Small Modular Reactors: Powering the World

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Abstract: ***Several world governments have announced policies to decommission their fossil-fired plants (FFPs) in the coming years, with the goal of eliminating all FFPs by 2070. Governments must now establish policies for the large-scale deployment of Small Modular Reactors (SMRs). Apart from technical considerations, financial support is also essential. Because FFPs currently account for approximately 57% of global electricity production, alternative power generation must be planned urgently. The principal alternative sources to fill this gap appear to be solar and nuclear energy. Solar power is suitable for meeting agricultural and domestic demands but is limited in geographic reach. Significant efforts have been made to install large-capacity nuclear power plants (NPPs) in the range of 700 MWe to 1,650 MWe using proven designs. However, their rates of installation may not be sufficient to meet the expected growth in electricity demand as coal-fired units are retired. To address the near-term shortfall, SMRs rated from approximately 40 MWe to 300 MWe are under global consideration. Large NPPs and SMR units should operate in tandem, not in competition. Large NPPs are best suited for base-load generation, while SMRs are well positioned to serve peaking loads. Large NPPs must be located at remote sites and must provide for Exclusion Zones, Protective Action Zones, and Emergency Response Zones. SMRs, which are intended for siting near populated areas, must achieve the same level of protection through Exclusion Zones alone. These differences in safety requirements between NPPs and SMRs constitute major design and regulatory challenges. This paper presents the types of SMR designs currently under development, including their status in the design, construction, and operational phases in various countries. Given the nascent stage of SMR development, design and safety regulatory criteria are still evolving. The paper discusses the benefits and drawbacks of deploying advanced SMR units, as well as the associated technological challenges. Comparisons between SMRs and large-capacity NPPs in the context of India are also included. Enabling technologies such as 3D modelling, 3D printing, and artificial intelligence, which enhance safety and supply-chain management, are also addressed.***

Keywords: Small Modular Reactors; Renewable Energy; Coal-Fired Plants; Boiling Water Reactors (BWRs); Pressurized Water Reactors (PWRs)

1. World Nuclear Power Scenario

Global electricity generation was approximately 32,000 TWh in 2025. The generation mix consisted of roughly 57% fossil fuels, approximately 34% renewables (including about 14% hydroelectric power), and approximately 9% from nuclear power plants.

In this mix of electricity-generating technologies, fossil fuels- coal and natural gas- occupy a dominant position. Concerns about the adverse environmental effects of carbon dioxide emissions have led several governments to set target dates for achieving net-zero carbon dioxide additions to the atmosphere. These targets aim to eliminate net carbon dioxide emissions by 2050 and to limit the rise in global air temperature to 1.5°C above pre-industrial levels. Additions to the power generation portfolio should be proportioned to accommodate both base-load and load-following generating plants.

Coal-fired power plants, and particularly nuclear power plants, are well suited for base-load operations. Large-capacity nuclear power plants, being capital-intensive and equipped with massive turbine-generator sets, are not designed to respond rapidly to changes in grid demand, unlike hydroelectric generators or gas-fired generators. Renewable energy (RE) sources generate power only during daylight hours or favorable wind conditions and, being relatively economical to dispatch, are not well suited for load following. Nuclear energy generates substantial power using minimal land area and operates independently of weather conditions. Nuclear power plants have historically demonstrated capacity factors exceeding 80%, making them a dependable base-load source compared with intermittent renewable sources. Nuclear power also improves local air quality by replacing polluting fossil fuel assets with a zero-emission source, thereby eliminating carbon dioxide, sulphur dioxide, nitrogen oxides, and particulate matter.

Therefore, replacement of fossil-fired plants with nuclear power units is a preferred option for base-load supply. Some of these units should also be capable of load following. Nuclear power plant units of large capacities (700 MWe to 1,650 MWe), along with smaller units (40 MWe to 300 MWe), need to be considered to meet the impending shortfall as fossil-fired power declines. Small power units, known as Small Modular Reactors (SMRs), are being developed by several countries. Most of these- referred to as Category 1- are conceptually smaller versions of existing proven large nuclear power plant designs. High-Temperature Gas-Cooled Reactors (HTGRs), Sodium-Cooled Fast Reactors (SFRs), and Molten Salt Reactors (MSRs), classified as Category 2, require considerable further development and are expected to enter the commercial market as demonstrated power generators in the more distant future.

2. Introduction to SMRs

Small Modular Reactors represent one of the most significant additions to nuclear energy strategy in recent decades. SMRs are broadly defined by the International Atomic Energy Agency (IAEA) as nuclear reactors with an electrical output of up to 300 MWe. However, their defining characteristic is not merely their size but their underlying philosophy of modularity and factory fabrication.

Unlike large reactor components- which are massive and involve extensive site-specific civil and mechanical engineering construction- SMR components are designed to be manufactured and assembled in manageable modules in a controlled factory setting and then shipped to a site. This approach has the potential to reduce construction times for the nuclear island. By relocating the construction of major equipment, such as reactor pressure vessels and their internal components, to a factory environment, SMR designers plan for serial production under controlled conditions. While the first-of-a-kind (FOAK) unit is costly, the installation of a greater number of units reduces costs through standardization, mass production, and shorter construction schedules.

Current SMR designs incorporate improved safety features intended to meet projected regulatory requirements for reducing reactor core melt probability to negligibly low values. Many designs rely on passive safety systems- using natural physical phenomena such as gravity and natural circulation rather than complex, powered systems such as pumps and diesel generators- to cool the reactor during an emergency. Present designs of large nuclear power plants also rely substantially on stored water, such as emergency core cooling water storage, to provide cooling during severe accident conditions for a limited time without operator action. Similar features are incorporated into most upcoming SMRs, but with an operator grace period extended to several days during severe emergencies. A smaller reactor contains less radioactive material and a proportionally larger in-vessel coolant inventory relative to its power output. This, combined with passive safety systems, forms the foundation of the entire SMR siting and public safety assurance framework. The best practices developed over approximately 20,000 reactor-years of accumulated global operation- in areas including operational safety, waste management, and regulatory oversight further ensure low risk from SMRs.

SMR sites can be located near established population centers as replacements for existing fossil-fired plants due for retirement. placing nuclear facilities closer to urban areas can be done if siting regulations allow their siting. SMRs can also utilize existing infrastructure, including heavy-duty roads for equipment transport, grid transmission lines, and water access, thereby avoiding new and costly construction on land in local communities.

3. Main Features of SMRs Compared with Large-Capacity Nuclear Power Plants

The capacity of current large nuclear power plants ranges from 700 MWe to 1,650 MWe. Per IAEA definition, the maximum rating of an SMR is 300 MWe.

Small-rated SMRs (40 MWe to 70 MWe) are suitable for remote, isolated sites serving primarily local demand. Such sites should ideally host two or more units under a single operational command. A contingent of approximately 200 personnel could operate such units as part of a single station. If such sites are located far from high-voltage grids, they can supply power locally at lower voltages, reducing transmission and distribution (T&D) losses. This is predicated on the assumption that such sites satisfy all other applicable siting criteria.

Higher-rated SMRs (160 MWe to 300 MWe), which are currently under design or in manufacturing, are better suited to replace coal-fired units in situ. Such replacement units could utilize existing switchyards and other auxiliary systems- provided they are found serviceable -to reduce replacement costs.

Nuclear regulatory bodies prescribe limits on radiation exposure to surrounding populations during both normal operations and severe accident conditions applicable to large nuclear power plants. SMRs would need to be designed to provide the same or higher level of radiological protection as mandated for Protective Action Zones and Emergency Response Zones applicable to large NPPs. Detailed regulatory requirements for SMRs will evolve as specific designs are presented for licensing. The design target for SMRs is to require only a smaller Exclusion Zone, enabling siting closer to population or industrial centers and utilizing less land.

Because of their smaller size, SMRs contain less stored radioactivity. They are designed with safety systems to ensure effective containment and emergency control such that no emergency conditions extend beyond the Exclusion Zone, even under accident conditions. These characteristics are now also part of the regulatory requirements for Generation III, Generation III+, and Generation IV large nuclear power plants.

4. SMR Design Options: Category 1 (Generation III+)

Category 1 SMRs are based on light-water reactor (LWR) technology and broadly reflect Generation III+ safety philosophies. These designs encompass pressurized water reactors (PWRs) and boiling water reactors (BWRs) and represent evolutionary developments of commercially proven large reactors. As a result, they are the most mature SMR concepts for near- to medium-term deployment.

Early low-power LWRs, including natural-circulation BWRs such as Humboldt Bay (USA), Dodewaard (Netherlands), and KLT-40S (Russia), operated successfully at power levels of approximately 50–65 MWe. These plants demonstrated the feasibility of low-power LWR operation and provide a historical basis for current SMR concepts. Current large NPP designs and SMR designs alike incorporate enhanced safety provisions reflecting lessons learned from the severe accidents at Three Mile Island (1979) and Fukushima Daiichi (2011).

A defining feature of certain SMR-PWR designs is the adoption of an integral primary system configuration, in which the reactor core, pressurizer, steam generators, and primary coolant pumps are housed within a single pressure vessel. In some designs, only the coolant pumps are located outside the vessel but in close proximity; others eliminate coolant pumps entirely by relying on natural circulation. These configurations significantly reduce large-diameter primary piping and, consequently, the likelihood and consequences of loss-of-coolant accidents. SMR-BWR designs similarly employ large pressure vessels with integrated steam separation and drying systems. Most SMRs incorporate substantial internal water inventories to support passive decay heat removal.

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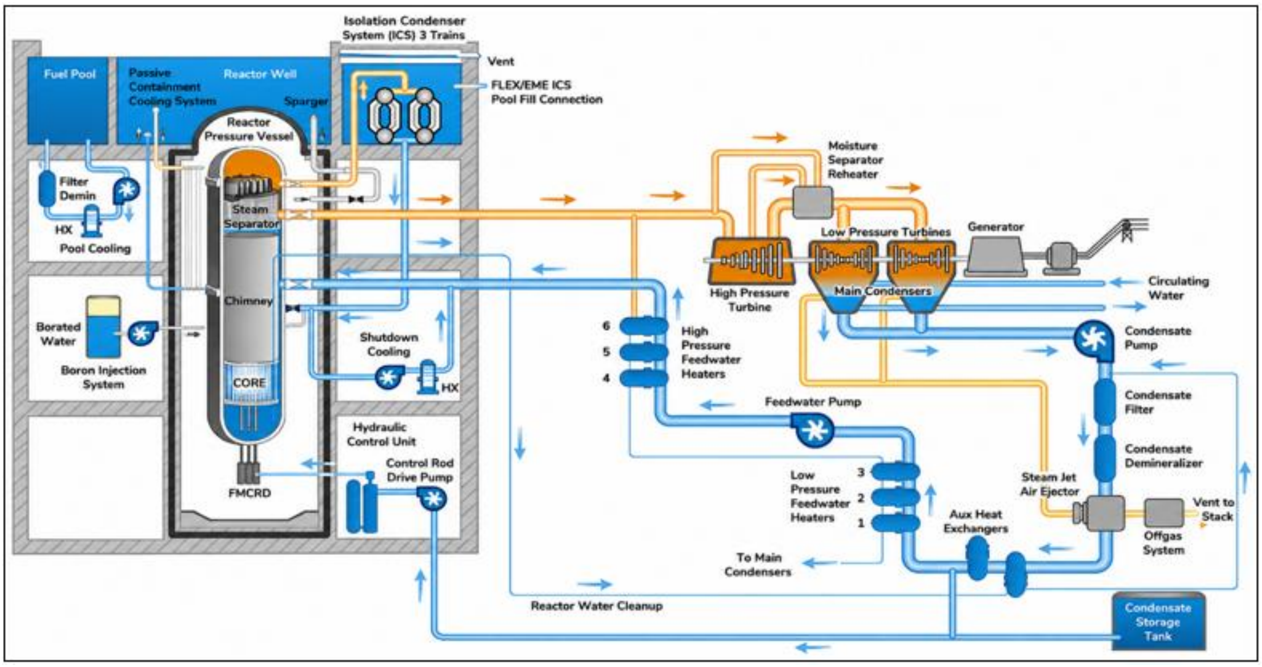
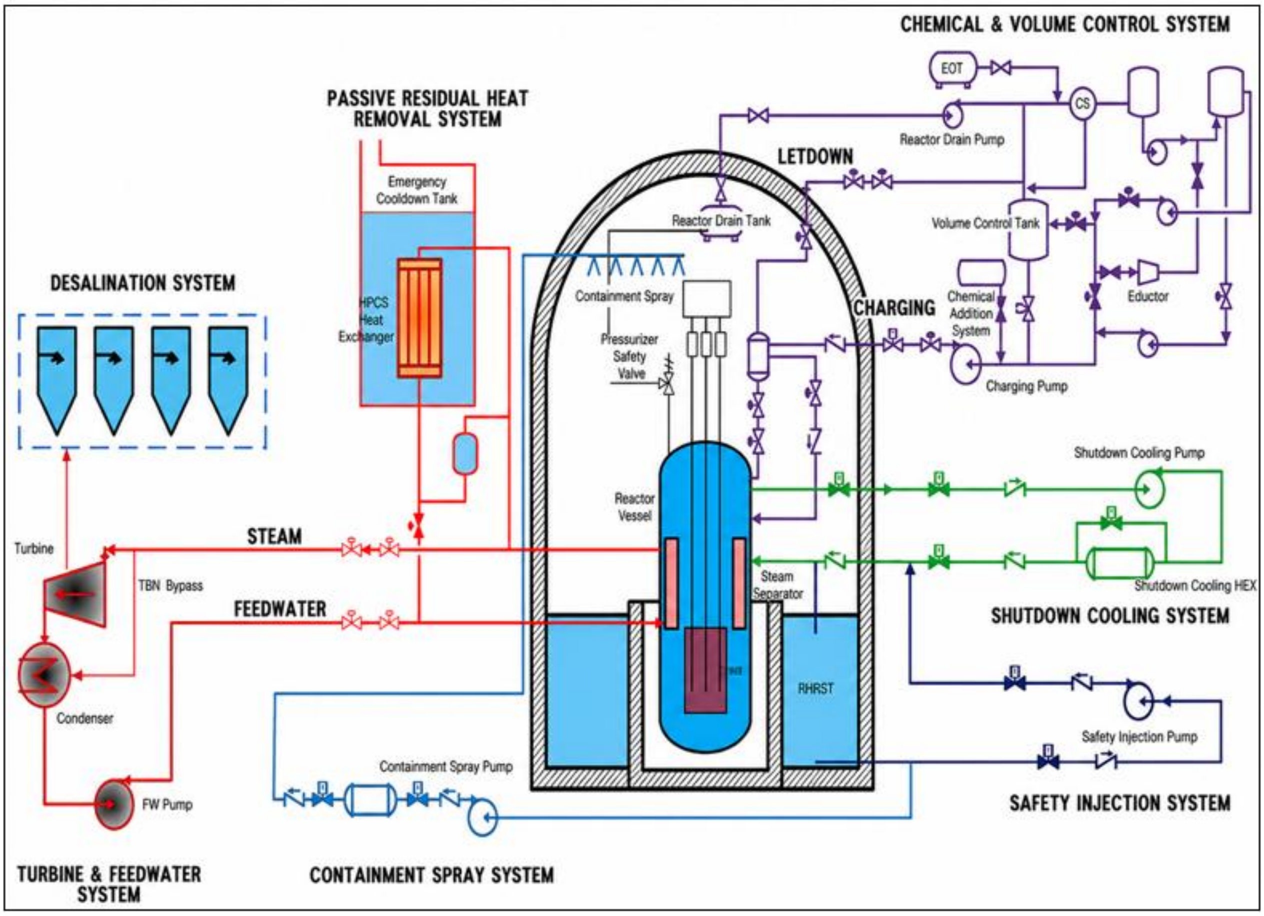
Several SMR-PWR concepts eliminate soluble boron for routine reactivity control, relying instead on fine-motion control rods for power regulation and load following. Diverse and redundant shutdown systems- including gravity-driven control rods and boron injection- are retained for accident mitigation. The elimination of soluble boron reduces the potential for positive void reactivity feedback and simplifies chemical control of the primary system. It also reduces the extent of corrosion of the primary coolant circuit and gives the plant operator the freedom to flood the primary coolant system with demineralized water alone. The combined effect of these features supports a design target of fewer than one severe core damage with off-site effects event per 100 million reactor-years.

Comparative assessments of representative designs indicate reduced core power density, extended station blackout coping times, and lower calculated frequencies of core damage and large radioactive release compared with large Generation III reactors. These characteristics support proposals for reduced emergency planning zones, subject to regulatory acceptance.



Flow Schematic for SMR-BWR



Flow Schematic for SMR-PWR

The simplicity and economy of SMR-BWR and SMR-PWR designs relative to their larger counterparts can be inferred from the technical comparison provided in Table 1.

Table 1: Technical Features of Representative SMR-BWR and SMR-PWR Designs

Feature	SMR-BWR	SMR-PWR
Reactor Pressure Vessel Geometry	Vertical	Vertical
Primary Coolant / Secondary Coolant	Demineralized water (moderator and coolant)	Primary: demineralized water Secondary: demineralized water
Primary Coolant Pumping System	Natural circulation	Recirculation by canned motor pumps
Primary Coolant Volume Control	Integral steam space above reactor core	Integral steam space above reactor core
Steam Generation	Primary coolant used directly as live steam for turbine-generator	In-vessel heat transfer tubes for raising steam for turbine-generator
Reactor Power Control (Normal Operations)	Fine-motion control rod clusters	Fine-motion control rod clusters
Emergency Shutdown System	Gravity-driven shutoff rod clusters	Gravity-driven shutoff rod clusters
Backup Emergency Shutdown	DC-powered boron injection into reactor pressure vessel	DC-powered boron injection into reactor pressure vessel
Containment Material	Carbon steel	Carbon steel
Containment Volume (m³)	5,600	15,625
Containment Pressure (kg/cm²)	4.27	Not available
Containment Leakage Rate	~0.25% per day under DBA	~0.25% per day under DBA

DBA = design basis accident.

5. SMR Design Options: Category 2 (Generation IV)

Category 2 SMRs- often referred to as Advanced Modular Reactors (AMRs)—are based on Generation IV concepts developed collaboratively by a group of countries and employ alternative coolants, fuels, and neutron spectra. The principal reactor classes include High-Temperature Gas-Cooled Reactors (HTGRs), Molten Salt Reactors (MSRs), and Sodium-Cooled Fast Reactors (SFRs).

HTGRs utilize TRISO-coated particle fuel and helium coolant, enabling operation at coolant outlet temperatures typically between 750°C and 900°C. This high outlet temperature makes HTGRs attractive for industrial process heat applications and hydrogen production. MSRs dissolve fissile material directly in molten salt coolant, allowing operation at low system pressure and offering potential advantages in fuel utilization and inherent safety characteristics. SFRs employ liquid sodium coolant and a fast neutron spectrum, enabling efficient use of uranium resources and the potential transmutation of long-lived radioactive waste.

India has operated a sodium-cooled Fast Breeder Test Reactor with a thermal power of 40 MWt (approximately 12 MWe) for more than 40 years. The Indira Gandhi Centre for Atomic Research, under the Department of Atomic Energy, has conducted substantial research and development on SFRs, and a 500 MWe prototype fast breeder plant is currently in the commissioning phase.

Despite their theoretical advantages, Category 2 SMRs have limited operating experience and face substantial challenges related to materials performance, fuel qualification, licensing, and fuel-cycle infrastructure. Consequently, their widespread commercial deployment is expected to follow that of Category 1 SMRs.

6. Policy Framework for SMR Deployment

For SMRs to contribute meaningfully to decarbonization goals, national policy frameworks must clearly articulate their role within broader energy strategies. Policies must address how SMRs will integrate with existing electricity grids. Policymakers need to establish clear rules for siting, permitting, and environmental assessment that account for the unique modular nature of SMRs. Policies should also address the full lifecycle of SMRs, from construction and operation through waste management and eventual decommissioning.

The successful deployment of SMRs depends heavily on international cooperation and the establishment of consistent global standards. The IAEA plays a central role in setting global benchmarks for nuclear safety, security, and safeguards. It guides national regulators and helps build public confidence that SMRs can be deployed responsibly.

7. Cost and Financing of SMRs

The cost of electricity from SMRs remains largely uncertain at present, as no firm commercial data are available. Current international estimates for first commercial SMRs indicate overnight capital costs in the range of USD 3550 to USD 6,250 per kWe in terms of 2022 US$. For practical planning, many analysts currently use USD 4,500–5,500 per kWe for early commercial deployments. Capital and annual operating costs in India are expected to be lower than international averages.
The principal contributors to capital costs are: US$
1) Reactor island and nuclear steam supply system
2) Civil works and buildings
3) Modular fabrication and transport
4) Instrumentation and control systems
5) Cooling water systems
6) Safety systems and containment
7) Engineering, licensing, and project management
8) Owner's costs, training, and commissioning

The total annual operating cost of a 300 MWe SMR is estimated at USD 44–51 million in terms of 2022 US$. The principal contributors to annual operating costs are:
9) Nuclear fuel
10) Operations staff
11) Maintenance
12) Waste management
13) Insurance
14) Decommissioning fund contributions

Financing is a critical determinant of whether SMRs can advance from concept to widespread deployment. Despite their inherent advantages, SMRs still face high upfront capital requirements and significant investor uncertainty. A key financial hurdle is the perceived risk associated with nuclear energy; investors remain cautious due to historical cost overruns, construction delays, and public opposition. In this context, domestic financing plays a critical role in enabling SMR deployment, particularly during the early phases of commercialization. Public–private partnerships can also mobilize private capital while distributing financial risk, especially for FOAK deployments.

8. Global Status of SMR Development

Many countries are pursuing SMR development programs encompassing a wide range of reactor types, power levels, fuel enrichments, and coolants. Designs range from sub-megawatt microreactors intended for remote applications to units approaching 300 MWe designed for grid-scale electricity production. Current projections suggest that several hundred SMR units could be deployed worldwide by 2040, subject to regulatory approval, supply-chain readiness, and economic viability. While this diversity reflects national priorities related to energy security and decarbonization, it also presents challenges for regulatory harmonization and standardization.

Artificial intelligence is creating a new class of ultra-high-power consumers that require reliable, around-the-clock electricity. SMRs offer a unique combination of reliability, scalability, energy security, and carbon-free generation that aligns well with the operational requirements of AI data centers. As SMR technology matures and regulatory frameworks evolve, dedicated nuclear-powered AI campuses are likely to become an important component of the global digital infrastructure ecosystem. Countries that successfully integrate SMRs with AI and cloud computing facilities may gain significant advantages in technological competitiveness, energy security, and sustainable economic development.

At present, the share of total nuclear power generation attributable to SMRs is very small. By 2035, it is projected to reach 1–2%. By 2040, this share is expected to rise to 5–10%, and to 10–50% by 2050.

9. Status in India

India currently generates approximately 19% of its electricity from renewables (including hydropower), 75% from fossil fuels, and approximately 3% from nuclear power plants. The national objective is to reduce the contribution of fossil fuels and increase the share of nuclear power.

In the Union Budget 2025–26, the Government of India announced an allocation of ₹20,000 crore (approximately USD 2.3 billion) for SMR research and development. India's strategy is built on self-reliance and is aimed at decarbonizing its heavy industrial base by deploying SMRs as captive power plants. Recognizing nuclear power as a critical component for achieving energy security and sustainability, the Government has introduced the Nuclear Energy Mission for Viksit Bharat.

The Government plans to enter into public–private partnerships with the following objectives:

Establishment of Bharat Small Reactors: Nuclear Power Corporation of India Ltd. (NPCIL) is offering its proven BSR 220 design- a 220 MWe pressurized heavy water reactor (PHWR) incorporating advancements over its existing fleet- as a captive power unit option.

Research and Development of Bharat Small Modular Reactors: NPCIL and the Bhabha Atomic Research Centre (BARC), under the Department of Atomic Energy, are designing and developing the following SMR models:

- BSMR-200: A PWR-based design utilizing low-enriched uranium (LEU) fuel. Commercial operation is planned by 2033.
- SMR-55: A PWR-based design featuring a block-type, highly modular configuration. Commercial operation is planned by 2033.

The Parliament of India has enacted the Sustainable Harnessing & Advancement of Nuclear Energy for Transforming India Act, 2025 (SHANTI Act). This legislation repeals both the Atomic Energy Act, 1962, and the Civil Liability for Nuclear Damage Act, 2010, and aims to accelerate the civil nuclear regulatory framework while opening the nuclear power sector to regulated private participation.

In the Union Budget 2026, the Government announced a proposal to extend the exemption on basic customs duty for imported goods required for nuclear power projects until 2035, as India accelerates its efforts to expand atomic energy capacity to 65 GWe by 2032 and 100 GWe by 2047.

Internationally, India is actively collaborating with France, the United States, and Russia on SMR development to complement its indigenous capabilities. India is also working with the IAEA to help develop global safety and licensing frameworks for SMRs. Through coordinated efforts in domestic innovation, regulatory modernization, policy reform, and international cooperation, India is positioning itself as a leading global center for SMR development and deployment.

10. Role of the IAEA in SMR Development

The IAEA has established a Platform on SMRs to enable member countries to coordinate review and support for all aspects of SMR development and deployment, including applications such as district heating and desalination. The IAEA is assessing the extent to which existing safety standards can be applied to innovative SMR technologies and published Safety Report TECDOC-1036, "Design Requirements for Small Modular Reactors for Near-Term Deployment," in 2020. These requirements are particularly relevant for SMRs intended for siting in or near industrial or population centers.

The principal safety considerations for SMRs based on LWR technology, as identified in that report, are as follows:

While design requirements regarding redundancy, diversity, and single-failure criterion are retained, particular attention must be given to fluid-flow phenomena arising from the small driving heads in reactors operating under natural circulation during both normal operations and accident conditions. The use of sophisticated analytical tools covering all aspects of plant behavior-including accidents- is both necessary and facilitated by the fact that SMRs are relieved of certain active core cooling systems due to their large passive water-filled pressure vessels and gravity-driven containment cooling tanks. Modern SMRs are also well suited to application of digital system and sub-system modeling in active operational modes, to the provision of expert guidance to operators under all operational and emergency conditions, and to guidance of plant authorities in emergencies with potential for off-site consequences.

SMR designs are intended to practically eliminate severe accidents and design extension conditions leading to large-scale fuel melt and environmental release. Design targets call for severe accidents to occur at a frequency of less than one event per 10^8 reactor-years, rendering such accidents highly improbable.

The design of multi-unit SMR sites must address the following considerations:

- Design extension conditions (DECs) arising from the co-location of multiple SMR units at a single site.
- Access to containments under DEC conditions.
- Loss of off-site power affecting multiple units at the same site, noting that SMRs are expected to cope with total loss of electrical power for initial periods of several days.
- Ventilation and air-conditioning issues for multi-unit sites, particularly with respect to off-site public doses at the boundary of the Exclusion Zone.
- Radioactive waste management for multi-unit installations.
- Internal and external hazards associated with multi-unit siting.
- Establishment of emergency response stations within the Exclusion Zone.
- Control and protection systems configured to prevent a postulated initiating event (PIE) on one unit from propagating to other units at the same site.
- Human factors issues, including those associated with a single operator managing two or more units from a common control room, supplementary control stations, and off-site emergency control centers.

11. Critical Challenges on the Road to Commercialization

Despite their considerable promise, SMRs face formidable strategic, economic, and social hurdles:

- SMRs, being relatively new, do not possess the extensive operating history of their larger counterparts. There is understandable reluctance to accept their siting near population or industrial centers without the perceived protection afforded by Protective Action Zones and Emergency Response Zones.
- Public concern persists regarding the potential release of radioactive pollutants into local water or air. Security requirements for nuclear installations, complex international safeguards obligations, and the limited availability of adequately trained manpower for SMR design, construction, and operation represent additional barriers to widespread deployment. Large reactors were installed rapidly and in large numbers by advanced countries in the 1960s and 1970s, establishing a precedent. SMRs similarly need to be adopted by advanced countries in significant numbers to demonstrate and validate the technology.
- The upfront costs associated with research, design, infrastructure development, manufacturing, technology acquisition, and skilled labour are very high on a per-megawatt basis.
- FOAK units are relatively costly per megawatt compared with established large-plant technologies. The SMR economic model relies on economies of scale from large production volumes, but initial units are proving costly to build.
- The scarcity of actual design and performance data makes it challenging to develop comprehensive regulatory standards.
- Critical components such as reactor pressure vessels and advanced heat exchangers are difficult to procure, with manufacturing capacity concentrated in a few countries. Developing indigenous supply chains requires significant time and investment.
- SMRs are marketed as a clean technology, but Category 1 designs produce the same types of long-lived radioactive waste as large reactors and do not resolve the long-term nuclear waste management challenge. India, having entered the fast reactor technology domain, is already managing spent nuclear fuel in a manner whereby long-lived waste is consumed in fast reactors and other advanced technologies currently under development.

12. Supply Chain Considerations

The SMR supply chain encompasses raw material procurement, component manufacturing, module assembly, transportation, site construction, operation and maintenance, and eventual decommissioning. Modular fabrication offers opportunities for schedule compression and cost reduction but also introduces logistical challenges, particularly for the transport of larger modules and the management of nuclear fuel, radioactive waste, international safeguards, and security across a potentially large number of sites.

Reliable off-site supply chains are essential for fuel delivery, spent fuel removal, and waste disposal, as extended on-site storage is generally undesirable for SMR installations. Supply-chain resilience is therefore a critical factor in SMR project viability.

13. Application of Enabling Technologies

Advanced engineering and digital technologies are expected to play a significant role throughout the SMR lifecycle. Intelligent piping and instrumentation diagrams, integrated three-dimensional plant modeling, additive manufacturing, and artificial intelligence-based systems support design optimization, construction planning, predictive maintenance, and operational decision support.

The application of these technologies has the potential to enhance safety, reduce construction times, and improve economic performance. However, their deployment in nuclear applications requires rigorous qualification, validation, and regulatory acceptance. To date, three-dimensional plant modelling using licensed software has received regulatory acceptance, while the use of additive manufacturing and artificial intelligence remains subject to limited regulatory endorsement.

14. Conclusions and Recommendations

Small Modular Reactors constitute an important evolutionary step in nuclear power technology, offering enhanced safety characteristics, siting flexibility, and options for more flexible electricity grid management. Category 1 SMRs based on LWR technology are approaching commercial readiness, whereas Category 2 designs require further development and demonstration. Successful deployment will depend on rigorous safety assessment, mature regulatory frameworks, and resilient supply chains—particularly for installations in or near urban and industrial environments. Large-capacity NPPs and SMR units should be developed and deployed in a complementary manner, with large NPPs serving base-load demand and SMRs addressing peaking loads and distributed energy needs. National policies must provide clear, stable support frameworks to enable the investment and international cooperation required to bring SMRs to commercial scale.

References

[1] Energy Institute – Statistical Review of World Energy.
[2] Global Electricity by Source 2024-Wikipedia.
[3] Government of India Document June,2025 “Road Map for Achieving the Goal of 100 GW of Nuclear Power by 2047”
[4] IAEA-IRIS” Advances in Small Modular Reactors” 2020.
[5] S.P.Singh “Small Modular Reactors in Indian Power Generation” International Journal of Science & Technology, vol. 8, issue no. 3, 2023.
[6] Small Modular Reactors-World Nuclear Association.
[7] S. P. Singh “Abnormal Generation of Hydrogen in Fukushima BWRs” International Journal of Science and Research (IJSR)” July 2020.
[8] Small Modular Reactors: A Global Climate Solutions Insights on Emissions Reduction, Low-Carbon Development, Clean Energy Transition, Sustainable Infrastructure, and Energy Security-Robert C. Brears
[9] Energy Institute. Statistical Review of World Energy. London: Energy Institute; 2024.

[10] Global Electricity by Source 2024. Wikipedia. Available at: https://en.wikipedia.org/wiki/Global_electricity_by_source.
[11] Government of India. Road Map for Achieving the Goal of 100 GW of Nuclear Power by 2047. New Delhi: Government of India; June 2025.
[12] International Atomic Energy Agency. Advances in Small Modular Reactors. IAEA-IRIS. Vienna: IAEA; 2020.
[13] Singh SP. Small Modular Reactors in Indian Power Generation. International Journal of Science & Technology. 2023;8(3).
[14] World Nuclear Association. Small Modular Reactors. London: World Nuclear Association. Available at: https://world-nuclear.org.
[15] Singh SP. Abnormal Generation of Hydrogen in Fukushima BWRs. International Journal of Science and Research (IJSR). July 2020.
[16] Brears RC. Small Modular Reactors: A Global Climate Solutions Perspective — Insights on Emissions Reduction, Low-Carbon Development, Clean Energy Transition, Sustainable Infrastructure, and Energy Security. [Publisher information to be supplied by authors].

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