



A Review of Small Modular Reactor (SMR) Future in Bangladesh

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ABSTRACT

Small Modular Reactors (SMRs) represent a transformative development in nuclear power technology, offering potential solutions — including electricity generation, district heating, water desalination, hydrogen production, and process heat — to meet the growing demand for clean and sustainable energy. Their smaller size, modular design, improved safety features, flexibility, scalability, and reduced capital costs distinguish them from conventional large-scale nuclear power plants. This review examines the historical background, technological developments, design principles, safety considerations, economic feasibility, and regulatory issues surrounding SMR technology, with attention to its potential to revolutionize the energy sector and contribute to a sustainable, low-carbon future. SMRs are generally defined as reactors with an electrical output of up to 300 MW(e) per unit, compared with 1,000 MW or more for a typical conventional reactor, and are designed with passive and inherent safety features that reduce the likelihood of accidents relative to traditional reactors.

1. Introduction

1.1 Background and Motivation

Concerns about climate change have made the decarbonization of the energy sector a global priority. The most practical route to reducing greenhouse gas (GHG) emissions and keeping global warming below 2°C above pre-industrial levels is to eliminate emissions from the power sector almost entirely, while extending clean electricity to other energy-intensive sectors such as transportation, heating, and industry [1]. Achieving this requires a shift from fossil fuels toward low-carbon technologies, including nuclear, wind, and solar power.

The first SMR design was proposed in the United States in the early 1960s, but SMRs did not receive substantial research and development attention until the 1990s. The U.S. Department of Energy (DOE) began supporting a number of SMR development initiatives in the 2000s. Decentralization of energy generation is increasingly seen as necessary to meet growing global electricity demand while diversifying the mix of sustainable energy sources, and SMRs offer a workable path for regions with less-developed infrastructure or smaller grids.

Interest in SMRs has grown globally because of their potential for flexible, factory-built power generation that can be shipped to site and deployed to replace aging fossil-fuel plants. Their smaller size allows power to be generated closer to where it is needed, reaching remote locations or serving as backup capacity. SMRs also carry lower initial capital costs, are well suited to non-electric and cogeneration applications, and can offer improved safety performance through inherent and passive safety features [2]. They further open opportunities for regions with less-developed infrastructure and for hybrid energy systems that combine nuclear and renewable sources. Their reduced complexity — a consequence of the smaller per-module output, generally up to 300 MW(e) — is a further attraction [3].

There are currently around 50 SMR designs and concepts in various stages of development worldwide, with a small number already under construction in Argentina, China, and Russia, and many other established and emerging nuclear energy countries pursuing SMR research and development programs.

The IAEA supports its Member States in developing SMRs of various types through a systematic approach to identifying and advancing the enabling technologies needed to achieve competitiveness and reliable performance. The flexibility, scalability, and safety characteristics of SMRs make them suitable for applications ranging from powering remote villages to supporting industrial operations and large electrical grids; the Agency's work also extends to shared infrastructure arrangements between Member States [4]. The principal drivers behind this growing interest can be summarized as:

- The need for more adaptable and scalable nuclear power facilities.
- The rising cost of conventional, large-scale nuclear reactors.
- The potential for SMRs to contribute to climate change mitigation.

A range of SMR designs is now under development in the United States, Canada, Europe, China, and elsewhere. Prominent examples include GE Hitachi Nuclear Energy's BWRX-300, Holtec International's SMR-160, Terrestrial Energy's IMSR, and Westinghouse Electric Company's AP300 (SMR-110).

2. Small Modular Reactors: An Overview

2.1 Definition of Small Modular Reactors

Small Modular Reactors (SMRs) are advanced nuclear fission reactors with an electrical output generally up to 300 MW(e) per unit. Unlike conventional large nuclear power plants, SMRs are designed using modular construction techniques that allow major components to be manufactured in factories and transported to the installation site for assembly. This modular approach can significantly reduce construction time, improve quality assurance, lower initial capital investment, and enhance deployment flexibility. SMRs also incorporate advanced passive safety systems that rely on natural physical processes — gravity, natural circulation, and convection — thereby reducing dependence on active safety systems and operator intervention. These advantages position SMRs as a promising route to reliable, low-carbon, and sustainable energy generation.

2.2 Evolution of Nuclear Reactor Generations

Nuclear reactor technology has evolved through several generations aimed at improving safety, efficiency, economics, and sustainability.

Generation III reactors represent an evolutionary advancement of Generation II designs, incorporating improved fuel technology, enhanced operational performance, and additional engineered safety systems. Examples include the Advanced Boiling Water Reactor (ABWR) and System 80+.

Generation III+ reactors introduce advanced passive safety features, extended operating lifetimes, and improved resistance to severe accidents. Notable examples include the AP1000, APR1400, EPR, and VVER-1200; many contemporary SMR designs adopt Generation III+ safety philosophies.

Generation IV reactors are being developed to address longer-term challenges associated with nuclear energy, including resource utilization, waste minimization, sustainability, and proliferation resistance. Examples include Sodium-Cooled Fast Reactors (SFRs), Molten Salt Reactors (MSRs), Lead-Cooled Fast Reactors (LFRs), and Very High Temperature Reactors (VHTRs); a number of advanced SMR concepts draw on Generation IV technologies.

2.3 Global Development Status of SMRs

SMR development has accelerated worldwide in response to increasing demand for clean energy, energy security, and decarbonization.

United States

The United States is a global leader in SMR development. Several designs, including the NuScale Power Module, Xe-100, and Natrium, are undergoing licensing, demonstration, or deployment activities, with the U.S. Department of Energy actively supporting commercialization through funding and regulatory assistance.

Canada

Canada has adopted a national SMR Action Plan to promote deployment for remote communities, mining operations, and grid decarbonization, and is actively evaluating multiple SMR technologies through its regulatory framework.

China

China has made significant progress with the ACP100 (Linglong One), which became one of the world's first land-based commercial SMRs to reach an advanced construction stage. China regards SMRs as an important component of its future energy strategy.

South Korea

South Korea has developed the SMART reactor, an integrated pressurized water reactor designed for electricity generation and desalination applications, with ongoing research aimed at enhancing SMR safety and economic competitiveness.

Other Asian Countries

Japan and India are conducting research on advanced reactor technologies and evaluating SMR deployment opportunities, while several Southeast Asian nations are assessing SMRs as potential solutions to future energy demand. Bangladesh, having recently commissioned its first large-scale nuclear power plant at Rooppur, is among the countries beginning to consider SMR technology as part of its longer-term energy strategy, though a dedicated national assessment remains an area for further study [5].

3. Advantages of SMR Technology

SMRs offer a distinct set of advantages relative to large, conventional nuclear power plants, spanning design, safety, economics, and deployment flexibility.

3.1 Design Principles and Technological Development

SMRs are generally designed to produce between 10 and 300 MW(e), with modularity built into their design to simplify construction, maintenance, and scaling. Design strategies under investigation include integral pressurized water reactors (iPWRs), molten salt reactors (MSRs), high-temperature gas-cooled reactors (HTGRs), and fast neutron reactors (FNRs), each offering distinct advantages and challenges suited to different applications [6]. Current development efforts emphasize boosting performance, lowering costs, and improving safety. Passive safety features — natural circulation and built-in shutdown mechanisms — reduce the need for operator intervention and help prevent accidents, while advanced fuel designs, including accident-tolerant fuels, aim to improve fuel performance and reduce the risk of core damage. Developments in materials science, such as high-temperature alloys and ceramic fuels, are also being pursued to increase reactor efficiency and lifetime [7].

3.2 Applications

SMRs offer flexibility in addressing a range of energy needs. They can supply dependable, sustainable electricity to local communities or commercial enterprises in remote locations with limited grid connections, support water desalination through their process heat, and serve as part of hybrid energy systems combined with renewable sources to provide steady, reliable power [8].

3.3 Economic Considerations

One of the principal attractions of SMRs is their potential for cost savings relative to larger nuclear reactors. Factory fabrication and simplified, modular construction reduce both construction time and cost, while manufacture under controlled factory conditions can support higher and more consistent levels of quality and safety. The smaller scale of individual projects also reduces financial risk and makes funding more manageable [9].

3.4 Regulatory Considerations and Public Perception

Licensing, standardization, and public perception remain significant considerations for SMR deployment. Licensing procedures need to be adapted to reflect the distinctive characteristics of SMRs in order to ensure safety without introducing unnecessary delay, and standardization across manufacturing, construction, and operating processes can help reduce costs. Public perception and acceptance of nuclear energy continue to significantly influence the pace of SMR deployment and the evolution of regulatory frameworks.

3.5 Safety Characteristics

Safety is one of the most significant advantages associated with SMR technology. Modern SMR designs incorporate multiple layers of defense-in-depth, passive heat removal systems relying on organic processes such as natural circulation and gravity-driven cooling, and simplified plant designs that reduce the need for active intervention and external power sources. Many designs also employ underground reactor placement, reducing vulnerability to external hazards and improving containment effectiveness, while the reduced core size and lower radioactive inventory further contribute to enhanced safety performance under accident conditions [10].

3.6 Flexibility, Scalability, and Grid Integration

The modular architecture of SMRs simplifies construction, maintenance, and capacity expansion. Units can be manufactured in a factory environment and delivered to site, shortening construction time and cost, while additional modules can be added incrementally to meet rising demand [11]. This flexibility extends to deployment in rural regions with limited or intermittent grid connections, where SMRs can supply dependable electricity to towns, mining operations, and industrial enterprises not connected to the main power system, supporting local economic development. Integrating SMRs into hybrid energy systems alongside solar and wind can also improve grid stability, with SMRs providing a reliable baseload supply that offsets the intermittency of renewable generation [12].

3.7 Environmental, Process-Heat, and Decommissioning Benefits

Like conventional nuclear reactors, SMRs generate electricity without directly emitting greenhouse gases, helping to lower carbon dioxide emissions and supporting the broader shift away from fossil-fuel-based power generation [13]. Beyond electricity, SMRs are capable of producing high-temperature heat suitable for industrial processes such as desalination, hydrogen generation, and district heating, extending their usefulness beyond power production alone. Their modular architecture also extends to decommissioning: module-by-module decommissioning can reduce the overall duration and cost of the process and support more efficient resource use.

4. Challenges to SMR Deployment

Despite their potential advantages, SMRs face a number of challenges that must be addressed before widespread commercial deployment is achieved.

1. Limited market demand: As a new technology, SMRs do not yet have a large established market, which can make financing development and deployment difficult.
2. Technical challenges: A number of technical issues remain to be resolved before commercial-scale deployment, including the development of new materials and components and the demonstration of safety and reliability [14].
3. Novel materials: Some SMR designs rely on materials that have not been extensively tested in nuclear reactor environments, posing a risk of unexpected failures.
4. Operational experience: Limited operational experience with SMRs could delay deployment, as operators need to be trained to operate them safely.
5. Supply chain: The supply chain for SMR components and materials is not yet well established, which could delay deployment.
6. Technological maturity: Many SMR designs remain in relatively early stages of development, making it difficult to guarantee safe, dependable operation while meeting regulatory requirements without further research, development, and testing.
7. Licensing and regulation: The legal and regulatory environment for SMRs is still developing in many countries, and licensing procedures may need to differ from those used for conventional reactors because of SMRs' distinct design features and safety measures [15].
8. Safety and security: SMRs must meet high standards of safety and security, addressing reactor core integrity, coolant system failures, and the risk of accidents, which requires reliable safety systems, effective emergency response procedures, and robust security measures.
9. Fuel supply and waste management: Some SMR designs use advanced fuels or unconventional isotopes distinct from those used in conventional reactors, requiring a reliable and sustainable fuel supply chain as well as attention to the storage, transport, and long-term management of radioactive waste [16].
10. Grid integration and infrastructure: Integrating SMRs into existing electricity networks can present technical difficulties, requiring adequate grid infrastructure and transmission capacity; adapting grid infrastructure for SMRs can be especially challenging in regions with no prior nuclear power experience [17].
11. Public acceptance and perception: The success of SMR adoption depends significantly on public perception of nuclear power. Addressing public concerns about safety, waste management, and proliferation risks through effective communication and transparency is essential to building the trust needed for wider adoption.

5. Research Gaps

A review of the existing literature points to several areas where further research is needed to support SMR deployment, summarized in Table 1.

Area	Existing Research	Identified Research Gap
SMR Safety	Extensive studies on passive safety systems.	Limited long-term operational data from commercial SMRs.
Licensing Framework	Regulatory guidance exists in several countries.	Lack of harmonized international licensing standards.
Economics	Numerous cost-benefit analyses.	Uncertainty regarding first-of-a-kind deployment costs.
Waste Management	Studies focus on conventional reactors.	Limited assessment of SMR-specific waste streams.
Deployment in Developing Countries	Initial feasibility studies available.	Insufficient country-specific regulatory and infrastructure assessments.

6. Conclusion

Small Modular Reactors represent a significant development in nuclear technology, offering improved safety, flexibility, scalability, and cost advantages over conventional large-scale nuclear power plants. Through novel design concepts, ongoing technical improvements, and a growing range of applications, SMRs have the potential to help meet rising energy demand while supporting a cleaner, more sustainable future. Realizing this potential, however, will depend on overcoming remaining regulatory, technical, and public-acceptance obstacles. For a country such as Bangladesh — which has recently brought its first large nuclear power plant online and continues to build regulatory and technical capacity in the nuclear sector — SMRs present a longer-term option worth continued study, particularly for applications such as grid diversification, industrial process heat, and deployment in areas with less-developed grid infrastructure. A more detailed, Bangladesh-specific assessment of siting, regulatory readiness, and technology selection is a natural next step for this line of research.

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