate high-level radioactive waste, making it a highly promising ultimate energy source with minimal environmental impact.

On the other hand, the practical realization of nuclear fusion requires meeting the Lawson criterion, which is defined as the product of three factors necessary to sustain a fusion reaction: plasma temperature, density, and confinement time. For the D–T (deuterium–tritium) reaction, which is a primary focus for research institutions worldwide, this means achieving a staggering 100 million degrees Celsius, a density of 100 trillion particles per cubic centimeter, and a confinement time of one second. Achieving this requires overcoming a wide range of highly advanced technological challenges, including superconducting technology to generate strong magnetic fields; the development of high-power, high-repetition lasers; and materials capable of withstanding high temperatures and neutron irradiation. The realization of fusion would represent a paradigm shift in energy and have significant industrial ripple effects. Accordingly, in Japan, the “Fusion Energy Innovation Strategy” revised in June 2025 positions fusion as a new growth engine for Japan. Continuous efforts involving both the public sector, which supports foundational technologies, and the private sector, which aims for commercialization, are essential.

**(5) The Need to Address FOAK Risks**

Next-generation nuclear technologies are promising for the post-2030 era. However, their initial deployment involves uncertainties unique to first-of-a-kind (FOAK) projects. It is essential to address these uncertainties through a multifaceted approach, including (1) the development of supply chains, (2) the establishment and streamlining of regulatory and licensing processes, and (3) appropriate risk-sharing among the government, electricity consumers, and other stakeholders (Figure 2-3).

Figure 2-3: Key Issues and Countermeasures in Nuclear Power



- (Notes) 1. Created by DBJ.  
 2. In practice, these factors interact in complex ways.

Firstly, to address challenges related to technology and cost, it is necessary to resolve the “chicken-and-egg problem” that arises between power utilities and suppliers. For power utilities, it is difficult to make investment decisions unless the quality of equipment and components can be assured and a stable, reasonably priced supply is expected. On the other hand, suppliers are reluctant to make large-scale investments in R&D and commercial production unless there is clear demand. If this stalemate remains unresolved, there is a high risk of construction delays and cost overruns even if a project begins. Therefore, it is essential to simultaneously improve order predictability and develop the supply chain, with policy targets and support serving as additional incentives. In addition, from a long-term perspective, it is also essential to consider back-end issues such as the management, disposal, and reprocessing of spent fuel, as well as decommissioning.

Secondly, uncertainty in the regulatory and licensing process is also a significant risk. When implementing new technologies, the content and duration of the review process are often difficult to predict, which becomes a barrier to investment decisions. To promote widespread adoption, it will be important to rationalize and establish regulatory and licensing processes while maintaining the fundamental principle of ensuring safety.

Thirdly, even after establishing the supply chain and streamlining regulatory processes, it is important to have a framework in which various stakeholders appropriately share the remaining risks. For example, long-term power purchase agreements (PPAs) or direct investment in projects by hyperscalers and industrial consumers seeking stable, clean sources of electricity and heat can be effective. In addition, policy mechanisms to mitigate risks that private companies cannot bear alone in FOAK projects are also essential. For instance, in the United Kingdom, the Nuclear Energy (Financing) Act was enacted in 2022, making it possible to apply the Regulated Asset Base (RAB) model—previously used for highly public utilities such as water supply—to nuclear projects. The RAB model allows investors to recover approved investments through regulated charges calculated based on a predetermined rate of return. Cost increases incurred during construction can also be recovered if deemed reasonable by the regulator, and the model enables cost recovery to begin during the construction period, greatly improving revenue predictability for private companies and investors.

### **3.Light Water SMRs Attracting Particular Attention**

As discussed above, various next-generation nuclear technologies are under development, but among them, light water SMRs are attracting particular attention due to their high feasibility from the perspective of technological maturity and their strong potential to overcome conventional challenges associated with nuclear power. As a result, they are drawing interest from governments around the world as well as hyperscalers operating DCs.

#### **(1) Trends in SMR Development and Social Implementation**

Currently, more than 60 types of SMRs are under development worldwide, including light water SMRs and non-light water SMRs that use more innovative technologies such as HTGR (Figure 3). Among these, light water SMRs are expected to lead in social implementation, as they can leverage the technical expertise, supply chains, and regulatory frameworks developed over many years for large LWRs. Since there are few differences in characteristics among light water SMRs by design, securing cost competitiveness through mass production will be the key to success. Therefore, SMR manufacturers that can achieve early technological establishment, build a robust supply chain, and succeed in mass production are likely to emerge as industry leaders.

China and Russia are currently leading the way in the social implementation of SMRs. China National Nuclear Corporation (CNNC), a state-owned enterprise, is constructing the ACP100 (125 MWe) on Hainan Island, aiming to achieve the world's first commercial operation in 2026. Russia's state-owned Rosatom is building the RITM-200N (55 MWe) in the Sakha Republic, targeting operation in 2028. In other regions, particularly North America, the focus is shifting from development to commercialization. GE Vernova Hitachi Nuclear Energy, which is developing the BWRX-300 (300 MWe), is at the forefront of this movement. The Darlington New Nuclear Project in Canada, which has adopted the BWRX-300, has already obtained a construction permit from the province of Ontario and aims to begin operation of the first unit by the end of 2030. Also, in the United States, the Tennessee Valley Authority (TVA) has applied to the United States Nuclear Regulatory Commission (NRC) for a construction permit to deploy the BWRX-300 at the Clinch River site.

Figure 3: Comparison of Major Light Water SMRs

	BWRX-300	VOYGR	SMR-300	ACP100	RITM-200N	RR SMR	AP300	SMART	NUWARD SMR
Manufacturer	GE Vernova Hitachi	NuScale	Holtec	CNNC	ROSATOM	Rolls Royce	Westinghouse	KAERI	EDF
Country	US/Japan	US	US	China	Russia	UK	US	South Korea	France
Reactor Type	BWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Output (MWe)	300	77	300	125	55	470	300	100	170
Licensing	○	○	△	◎	◎	△	△	○	△
Social Implementation	◎	○	△	◎	◎	△	△	△	△
Financing	◎	○	○	◎	◎	○	△	○	○
Collaboration Framework	◎	◎	△	◎	○	◎	◎	○	◎
Fuel	○	○	○	○	○	○	○	○	○

(Notes) 1. Created by DBJ based on NEA's "The NEA Small Modular Reactor Dashboard: Second Edition."

2. Legend: ◎ = Advanced/Strong, ○ = Good, △ = Developing/Emerging.

3. Evaluations for each criterion are based on the NEA material. This report was published in March 2024 and may not reflect the most recent developments of each company.

Regarding addressing FOAK risks discussed a couple pages back in chapter 2 section (5), there are also concrete developments related to SMRs. For example, the rationalization and establishment of regulatory and licensing processes is an important issue for maximizing the advantages of SMRs. In the United States, the NRC has clarified its policy to efficiently and effectively promote the approval of new designs, in line with the ADVANCE Act, which came into effect in July 2024, and the presidential executive order signed in May 2025 mandating NRC reform. Various initiatives are being promoted, including international cooperation with the Canadian Nuclear Safety Commission (CNSC).

Regarding appropriate risk sharing among the government, electricity consumers, and other stakeholders, Great British Energy Nuclear (GBE-N), a UK government agency, is supporting private sector efforts not only by providing loan guarantees and subsidies but also by leading the selection of promising SMR technologies and design certification reviews. GBE-N is also taking on particularly high-risk tasks in the early stages, such as obtaining permits and licenses and carrying out site preparation work. Japan should also consider the potential for medium-term SMR deployment, considering the advanced frameworks being implemented in other countries.

## (2) Expectations for Strengthening the Industrial Competitiveness of Japanese Manufacturers

The growing expectations for nuclear power, including SMRs, present significant business opportunities for Japan, which has developed one of the world's leading nuclear supply chains. However, since 2011, the construction of new nuclear power plants in Japan has halted, making it difficult for many companies to maintain their technologies and human resources. The potential loss of Japan's nuclear supply chain could lead to decline in industrial competitiveness; therefore, concerted public and private sector efforts are needed to overcome these challenges.

In South Korea, the public and private sectors are working together to rapidly catch up and strengthen competitiveness by investing in and collaborating with leading overseas SMR manufacturers. Japan should also take note of such Korean initiatives and promote the participation of manufacturers, engineering companies, and construction firms in overseas projects. This would help Japan acquire the latest knowledge on project planning and operation, build networks with foreign companies, and contribute to international standardization.

Japan's 7th Strategic Energy Plan sets forth a policy to support the participation of Japanese companies in overseas SMR projects and R&D, from the perspective of maintaining and strengthening the industrial base. In addition, the Ministry of Economy, Trade and Industry (METI) and the Japan Atomic Industrial Forum (JAIF) established the Nuclear Supply Chain Platform (NSCP) in 2023 to build a support system that addresses supply chain-wide issues such as human resource development, measures against supply disruptions of parts and materials, and business succession. There are already examples of such initiatives, such as the investment by JGC Holdings, IHI Corporation, Chubu Electric Power, and Japan Bank for International Cooperation in the US SMR venture NuScale Power. Continued proactive efforts of this kind will contribute to strengthening Japan's industrial competitiveness in the future.

## **Conclusion**

As discussed in DBJ Research No. 420, the development and commercialization of various innovative technologies, including nuclear power, are urgently needed to address the diverse and complex challenges facing power systems. In utilizing next-generation nuclear technologies such as SMRs, it is essential to establish a stable supply system (including high-assay low-enriched uranium [HALEU] for the front end), address issues related to the management and disposal of spent fuel (the back end) and improve social acceptance through objective and careful decision-making and thorough dialogue. Crucially, all these efforts must be underpinned by a steadfast commitment to safety.

## Appendix 1: Technology Roadmap for Nuclear Technologies in Japan

	2023	2024	2025	2026	2027	2028	2029	2030	2030s	2040s	
<b>Innovative LWR</b>	Commercial Reactor										
	B		C					D	E		
<b>SMR</b>	Demonstration Reactor										
	A				B			C	D	E	
<b>FR</b>	Demonstration Reactor										
	A						B		C	D	E
<b>HTGR</b>	Demonstration Reactor										
	B					C	D		E		
<b>Fusion</b>	Prototype Reactor										
	A		C					E			

(Notes) 1. Created by DBJ based on METI's "Reference Materials for the Basic Policy for GX Realization."

2. Legend: A= Conceptual Design, B= Basic Design, C= Detailed Design, D= Construction, E= Operation.

## Appendix 2: Major SMR Developments in Individual Countries

	Public Sector Initiatives	Private Sector Initiatives
US	<ul style="list-style-type: none"> <li>➤ DOE's ARDP provides funding for advanced reactor demonstration</li> <li>➤ ADVANCE Act enacted in 2024 to streamline licensing and supply chain</li> </ul>	<ul style="list-style-type: none"> <li>➤ TVA has applied for permits to deploy the BWRX-300 at the Clinch River site</li> <li>➤ Amazon invested in X-energy; plans to deploy over 5 GW of SMRs in the US by 2039</li> </ul>
Canada	<ul style="list-style-type: none"> <li>➤ Released "2020 SMR Action Plan" to promote SMR development for domestic use and export</li> </ul>	<ul style="list-style-type: none"> <li>➤ OPG began construction for BWRX-300 deployment by 2030</li> </ul>
UK	<ul style="list-style-type: none"> <li>➤ GBN established in 2023 to support SMR financing and management</li> </ul>	<ul style="list-style-type: none"> <li>➤ Rolls-Royce SMR, selected by GBN, aims to start grid supply in the mid-2030s</li> </ul>
France	<ul style="list-style-type: none"> <li>➤ "France 2030" strategy: €1 billion for innovative SMR development</li> <li>➤ EDF aims to commercialize NUWARD SMR by 2030</li> </ul>	-
Russia	<ul style="list-style-type: none"> <li>➤ Rosatom leads SMR projects; first land-based ACP100 to operate in 2028</li> <li>➤ KLT-40S marine SMR set with EPZ within 1 km</li> </ul>	-
Poland	<ul style="list-style-type: none"> <li>➤ National Atomic Energy Agency strengthens SMR safety cooperation with CNSC</li> </ul>	<ul style="list-style-type: none"> <li>➤ OSGE plans to deploy up to 79 BWRX-300 units; multiple construction candidates announced</li> </ul>
Japan	<ul style="list-style-type: none"> <li>➤ 7th Strategic Energy Plan supports Japanese firms' participation in overseas SMR projects</li> </ul>	<ul style="list-style-type: none"> <li>➤ IHI, MHI, JAEA, Hitachi GE Vernova, Mitsubishi, and others collaborate with foreign firms on SMR R&amp;D, investment, and parts supply</li> </ul>
China	<ul style="list-style-type: none"> <li>➤ CNNC building first commercial SMR (ACP100)</li> <li>➤ Promotes SMR export via Belt and Road Initiative</li> </ul>	-
South Korea	<ul style="list-style-type: none"> <li>➤ Standard design certification for government-led i-SMR by 2028</li> </ul>	<ul style="list-style-type: none"> <li>➤ Doosan Enerbility, Hyundai E&amp;C, Korea Hydro &amp; Nuclear Power, and others collaborate with overseas firms</li> </ul>
India	<ul style="list-style-type: none"> <li>➤ "Nuclear Energy Mission" aims for domestic SMR operation by 2033</li> </ul>	-

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