



POWERING THE NEXT BILLION

A Regulatory and Investment Roadmap
for SMR Deployment in India

CAIG

CENTRE FOR
ACCELERATING INDIA'S GROWTH

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EXECUTIVE SUMMARY

1. India has scaled renewable energy capacity in the last decade. The next great energy challenge is securing reliable, clean, round the clock electricity for power intensive drivers of growth such as data centers, heavy industries, and semiconductors.
2. Small Modular Reactors are compact, factory built nuclear units that can provide firm decentralised solutions to the new and emerging loads.
3. Three gaps must be closed before SMRs can compete with mature technologies: improving technology readiness, bringing regulatory clarity and cutting down the levelised cost of First-of-a-Kind (FOAK) projects by 50%.

4. INDIA'S POLICY RESPONSE

a. Legislative Foundation

The SHANTI Act 2025 opens nuclear power to private sector participation. It fixes liability for reactors in the 150–750 MW range at ₹300 crore and in the <150 MW range at ₹100 crore, directly improving SMR financial viability. The space is opening for FDI also.

b. Public Investment

Government has allocated ₹20,000 crore under the Nuclear Energy Mission to develop at least 5 indigenously designed SMRs by 2033. Bhabha Atomic Research Centre (BARC) is developing the 220 MWe reactor, the 55 MWe (SMR-55) and a high temperature gas cooled reactor for hydrogen production.

c. International Partnerships

India has entered into bilateral partnerships on SMRs with France on codevelopment of SMR technologies, with Russia on equipment localisation, and with the US on transfer SMR technology.

5. STRUCTURAL CONSIDERATIONS

a. Cost Gap

FOAK SMR projects are estimated at \$120/MWh, 50% above the grid benchmark. The study models an 8% learning rate and identifies the 25th SMR unit as the point of cost competitiveness, with fiscal support required across all 25 units.

b. Supply Chain Gaps

Uranium import and enrichment remains a structural bottleneck, with domestic capacity developed primarily for strategic rather than civilian use. Steam turbine production takes a minimum of four years, with components like U-tube and reactor pressure vessel completely imported.

c. Indigenisation

Global OEMs currently prefer exporting complete units rather than local manufacturing. Indigenisation beyond 45% is achievable if demand expands.

d. Regulatory Misalignment

Developers claim that SMRs have walk away safety designs. However, exclusion zones calibrated for large reactors must be recalculated based on actual dose projections for each SMR design. As civil nuclear energy integrates into the broader electricity market, formal coordination between Atomic Energy Regulatory Board (AERB) and Central Electricity Regulatory Commission (CERC) needs to become the next institutional frontier.

e. Site Readiness

The study identifies 49 old and hyperpolluting thermal units with cumulative capacity of 11.2 GW as candidate SMR sites. They offer ready grid connections, existing cooling infrastructure, and trained workforces, reducing development timelines and greenfield costs.

f. Global Lessons

The US links fiscal support through a production tax credit that tapers as plant revenues rise, while joint US-Canada design reviews enable a fleet licensing model that India can replicate. Inclusion of nuclear energy in the EU sustainable finance taxonomy reduced borrowing costs by 25–50 basis points: India's climate finance taxonomy should follow suit.

6. POLICY ROADMAP:

a. Capital Support

An incentive model combining GST reduction, import duty waivers, and interest subvention, reduces the required Viability Gap Funding(VGF) to 17%, reducing fiscal burden to \$ 1.09 billion for the first 10 units. The next 15 Nth-of-a-Kind (NOAK) units achieve cost competitiveness through fiscal incentives alone, with no direct subsidy required. Import Duty waivers should be extended to SMR components for Indian designs as well.

b. Demand Signals

Incorporation in green finance taxonomy and aggregation through Railway Energy Management Company Limited (REMCL) under Indian Railways can gauge investments. Introduce phased Carbon-Free Power (CFPO) targets for large consumers. Aggregation must support indigenisation of components like U-tube and straight tubes.

c. Network and Dispatch Incentives

Must run dispatch status and an Inter State Transmission System charge waiver for up to the debt tenor of 15–20 years should be granted to SMR projects. Tax holidays of up to 7 years should be provided to emerging loads consuming SMR sourced electricity. A 30 day power banking facility should be enabled to enhance revenue optimisation across the project lifetime.

d. Community Acceptance

Land clearance should be fastracked and have community support. Host districts should receive fiscal benefits and a share of operator revenues, converting public acceptance from a risk into a policy variable.

e. Exclusion Zone Rationalisation

The AERB Safety Code should be amended to replace the fixed 16 km safety zones with a risk informed range of 400–800 metres for SMR based on dose projection.

f. Single Window Clearance

A timebound Nuclear Energy Single Window (NESW) should be established, digitally integrating approvals across ministries for non safety clearances.

g. Graded Liability

Liability proportional to project scale must be introduced. For example, a separate liability tier of ₹10–50 crore should be introduced for microreactors and portable power modules used in remote and captive applications.

h. Inter Regulatory Coordination

A formal protocol between AERB and CERC through a joint working group should be developed for joint role in grid integration, dispatch scheduling, and tariff determination.

i. Research and Development

Dedicated funds through Anusandhan National Research Foundation (ANRF), the Nuclear Energy Mission, and the RDI Fund for advanced technologies and research. Develop Centres of Excellence for long term scientific capacity building and training in reactor physics, 3S (Safety, Security and safeguard) and nuclear materials science.

j. Supply Chain

Commercial scale civilian enrichment facilities for slightly enriched uranium must be built as a prerequisite for fuel security. Link technology transfer with long term fuel supply agreements,

including government negotiated assurances of up to 20 years with supplier countries.

k. Indigenisation

Progressive domestic value addition targets should rise to 80% by 2047, supported by dedicated R&D for modularisation and advanced fuel fabrication. Ensure that incentives extend to supply chain components.

l. International Design Harmonisation

India should propose an IAEA-led institutionalised design clearance framework to streamline approvals for internationally certified reactor designs, removing redundant national reviews. The Indian Regulators should retain authority over local safety, environmental, and site-specific assessments, ensuring contextual oversight within a harmonised global system.

m. Minimum eligibility criteria

Minimum participation criteria should be established across five dimensions: 51% Indian ownership, financial health thresholds, certified nuclear quality and safety assurance systems, phased local value addition targets starting at 45%, and pre qualification standards for safety culture and emergency preparedness. These build on the SHANTI Act foundation incorporating global best practices.

BACKGROUND AND CONTEXT OF THE STUDY

1.1 Introduction

India's electricity demand is growing rapidly with rising economic development, industrialisation and urbanisation. In FY25, India consumed 1,694 billion units of power, 33% higher than FY21, representing a 5 year Compound Annual Growth Rate (CAGR) of 7.4% (IBEF, 2025). This underscores the need for sustainable and reliable energy solutions that continue to provide power which is essential for India's economic expansion while ensuring this growth is sustainable.

Coal remains crucial to India's energy mix, contributing over 67% of total electricity generation, supporting grid reliability amid rising electricity demand (PIB, 2025). With the falling costs of renewable energy and India's commitment to install 60% non-fossil energy by 2035, the country has increasingly adopted renewable energy technologies such as solar, wind and hydropower. However, the inherent intermittency of wind and solar power poses a significant challenge. Solar energy is typically available for only 6 to 8 hours a day and is subject to seasonal variation and wind power can also have significant intraday as well as inter seasonal variations (PIB, 2022). This has prompted India to explore nuclear energy as a complementary solution to enhance grid stability and advance its clean energy transition.

Nuclear energy is the fifth largest source of electricity in India, contributing about 3% of the country's total electricity generation (PIB, 2025). To complement the adoption of intermittent renewable with steady baseload, the Government of India aims to install 100 GW by 2047 up from the current 8.8 GW, which calls for more than 10 times expansion. To contextualise this into annual adoption, India needs to adopt 4.14 GW of nuclear energy per year for the next 22 years (CEA, 2025).

Despite its low carbon credentials, conventional nuclear power in India faces multiple challenges,

including long construction timelines and high upfront capital costs, that lead to delays and cost overruns (CEA, 2025). However, recent advancements and innovation have opened new possibilities in the nuclear energy sector. Small Modular Reactors (SMRs), with their compact size, modular construction, and enhanced safety features, are emerging as a solution to the capital cost problem. In the Union Budget 2025-26, the Government of India allocated ₹20,000 crore for developing at least 5 indigenously designed and operational Small Modular Reactors (SMR) by 2033 under the Nuclear Energy Mission (PIB, 2025). Furthermore, the enactment of the SHANTI Act provides greater regulatory clarity and enables licensed private participation, facilitating the transition of SMRs from policy intent to commercial deployment.

1.2 About the Report

India is one of the initial movers in the SMR technology. To become a global leader in this space, it needs to develop a dedicated roadmap to demonstrate these technologies. This report addresses the gap in commercial deployment of SMRs by conducting a techno economic comparative analysis against coal, large nuclear, and renewables. By evaluating supply chain constraints and financial enablers, the research identifies the systemic requirements to "crowd in" private investors and research institutions.

To catalyse the transition of the Indian nuclear ecosystem, the study concludes that a fragmented approach is insufficient. For large scale commercial deployment of SMRs the study proposes a roadmap designed to encourage private participation.

1.3 Research Methodology

This study adopts a qualitative research design based on secondary data sources, combining thematic analysis and stakeholder consultations with indicator based comparative evaluation. The methodology is structured to address two core components of the research: (i) comparing SMRs with other renewable energy technologies based on key indicators, and (ii) identifying and analysing the financial, supply chain and technological constraints, as well as the regulatory and institutional enabling conditions, shaping SMR deployment in India through a national level mission.

1. Data Sources

This research utilises a comprehensive array of secondary data to ensure a multi dimensional analysis of the nuclear energy landscape. Primary policy data was synthesised from government publications, parliamentary proceedings, and official communiqués from the Press Information Bureau (PIB). Quantitative trends and projections were derived from reports by national and international regulatory bodies, including the Central Electricity Authority (CEA), NITI Aayog, and the International Energy Agency (IEA). Furthermore, the study integrates peer reviewed academic literature and industry specific analyses to contextualise the socio-technical and regulatory constraints unique to SMR deployment in India.

2. Indicator Based Comparative Framework

For the comparative evaluation, the study will assess SMRs against coal, large nuclear, and renewable technologies currently deployed in India, including hydropower, wind, and solar photovoltaic systems. The comparison is based on a set of economic, environmental, technological, and operational indicators. These include Levelised Cost of Electricity (LCOE), land use intensity, carbon emissions, safety, Technology Readiness Level (TRL) and construction timeline. To capture operational reliability, round-the-clock power availability is represented using two proxy indicators: capacity factor (average utilisation) and seasonal variability (temporal stability of generation).

The selection of indicators is informed by

established conventions in energy systems analysis and comparative electricity assessment. LCOE is an important metric in assessing the economic viability of various energy generation technologies (Clean Energy Council, 2024). Environmental and social impacts are represented through lifecycle carbon emissions and safety metrics, consistent with comparative assessment by Our World in Data (OWD, 2020). Land use intensity is included to reflect spatial constraints that are particularly relevant in densely populated contexts such as India. The TRL index is a globally accepted benchmarking framework for tracking the progress of technologies from early research stages to system demonstration and deployment (ARENA, 2014). Capacity Factor is another important metric to compare performance of different generation technologies by comparing a power plant's actual output over time to its potential output if it operated at full capacity (IRENA, 2024) whereas seasonal variability captures temporal stability of output.

a. Data Normalisation and Visualisation

Given the differing units and magnitudes of selected indicators, all values were normalised using min-max scaling to enable relative comparison across technologies. For indicators where lower absolute values indicate superior performances, namely LCOE, land use intensity, carbon emissions and safety risk, and seasonal variability, normalisation was performed using an inverse min-max formula:

$$\text{Normalised value} = \frac{\text{Max} - \text{Value}}{\text{Max} - \text{Min}}$$



For indicators where higher absolute values indicate superior performance, specifically TRL, capacity factor, and resource abundance, standard min-max normalisation was applied:

$$\text{Normalised value} = \frac{\text{Value} - \text{Min}}{\text{Max} - \text{Min}}$$

Each indicator was scaled to a 1-5 range, ensuring consistent interpretation across all indicators, where a value of 1 represents the worst performing technology and value of 5 represents the best performing technology for each indicator.

The normalised results are presented using a heatmap visualisation, in which lighter shading indicates stronger relative performance (values closer to 5), while darker shading indicates weaker performance (values closer to 1). The analysis provides a relative comparison rather than absolute rankings and does not apply explicit weighting to individual indicators. (See Figure 3)

3. Thematic Analysis

The study uses thematic analysis to examine the financial and technological constraints, along with enabling conditions, shaping the operationalisation of SMRs in India. This involves reviewing relevant documents and publications to assess current nuclear infrastructure, regulatory structure, legal framework, technology readiness, financing models, and policy frameworks. The analysis evaluates the alignment between India's current energy ecosystem and the requirements for transitioning SMRs from design and policy intent to First-of-a-Kind (FOAK) deployment.

4. Supply Chain Mapping

This study adopts a structured value chain mapping approach to assess industrial readiness and localisation potential for the BSMR-200 and prospective molten salt based SMRs in India. The supply chain is segmented into four core stages: (i) Fuel Cycle, (ii) Nuclear Island / Reactor and Primary Systems, (iii) Balance of Plant, and (iv) Civil Works and EPC.

For each stage, the analysis evaluates domestic manufacturing capability, technological maturity (commercial, pilot, or

laboratory scale), import dependence, and regulatory preparedness. This structured disaggregation enables identification of supply chain vulnerabilities, localisation opportunities, and strategic intervention points for policy, technology transfer, and private sector participation.

5. Site Mapping for Coal to SMR Transition

To explore the feasibility of deploying SMRs in India, a site mapping exercise was undertaken to identify coal based thermal power plant (TPP) units suitable for phased transition. A multicriteria screening framework was applied to identify plants that are both technically viable and strategically relevant for repurposing. The selection of indicators and associated thresholds was guided by existing literature to ensure analytical robustness.

6. Cost Economic for SMRs

The methodology assesses the economic trajectory of SMR by modeling a 220 MW unit size against a FOAK cost of \$ 120/MWh. Utilising an experience curve with an 8% learning rate (LR), the cost of subsequent units is projected using the logarithmic function:

$$C_n = C_1 \cdot (n)^{-b}, \text{ where } b = \ln(1-LR) / \ln 2$$

Where C_n is the cost of the n th unit, C_1 is the FOAK and n represents the cumulative number of units produced.

This projected cost decline is benchmarked against India's "cost of service" for industrial and commercial consumers, priced at \$ 80/MWh to identify the critical "cost competitiveness point", the specific cumulative capacity required for SMRs to become market competitive. Ultimately, the fiscal gap between the declining C_n and the \$ 80/MWh target serves as the quantitative basis for designing a capital incentive structure to support the industry's transition from FOAK to Nth-of-a-Kind (NOAK) status.

7. Global Benchmarking

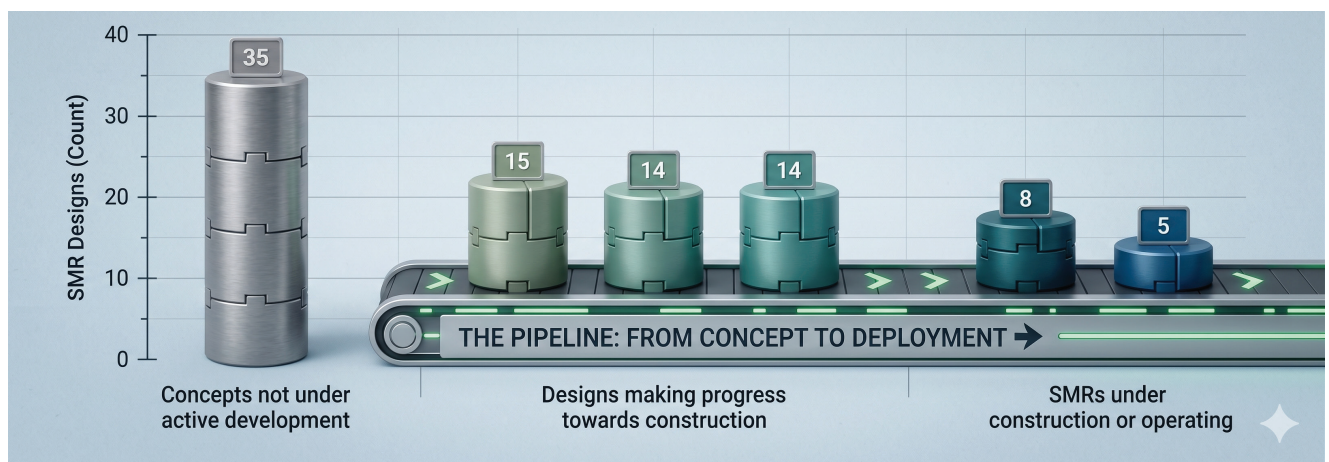
This study utilises a comparative multi jurisdictional framework to benchmark India's SMR initiatives against the global SMR initiatives in countries like the USA, Canada, and the UK. The research evaluates specific policy levers like fiscal and non-fiscal incentives, site identification parameters, ease of deployment measures and standards/licensing to formulate a tailored roadmap for FOAK SMR commercialisation in India.

8. Roadmap for SMR deployment through private sector participation

The final chapter of the study develops a mission level intervention to expand SMR deployment in India aligning with the industrial decarbonisation and coal displacement. A sovereign anchored regulatory framework enables private participation while safeguarding safety and fuel cycle control. Participation models and local manufacturing targets are structured to mobilise capital and build domestic capability. Continuous innovation, fiscal incentives, and biennial reviews ensure adaptive recalibration and long term viability.

9. Limitations

The study relies on secondary data and stakeholder consultations. The findings depend on the availability, quality, and completeness of existing sources. However, efforts are made to triangulate data from multiple reliable references and testing findings with stakeholders to ensure robustness and validity. Furthermore, SMRs have not yet been piloted or commercially deployed in India; current developments remain at the R&D and design stage.



SMR Global pipeline: Progress from concept towards first commercial deployment

CHAPTER - II

WHAT ARE SMRs?

Small Modular Reactors (SMRs) generate power through the same fundamental process as conventional nuclear reactors (harnessing nuclear fission) which produces heat to generate steam, which in turn powers a turbine that creates electricity. SMRs have a lower power output, typically ranging from 5 to 300 MWe, and are modular, meaning that its components can be factory assembled and transported to the installation site as a unit. They can use a range of coolant technology including light water, liquid metal, gas-cooled or molten salt, depending on reactor design (NITI Aayog, 2023). Globally, only 2 SMRs are currently in commercial operation. The first is Russia's Akademik Lomonosov floating power plant, which comprises 2 reactor modules of 35 MWe each and entered commercial operation in May 2020. The second is China's HTR PM high temperature gas-cooled reactor, which entered commercial operations in December 2023 (The Indian Express, 2025).

1. Economic Potential

SMRs present significant economic advantages, especially for developing countries like India with constrained financial resources. Their competitiveness is driven by several factors, including, multiple production of identical units, increased factory production and learning effects, shorter construction timelines, simplified plant designs, and flexible unit deployment. In addition, SMRs can reduce overall electricity system costs by minimising transmission requirements. Unlike large, centralised power plants that rely on extensive high voltage transmission infrastructure, SMRs can be sited close to end users such as data centres, industrial clusters, or repurposed thermal power plant sites. Proximity to demand reduces the need for new transmission lines, lowers grid interconnection costs, and limits transmission losses (ITIF, 2025).

Criterion	Large Reactors	SMRs
Output	700 to 1400 MWe	5 to 300 MWe
Land Use Intensity	259 hectares	7 hectares
Construction Timeline	6 to 12 years	3 to 5 years
Investment	Large scale national infrastructure investment	Smaller investment per reactor
Manufacturing	Partly modularised, large scale onsite construction	Fully modularised, more than 90% of components are prefabricated in factory environment
Safety	Active safety system (require human intervention)	Passive safety system
Fuel Usage	High	Low
Refueling Cycle	1 to 2 years	3 to 7 years
Benefits of Learning Curve	1 unit can be built every 5 to 7 years.	Modularisation can help increase the number of units.

Table 1: Comparison of Large Reactors (LRs) and SMRs

CHAPTER - III

STATUS OF SMALL MODULAR REACTORS IN INDIA

Indigenous SMR portfolio under Nuclear Energy Mission

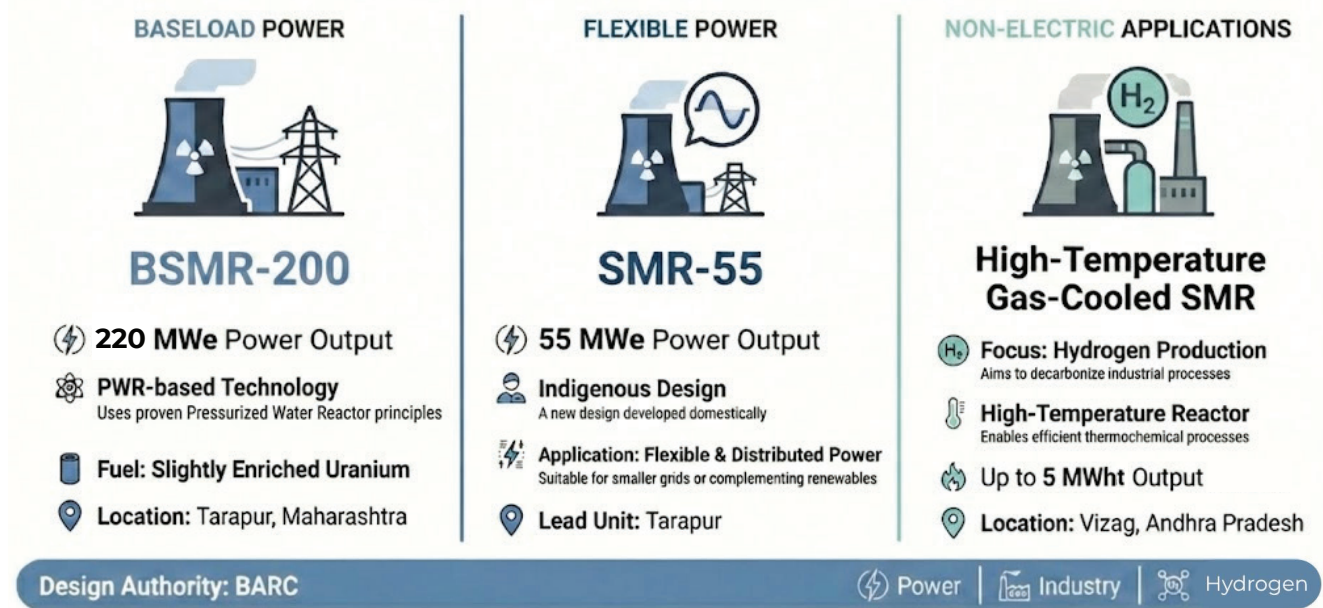


Figure 1: India's Indigenous SMR Portfolio

Under the Nuclear Energy Mission, Bhabha Atomic Research Centre (BARC) has initiated design and development of indigenous SMRs for both power generation and non-electric applications. A key project is the 220 MWe Bharat Small Modular Reactor (BSMR-200) with its lead unit proposed at Tarapur Atomic Power station in Maharashtra. The project is currently at an advanced stage of obtaining administrative and financial sanction. In addition, BARC is developing a 55 MWe Small Modular Reactor (SMR-55), with the lead unit also proposed at Tarapur site. Beyond electricity generation, BARC is pursuing an up to 5 MWth high-temperature-gas-cooled-reactor for hydrogen generation, proposed to be constructed at BARC Vizag, Andhra Pradesh (DEA, 2025). NPCIL issued the RfP for BSMR200 and has received responses from conglomerates like Reliance, Tata Power, Adani Power, Hindalco, JSW Energy, and Jindal Steel & Power responded. The 2033 target plans to install 5 indigenised SMRs including 1 BSMR200 and 4 SMR-55.

India has also begun to engage in targeted international partnerships to facilitate technology transfer, localisation and risk sharing in SMR development. In February 2025, India and France signed a Letter of Intent on Advanced Modular Reactors (AMRs) and SMRs, aimed at co-designing, co-developing, and co-producing SMR technologies (MEA, 2025). In parallel, cooperation with Russia has focused on localisation of nuclear equipment manufacturing and potential deployment of Russia designed SMRs in India (DAE, 2025). Additionally, the United States Department of Energy authorised Holtec International to transfer SMR technology to India, subject to restrictions on third party transfer without US consent (Business Standard, 2025).

There has been increasing interest from private sector players in the deployment of SMR. Tata Power Company Limited, for instance, is currently evaluating potential sites across 3 states for future nuclear projects, including SMRs (Powerline, 2026).

CHAPTER - IV

COMPARATIVE PERFORMANCE ANALYSIS

The technologies selected for comparative analysis with SMRs include coal, large nuclear power plants, hydropower, wind and solar. These are mature technologies with sustained commercial operation in India and together account for the overwhelming majority of installed capacity and actual electricity generation. Technologies such as oil and gas-based power, small hydropower, and bio-power have not been included due to limited availability of consistent and comparable data across selected indicators. Their exclusion does not materially affect the analysis, as these sources together account for a relatively small share both installed capacity and electricity generation in India. Focusing on technologies with substantial grid presence ensures that the comparative assessment remains reflective of India's dominant electricity generation landscape.

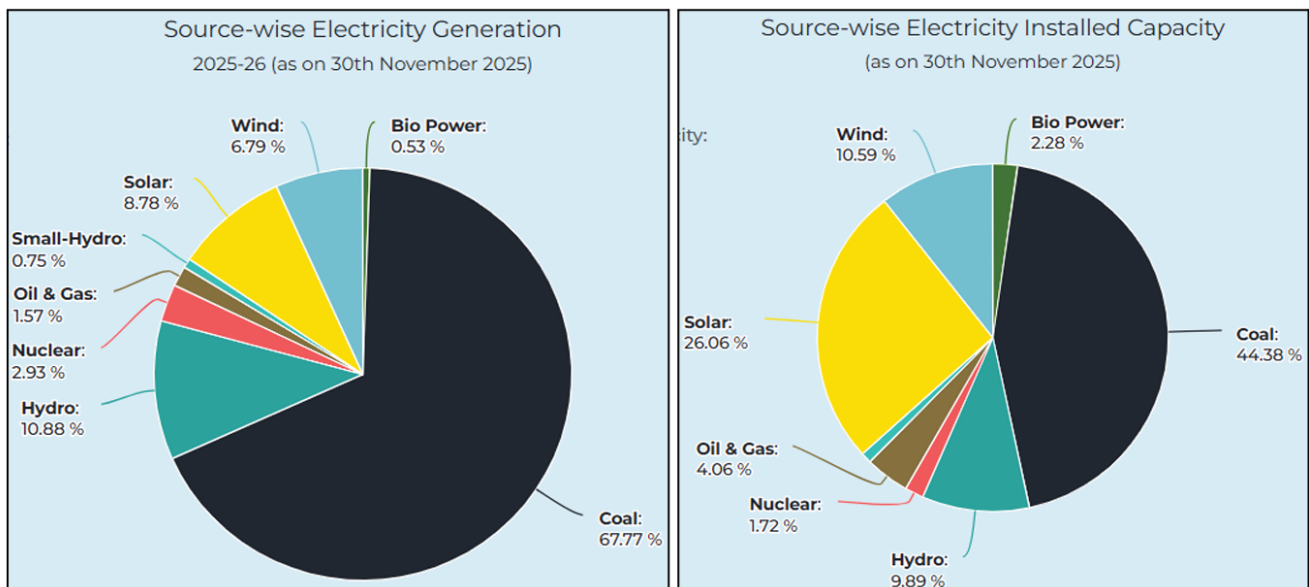


Figure 2: Electricity Generation Mix and Installed Capacity Mix by Source (NITI Aayog, 2025)

[1 = Worst 5 = Best]

Technology	LCOE	Land Use	Carbon Emissions	Safety	TRL	Capacity Factor	Seasonal Variability	Construction Timeline
Coal	2.38	4.40	1.00	1.00	5.00	2.11	5.00	3.13
Hydro	3.90	4.44	4.57	2.65	5.00	1.64	2.33	1.00
Wind (onshore)	5.00	1.00	5.00	4.61	5.00	1.63	1.00	4.47
Solar PV	4.49	4.23	4.46	5.00	5.00	1.00	5.00	5.00
Large NPP	4.05	4.99	5.00	4.77	5.00	5.00	5.00	2.07
SMRs	1.00	5.00	5.00	4.77	1.00	5.00	5.00	3.13

Figure 3: Comparative performance of electricity generation technologies across selected indicators

1. **LCOE** represents the average minimum price at which the electricity must be sold for a power plant to recover its total lifetime costs, including capital, operation, maintenance, and fuel expenses. Existing estimates suggest that the LCOE of SMRs remains higher than that of mature alternatives, especially renewable energy. However, continued investment into R&D, standardisation, and regulatory licensing can potentially reduce costs over time.

As SMR deployment scales up, improved risk profiles and learning effects may enable access to more favourable financing conditions, thereby contributing to lower overall electricity generation costs (EY, 2024). Even if SMRs have higher LCOE than renewables, integrating nuclear power reduces overall system costs because their grid integration costs are lower than those associated with variable renewable energy sources because NPPs generate power 24x7 in all kinds of weather (NEA, 2025). Moreover, SMRs can also be integrated with cheaper but intermittent sources to provide firm power, which reduces the overall system cost.

2. **Land use intensity** reflects the amount of land required per unit of electricity generated, expressed in m²/MWh. Wind and solar PV exhibit substantially higher land use intensity than NPPs, which has among the lowest land requirements. SMRs have a much smaller land footprint than large NPPs (ITIF, 2025). They further enhance land use efficiency due to smaller exclusion zones relative to large NPPs, improving flexibility in site selection and potentially reducing land acquisition challenges.
3. **Safety and carbon emissions** are evaluated jointly to reflect health and environmental impacts per unit of electricity generated. Safety is measured using the death rate per terawatt hour (TWh) of electricity produced, incorporating fatalities from air pollution as well as accidents occurring across the energy supply chain. Source emissions are measured in kg of CO₂ equivalent per MWh. Coal based electricity performs poorly across both indicators due to high air pollution related mortality and greenhouse gas emissions. In contrast, nuclear and renewable energy

technologies exhibit low death rates per terawatt hour and low lifecycle emissions, with residual risks primarily arising from supply chain and construction related accidents. Overall, the findings highlight that reducing dependence on fossil fuels is more critical for improving safety and emissions outcomes than choosing between nuclear and renewable technologies (Our World Data, 2020).

However, this safety indicator does not account for radioactive waste generation. As per the existing estimates, SMRs may generate larger, energy equivalent volumes of low and intermediate level waste (LILW) compared to conventional reactors. In particular, neutron activated LILW presents additional management challenges, as radiation exposure must be controlled both during reactor operation and over long term geological disposal periods. Hence, the large volumes of radioactive SMR waste will need to be treated, conditioned, and appropriately packaged prior to disposal and these processes will introduce significant costs (Krall et al., 2022).

4. **Technology Readiness Level (TRL)** is used to assess the maturity of a technology, ranging from early stage research to commercial deployment. In India, all major electricity generation technologies including coal, hydropower, wind, solar and large NPP have achieved TRL 9 indicating that technologies are fully mature and have been proven through sustained commercial operation. In contrast, SMRs are currently at TRL 3, indicating that active research and conceptual design work are underway (PIB, 2025).
5. **Capacity factor** indicates ratio of the actual electrical energy produced over a given period of time to the maximum possible energy it could have produced if it had operated at its full rated (nameplate) capacity continuously during that same period. Nuclear power demonstrates the highest capacity factor among the technologies assessed, due to its long operational cycles, less frequent fueling intervals (typically 18 to 24 months) and low planned outage rates. In contrast, renewable energy technologies exhibit lower capacity factors due to variability in resource

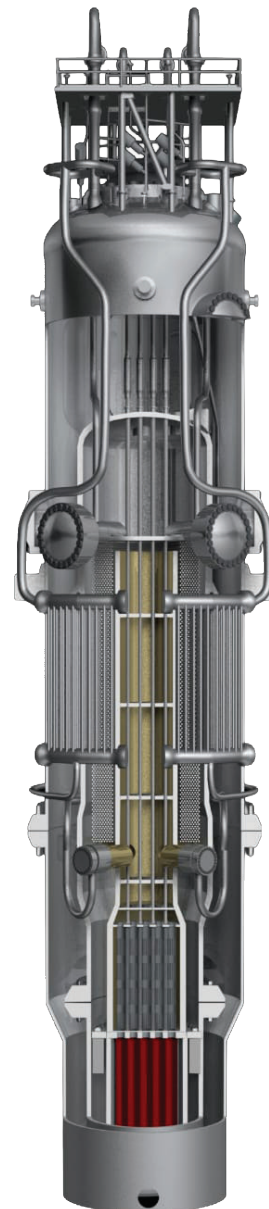
availability, while thermal plants are constrained by maintenance and fuel requirements. These differences imply that technologies with lower capacity factors require higher installed capacity to deliver equivalent electricity output, reinforcing the role of nuclear energy as a complementary source to renewables (DOE, 2021).

6. **Seasonal variability** captures fluctuations in electricity generation across months of the year. Nuclear power and coal exhibit lowest seasonal variability, with highly stable monthly output throughout the year. However, nuclear energy offers a more carbon neutral base load generation option. In contrast hydropower and wind display pronounced seasonal variability driven by climatic conditions, particularly monsoon related patterns. Solar generation appears to exhibit comparatively low seasonal variability in this analysis relative to wind and hydro. This result does not imply the absence of intermittency in solar power, but rather indicates limited intra annual fluctuation (PFI, 2025).
7. SMRs, once commercialised, could match the construction timelines of thermal power plants, with construction taking about 4 years as per global average. Large nuclear and hydro projects usually take much longer. This makes SMRs one of the fastest options for round the clock clean power. Only wind and solar can be deployed more quickly, but they remain intermittent sources. A key determinant of nuclear project timelines is the manufacturing of critical components such as the steam engine and turbine, which can take up to 3 to 4 years and therefore largely determine the overall project schedule (Energy Planning, 2025).

In the Indian context, official estimates indicate slightly longer timelines for initial deployments. The estimated construction period for the BSMR-200 is approximately 5 to 6 years from the receipt of administrative and financial approval (PIB, 2026). Nevertheless, construction timelines may improve as supply chains mature and manufacturing capacity expands. For instance, NPCIL aims to complete construction and achieve criticality for 700 MW reactors within 5 years (PIB, 2026). Delivery timelines from

major domestic manufacturers such as Bharat Heavy Electricals Limited (BHEL) and Larsen & Toubro (L&T) are also improving (L&T, 2025). Furthermore, the partnership between GE Vernova and BHEL to supply steam turbines could further shorten manufacturing timelines (GE Vernova, 2022).

Overall, the findings indicate that while SMRs currently face higher costs, more complex waste management techniques, and lower technology readiness compared to established generation technologies. However, they perform strongly across land use intensity, safety, emissions, capacity factor and seasonal variability and construction timeline. These characteristics suggest that SMRs have the potential to complement renewable energy and address challenges such as intermittency, land constraints, and the provision of reliable, round the clock power.



CHAPTER - V

TAILORED APPLICATION FOR INDIA'S ECONOMIC GROWTH

The NITI Aayog Report on Net Zero and Viksit Bharat identifies nuclear energy as a driver of India's development and decarbonisation journey. Nuclear power provides the lowest lifecycle greenhouse gas emissions while providing reliable, round the clock baseload capacity critical for energy intensive processes (NITI Aayog, 2026). This gives them an ability to operate flexibly to complement variable renewable generation. Beyond electricity generation, nuclear energy can be used for hydrogen production, desalination and district heating. Additionally, the sector provides benefits of low operating expenses, creation of high skilled jobs in technology, manufacturing, and operations, and ensures economic activity throughout the life cycle of power plants (NITI Aayog, 2023).

This section outlines the strategic segments where SMRs can contribute most effectively.

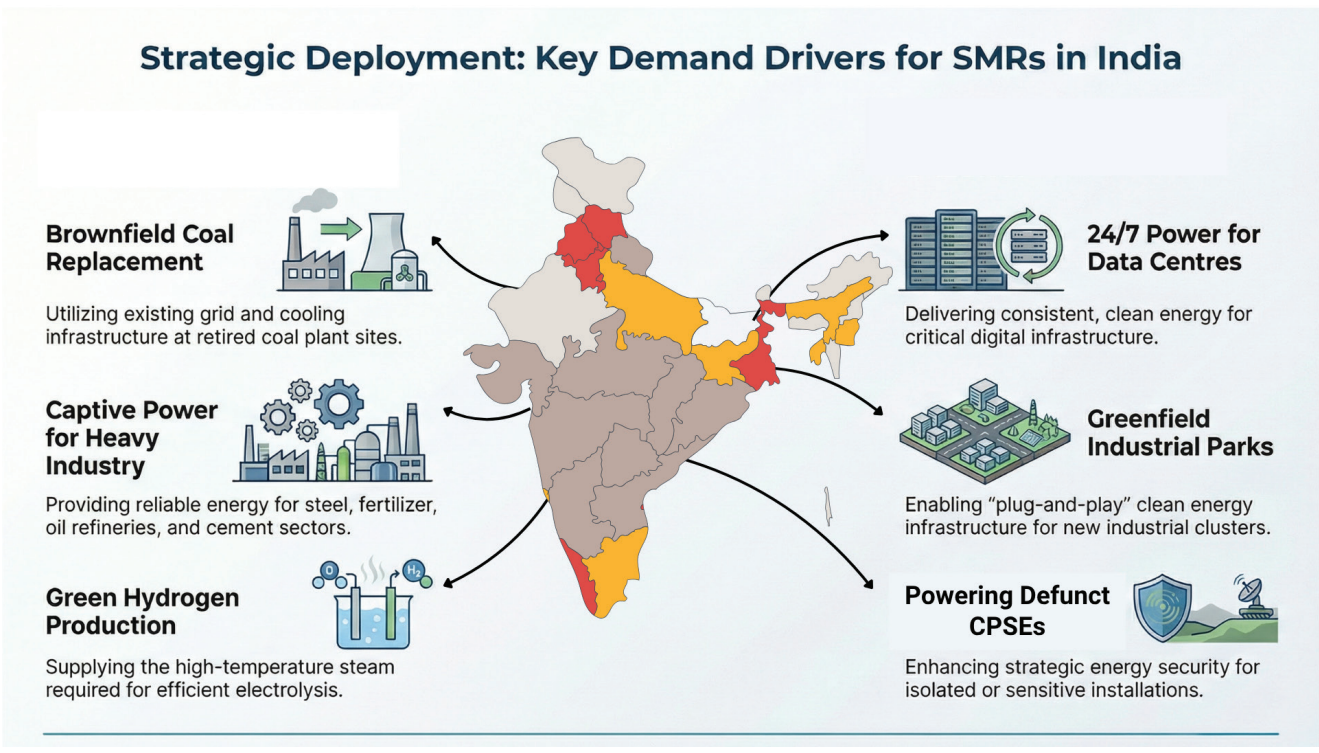


Figure 4: Application of SMRs in India

- 1. Brownfield Coal Plant Sites: A Coal to Nuclear Transition Strategy**
 India's electricity system remains significantly dependent on coal fired generation. Over the past 5 years, approximately 2.3 GW of ageing coal capacity has already been retired, and a larger wave of retirements is expected as plants reach end of life (PIB, 2024). To continue its decarbonisation journey India needs to retire highly polluting and inefficient coal plants and replace them with alternate sources of firm and reliable power (NITI Aayog, 2026). Hence, these brownfield sites present a strategic opportunity for SMR deployment. Such locations offer:
 1. Existing grid connectivity
 2. Established cooling water infrastructure
 3. Available land parcels
 4. Skilled local workforce familiar with power plant operations

SMRs, due to their smaller footprint and modular design, can be more easily accommodated at these sites compared to large nuclear power plants (NEA, 2025). Repurposing coal sites can minimise land acquisition challenges, reduce displacement concerns, and enable a smoother transition for coal dependent regions.

2. Captive Power Applications

India's captive power sector currently stands at approximately 80 GW and is growing at a compound annual growth rate (CAGR) of 4.5%. It is projected to reach 206 GW by 2047, implying 126 GW of incremental capacity (CERC, 2024). This expansion reflects rising demand from data centres, industrial parks and manufacturing hubs, IT parks and Global Capability Centres (GCCs). Unlike wind and solar, nuclear power provides both electricity and process heat, making SMRs particularly suitable for energy intensive industries such as steel, cement, petrochemicals, minerals, pulp and paper, and sugar. Their compact footprint, cogeneration potential, and ability to provide stable, zero carbon baseload power make them strategically aligned with India's industrial decarbonisation objectives.

3. Data Centres

Data centres create concentrated, high density electricity loads that are challenging to integrate into existing grids without raising system costs. Operators increasingly seek dedicated, firm, round the clock power rather than relying solely on grid supply. Internationally, data centre operators have shown willingness to pay a premium for firm clean power and enter long term power purchase agreements (PPAs), making them potential anchor customers for FOAK SMR deployment. For instance, Amazon has invested USD 700 million in X-energy and SMR deployment in the United States (ITIF, 2025). In India, data centre capacity is projected to expand significantly, from approximately 1.5 GW at present to nearly 45 GW by 2050, further strengthening the case for dedicated firm power solutions (NITI Aayog, 2026).

4. Green Hydrogen

Under the National Green Hydrogen Mission, India aims to achieve an annual green hydrogen production capacity of 5 Million Metric Tonnes (MMT) by 2030. SMRs have the potential to power water electrolysis for green hydrogen production (EY, 2024). Colocation of SMRs with emerging industrial hydrogen clusters can further enhance economic viability by reducing transmission constraints, and ensuring dedicated power supply.

5. Powering Defunct Central Public Sector Enterprises (CPSEs)

India's defunct CPSEs, as identified in the reports of Department of Public Enterprises, represent a pool of stranded industrial land that can be leveraged for SMR deployment. For preliminary screening potential, potential sites were assessed against key indicators, including availability of water resources, proximity to transmission infrastructure, existing industrial facilities, site accessibility, topographical suitability, and seismic considerations. While land availability is a critical parameter, it has not been explicitly assessed at this stage due to uncertainties regarding SMR specific land requirements, exclusion zones, and population density thresholds.

6. Greenfield Industrial Parks

Greenfield industrial parks developed under the BHAVYA Scheme offer an opportunity to integrate SMRs as part of plug and play clean energy infrastructure for emerging industrial clusters. With pre approved land, ready infrastructure, and integrated services, these parks are designed to support manufacturing units, MSMEs, startups, and global investors. For assessing suitability of SMR deployment within such parks, key indicators include availability of water resources, proximity to transmission infrastructure, topographical suitability, seismic considerations, and accessibility.

7. Remote and Defence Installations

SMR technology can provide reliable, dispatchable power to remote regions and defence establishments, replacing diesel based generation. In geographically isolated or strategically sensitive locations, SMRs enhance energy security while reducing logistical fuel supply risks. Their modularity and long refuelling cycles make them particularly suitable for such applications.

CHAPTER - VI

SITE MAPPING FOR COAL TO SMR TRANSITION

A multicriteria screening framework was applied to identify coal-based thermal power plant (TPP) units that are both technically viable and strategically relevant for repurposing towards SMR deployment. The screening criteria were defined on the basis of plant age and installed capacity, drawing on established benchmarks for operational efficiency and technological obsolescence. Specifically, units aged 25 years or older and with a nameplate capacity below 500 MW were flagged as candidates for retirement, consistent with the classification of such facilities as technologically outdated and economically inefficient (NIAS, 2021).

The identified units exhibit compounding indicators of declining viability: all units meeting the above criteria record an emission intensity exceeding 0.97 tCO₂/MWh, alongside a Plant Load Factor (PLF) below 52%, signifying chronic underutilisation relative to installed capacity. Together, these parameters reflect not only diminishing economic returns but also a disproportionately high carbon footprint per unit of electricity generated, reinforcing the case for accelerated retirement and site repurposing.

Application of this framework resulted in the identification of 49 coal-based generating units with a cumulative capacity of 11.2 GW, distributed across multiple states in India. Notably, all identified units are located within seismic zones II, III, and IV, which has important implications for site suitability assessments, reactor design considerations, and regulatory compliance in the context of SMR deployment. In terms of ownership, these units are held by a combination of central and state government entities, with a limited proportion under private ownership. This carries significant implications for the governance, financing, and regulatory pathways associated with any transition strategy. The spatial distribution of these candidate sites, as illustrated in Figure 5 (Refer to Annexure-1 for the list).

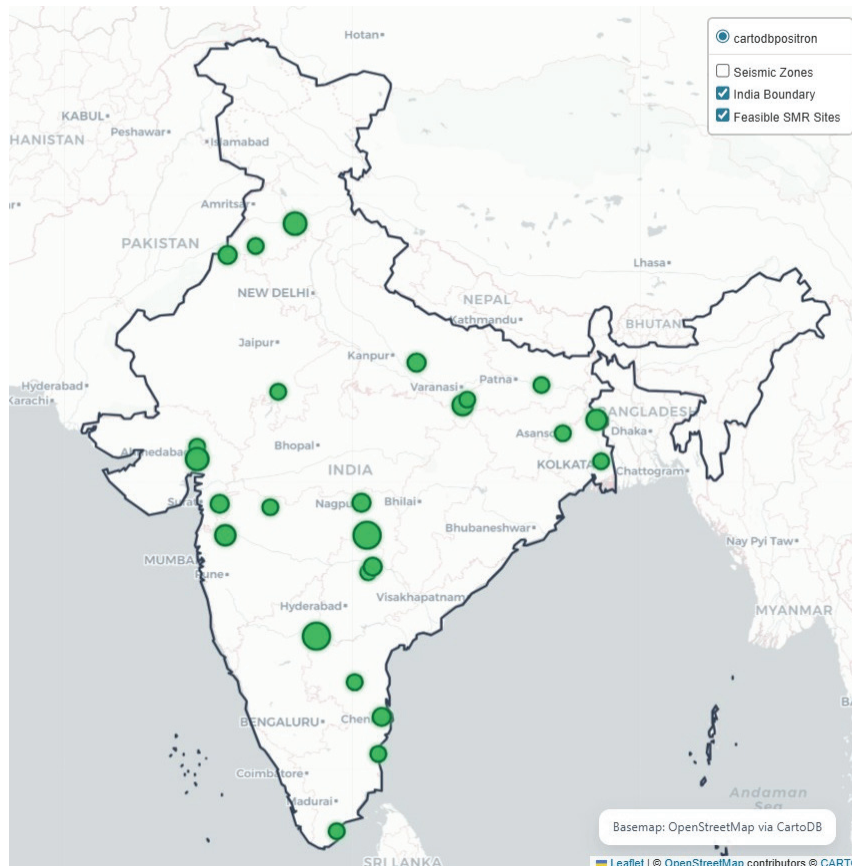


Figure 5: Candidate Coal Based TPP Sites for SMR Transition in India

CHAPTER - VII

SMR SUPPLY CHAIN IN INDIA

The report maps the supply chains of Pressurised Water Reactors (PWRs) and Molten Salt Reactors (MSRs) to illustrate two complementary policy priorities for India's nuclear strategy: immediate readiness and long term resource security. PWRs, forming the basis of the BSMR-200, represent a mature and globally deployable SMR technology that India can support with its existing supply chain and imported slightly enriched uranium, making them a near-term option for scaling nuclear power. MSRs, by contrast, embody an advanced reactor class with distinct material and fuel cycle requirements that can leverage India's abundant thorium reserves, thereby reducing dependence on imported fissile uranium and reshaping the country's energy security trajectory. Evaluating both supply chains ensures that India's SMR roadmap balances near term deployment feasibility with strategic innovation aligned to national resource endowments and long-term energy independence.

Criterion	Pressurised Water Reactors (PWRs)	Molten Salt Reactors (MSRs)
Coolant	Light water	Molten Salt
Moderator	Light water	Graphite
Operational Temperature	High (300-320°C)	Very high (600-700°C)
Plant efficiency	33.64	44.47
Fuel form	Solid fuel rods	Liquid fuel
Waste generation	Produces long lived waste	Potential for reduced long lived waste
Construction timeline	Long construction periods	Potentially shorter time
Fissile Material	Slightly Enriched Uranium (SEU)	SEU/High Assay Low Enriched Uranium(HALEU) + Thorium

Table 2: Characteristics of PWRs and MSRs

1. Mapping the BSMR-200 Value Chain

The 220 MWe Bharat Small Modular Reactor is based on globally proven PWR technology which will use Slightly Enriched Uranium (SEU) as fuel (PIB, 2026). Historically, India has depended significantly on imports for PWR technology and associated fuel requirements. India's experience with large PWRs, including Russian supplied units at Kudankulam, and its ongoing indigenous mid sized PWR development provide the technological foundation for BSMR-200 deployment. The BSMR-200 value chain can be structured across four principal segments:

a. Fuel Cycle

In the fuel cycle, domestic uranium mining and milling are well established through UCIL operations. Fuel fabrication capabilities are mature, with the Nuclear Fuel Complex (NFC) possessing extensive experience in manufacturing fuel assemblies for PHWR and VVER reactors. However, enrichment remains a structural bottleneck due to limited domestic commercial capacity, resulting in continued import dependence in the near term.

b. Nuclear Island

The nuclear island represents the most technologically intensive segment. India has significantly strengthened domestic capability in heavy forgings, special grade alloy production (including BARC's APURVA steel), and titanium alloy tubing (BARC, 2025). Major vendors such as L&T and BHEL possess experience from the 700 MWe PHWR programme, positioning the nuclear island supply chain as largely indigenous with limited projected import exposure.

c. Balance of Plant

The balance of plant relies primarily on conventional power generation technologies, including steam turbines, generators, and auxiliary systems. India's mature heavy engineering ecosystem, led by firms such as BHEL, enables near complete localisation in this segment (BHEL, 2025). However, sustained low demand for nuclear-related components has created structural bottlenecks across the supply chain. Steam turbine procurement, for instance, carries lead times of up to four years, while demand-sensitive components such as U-tubes are no longer manufactured domestically and are sourced entirely from countries such as Argentina.

To address these constraints, the Government should consider instituting a bulk procurement framework for nuclear BoP components. Aggregating demand across planned reactor units would improve supply chain visibility, incentivise domestic manufacturers to re-enter the market, and reduce per-unit costs – thereby strengthening both energy security and indigenous manufacturing capacity.

d. Civil Works & Engineering, Procurement, and Construction (EPC)

Civil works and EPC activities are anchored by NPCIL and supported by established construction firms with experience across multiple indigenous reactor builds. This segment is industrially mature and represents a strength in India's SMR deployment capacity.

Overall, the BSMR-200 supply chain demonstrates high readiness across manufacturing and EPC segments, with

enrichment remaining the principal area of vulnerability.

2. Mapping the Molten Salt SMR Value Chain

Most operating reactors today are optimised for uranium based fuel cycles, with limited compatibility for large scale thorium utilisation. Among advanced concepts, Molten Salt Reactors (MSRs) are widely considered a promising pathway for thorium deployment due to their liquid fuel design and fuel cycle flexibility. Unlike the PWR based BSMR-200, MSRs involve distinct material, chemical, and supply chain requirements. While India has initiated research under the Indian Molten Salt Breeder Reactor (IMsBR) programme, industrial readiness remains uneven. The MSR value chain can similarly be structured into three segments:

a. Fuel and salt cycle

The fuel and salt cycle constitutes the primary structural bottleneck. Although India possesses substantial thorium resources, large scale lithium 7 enrichment and industrial molten salt purification remain under development. Current capabilities are largely confined to laboratory scale research, making this stage the most significant constraint to near term deployment (BARC, 2021).

b. Reactor and Primary Salt Systems

The reactor and primary salt systems require advanced materials such as corrosion resistant nickel based alloys, nuclear grade graphite, and high temperature salt compatible pumps and heat exchangers. However, domestic capability in these areas remains largely developmental, with most components at laboratory or pilot scale.

c. Balance of Plant and Civil Works

By contrast, the balance of plant relies on largely conventional turbine and electrical systems, allowing adaptation of existing industrial capabilities. Civil construction and EPC capacity are similarly mature; however, regulatory frameworks specific to MSR technologies will require further institutional development.

Overall, while India demonstrates strong research foundations in MSR technologies, industrial scale supply chain readiness remains significantly less mature compared to PWR based SMRs.

CHAPTER - VIII

EVOLVING REGULATORY AND LIABILITY FRAMEWORK

The regulation of nuclear energy occupies a sensitive position within India's legal and institutional architecture due to concerns relating to public safety, environmental protection, national security, and international non-proliferation obligations. Past global accidents such as the Three Mile Island Accident (1979), Chernobyl nuclear meltdown (1986) and Fukushima core meltdown (2011) have reinforced a precautionary approach to nuclear governance. This section examines the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act, 2025, which has replaced two key legislations: the Atomic Energy Act, 1962 and the Civil Liability for Nuclear Damage (CLND) Act, 2010.

1. Enabling Private Sector Participation in Civil Nuclear Energy

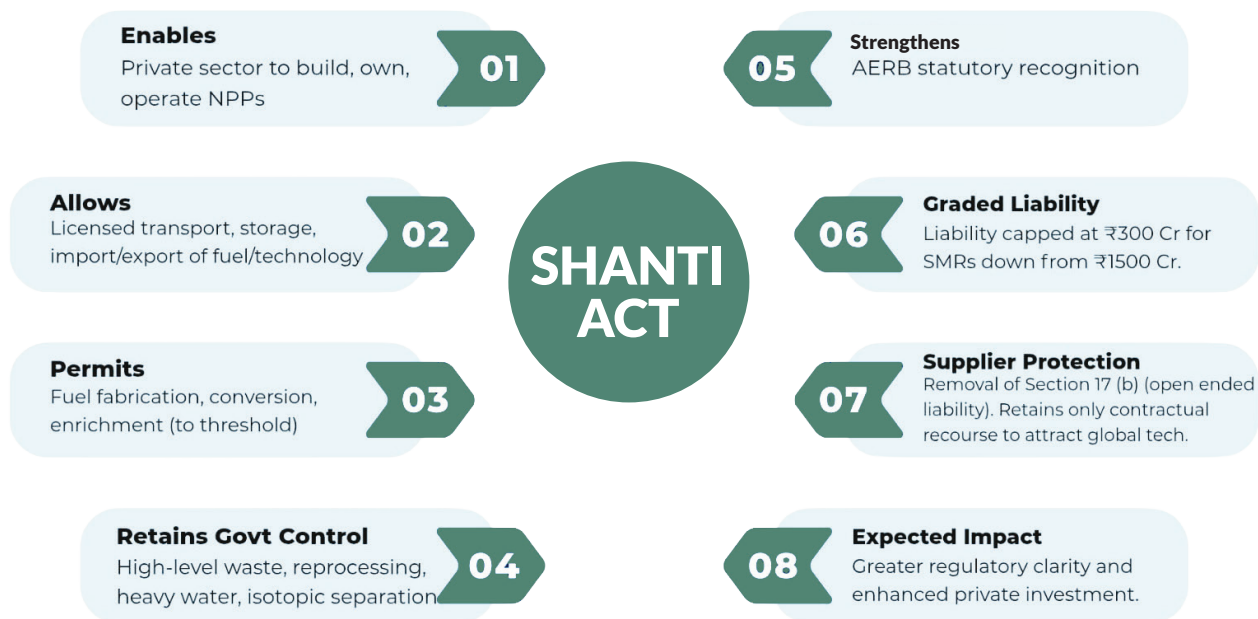
The new Act permits licensed Indian private companies to build, own, operate or decommission NPPs or reactors. It also allows private participation in activities related to the transport, storage, import and export of nuclear fuel, technology, and equipment subject to licensing of the Central Government. It also enables the private sector to undertake plant operations, power generation, equipment manufacturing, and activities such as the fabrication of nuclear fuel including conversion, refining and enrichment of uranium 235 up to such threshold value. Under the earlier legal regime, these activities were largely restricted to public sector entities such as the Nuclear Power Corporation of India Limited (NPCIL) and Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI) (PIB, 2016). All entities involved in the nuclear energy activities will be required to obtain safety authorisation from the Atomic Energy Regulatory Board (AERB). At the same time, the Act retains exclusive Central Government control over certain critical and sensitive activities, including enrichment and isotopic separation of

radioactive substances, reprocessing of spent fuel, management of high level radioactive waste, and the production and upgradation of heavy water (PRS, 2025). The act also grants formal statutory recognition to the AERB to strengthen regulatory independence and authority.

2. Liability for Nuclear Damage

Under internationally accepted nuclear liability principles, the operator of a NPP bears strict liability for nuclear accident and is required to compensate victims commensurate with the extent of harm caused. This approach ensures prompt relief to the victims without the need to establish fault or determine responsibility for the accident (Department of Atomic Energy, 2025). Under India's earlier nuclear liability framework, the plant operator was primarily responsible for compensating victims in the event of a nuclear accident. However, after paying compensation, the operator was allowed to seek recovery from equipment suppliers under certain conditions. Section 17 of the Civil Liability for Nuclear Damage (CLND) Act, 2010 permitted such recourse if: (a) the operator and supplier had an explicit contractual agreement, (b) the accident was caused by defective equipment or services supplied, or (c) the incident resulted from a deliberate act intended to cause nuclear damage. In practice, clause (b) created significant uncertainty for suppliers by exposing them to open ended and long term liability risks. This feature was often interpreted as a factor shaping industry perceptions and influencing the pace of private participation and foreign technology partnerships in India's nuclear sector. (The Hindu, 2023). The SHANTI Act, 2025 modifies this framework by removing clause (b), retaining only contractual recourse and cases involving intentional damage. In addition, marking a departure from the earlier flat liability cap of ₹1500 crore for nuclear reactors of 10 MW thermal capacity or above, the SHANTI Act adopts graded liability caps for operators based on their size of installation.

The enactment of the SHANTI Act is expected to provide greater regulatory clarity and enable licensed private participation in civil nuclear activities, thereby potentially accelerating private investment and facilitating the transition of SMRs from policy intent to commercial deployment. The reduction of the civil liability cap to ₹ 300 crore for reactors in the 150–750 MW range and ₹ 100 crore for reactors below 150 MW further strengthens the financial viability of SMRs. Reflecting this shift, Adani Power has established a dedicated subsidiary for nuclear-based power generation, transmission, and distribution, indicating rising private sector interest in the nuclear segment.



Replaces Atomic Energy Act 1962 + CLND Act 2010

CHAPTER - IX

LEARNING CURVE AND COST ECONOMICS OF SMRS IN INDIA

The study recommends use of SMRs for commercial and industrial users which require firm power round the clock to run their operations. However, the estimated LCOE for SMRs falls in the range of \$ 60-120, with FOAK projects expected to approach the upper limit (KPMG, 2025). In comparison, the average cost of electricity supply for commercial and industrial users in India is \$ 80 per MWh (World Population Review, 2025). This implies that early SMR units could be significantly more expensive than prevailing grid electricity, creating a cost gap that must be addressed through targeted policy support.

As SMR deployment expands, costs are expected to decline due to learning by doing, standardisation of reactor designs, and improvements in manufacturing and supply chains. The analysis assumes a learning rate of approximately 8% for successive deployments, as detailed in the methodology. Based on this learning trajectory, the analysis identifies a breakeven threshold around the 25th SMR unit, where the LCOE is projected to converge with the \$ 80 per MWh benchmark for electricity supply to commercial and industrial consumers.

Serial production drives costs down to grid parity (\$81.5/MWh) by the 25th unit

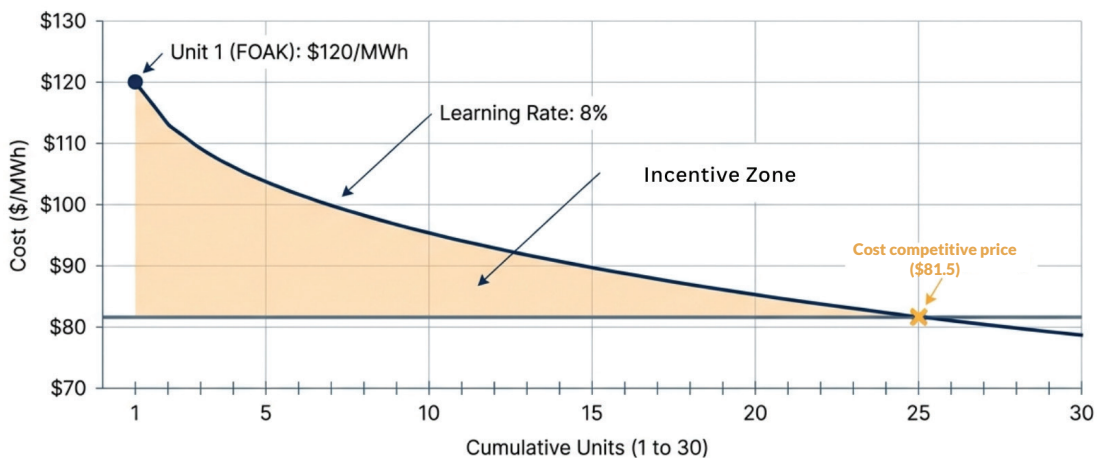


Figure 6: Projected Learning Rates and LCOE Trajectory for SMR Deployment

The study evaluates policy pathways for bridging this cost gap while minimising fiscal burden on the government. For this, it conducts a sensitivity analysis for the first 25 SMR units. Two alternative deployment pathways are evaluated.

1. Scenario 1: High Fiscal Burden

Phase 1: Capital Subsidy through Viability Gap Funding (VGF) for First 10 Units

The first 10 SMRs are categorised as FOAK units which typically face higher construction costs due to initial engineering and licensing costs, limited supply chain maturity, lack of manufacturing standardisation and higher financing risks.

In this phase, the government provides capital support through VGF to reduce the effective cost of electricity. Since capital expenditure (CAPEX) constitutes approximately 80% of the total lifecycle

cost of nuclear power plants, reducing CAPEX has a significant impact on LCOE.

The required subsidy level is estimated using:

$$\text{Required LCOE} = \text{Current LCOE}(1 - \text{CapexShare} \times \text{Incentives})$$

$$\$ 80 = \$ 120(1 - 0.8 \times \text{VGF})$$

$$\text{VGF} = 0.4 \text{ or } 40\%$$

Solving the equation indicates that a capital subsidy equivalent to 40% of project CAPEX would be required to reduce the LCOE from \$ 120/MWh to \$ 80/MWh. The BSMR-200 has a capacity of 220 MW, with an estimated capital cost of \$ 644 million per reactor (PIB, 2026). Under a 40% VGF framework, the estimated government support for the first 10 FOAK SMR units is presented below.

Parameter	Value
Capital cost per SMR unit	\$644 million
Required VGF	40% of capital cost
Government support per reactor	\$257.6 million
Number of SMR units	10
Total capital subsidy required	\$2.576 billion

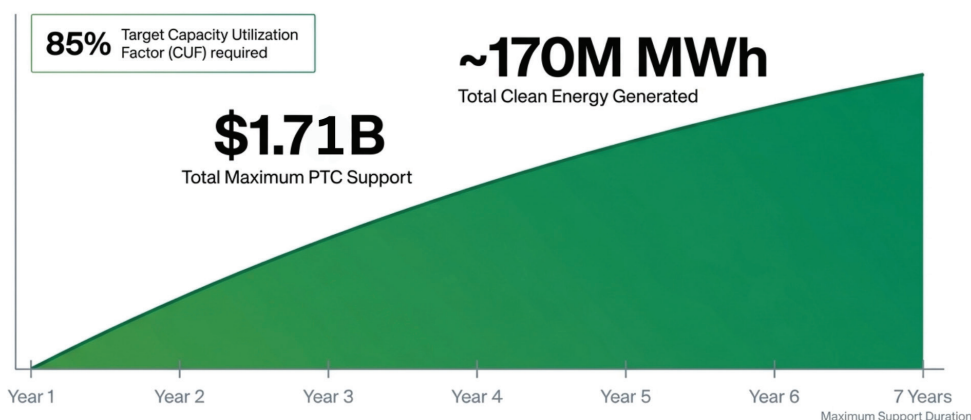
Table 3: Estimated Viability Gap Funding¹

Phase 2: Production Tax Credits for Next 15 units

The next 15 reactors are categorised as Nth-of-a-Kind (NOAK) units. At this stage, SMR deployment benefits from standard reactor designs, improved manufacturing processes and mature supply chains. As a result, the LCOE is assumed to fall from \$ 120/MWh for FOAK units to approximately \$ 90/MWh for NOAK units. However, a residual gap of \$ 10/MWh remains relative to the \$ 80/MWh benchmark.

To address this gap, the government provides production-based incentives rather than capital subsidies. Developers receive a Production Tax Credit (PTC) of \$ 10 per MWh of electricity generated, which directly offsets the remaining cost gap.

Cumulative Impact of Production Credits



Parameter	Value
LCOE (NOAK)	\$90/MWh
Cost Competitiveness benchmark	\$80/MWh
Feasibility gap	\$10/MWh
Production Tax Credit	\$10/MWh
Total installed capacity	3.3 GW
Capacity Utilisation Factor (CUF)	85%
Annual electricity generation	24,571,800 MWh
Electricity generation (7 years)	172,002,600 MWh
Adjusted generation (after degradation)	170,798,582 MWh
Total government support (PTC)	\$1.71 billion

Table 4: Estimated Government Support under PTC Mechanism

Based on the projected generation of approximately 170.8 million MWh, the total fiscal outlay is estimated at \$1.71 billion over 7 years².

2. Scenario 2 : Hybrid Approach

Phase 1: Hybrid Incentive Model for the First 10 units

This phase adopts a hybrid approach combining fiscal incentives with partial capital support. Instead of relying entirely on capital subsidies, this approach reduces project costs through a combination of GST reduction on nuclear components, import duty exemptions, interest subvention on project financing, and partial VGF. The proposed incentives include:

Reducing GST from 18% to 5% lowers overall project cost. The base project cost (excluding GST) can be estimated as:

$$\text{Base Cost} = \frac{\text{Cost with GST}}{1 + \text{GST}}$$

$$\text{Base Cost} = \frac{644}{1.18} = \$ 545.76 \text{ million}$$

Applying the revised GST rate:

$$\text{New Cost} = \text{Base Cost} \times (1 + 0.05)$$

$$\text{New Cost} = \$ 545 \text{ million} \times 1.05 = 573.05 \text{ million}$$

This represents an approximate 11% reduction in capital costs. Additional policy measures further reduce capital costs, including import duty exemptions and interest subvention, resulting in a total effective CAPEX reduction of 24% prior to subsidy support.

$$\text{New LCOE} = 90(1 - 0.8(0.11 + 0.08 + 0.05))$$

$$\text{VGF} = 0.17 \text{ OR } 17\%$$

Solving the equation yields a required VGF of approximately 17% of capital cost, significantly lower than the 40% required under a full subsidy model. Based on the revised capital cost, the government support per reactor is estimated at approximately \$ 109.5 million, and for the first 10 SMR units, the total subsidy requirement amounts to approximately \$ 1.09 billion. A summary of these estimates is presented below.

Parameter	Value
Capital cost per SMR unit	\$644 million
GST reduction impact	11%
Import duty exemption	10%
Interest subvention	3%
Total CAPEX reduction (pre-VGF)	24%
Required VGF	17% of capital cost
Government support per reactor	\$109.5 million
Number of SMR units	10
Total subsidy required	\$1.09 billion

Table 5: Estimated Government Support under Hybrid Incentive Model

Phase 2: Cost Reduction through Fiscal Incentives for Next 15 units (NOAK reactors)

In this phase, cost parity is achieved solely through fiscal measures without direct subsidies or production credits. The same tax rebates and incentives (GST reduction, import duty exemption, and interest subvention) result in a 24% CAPEX reduction.

$$\text{New LCOE} = \text{Current LCOE}(1 - \text{Capex}(\text{upfront tax rebate}))$$

$$\text{New LCOE} = 90(1 - 0.8(0.11 + 0.08 + 0.05))$$

$$\text{Required LCOE} = \$72.72$$

Applying these incentives reduces the LCOE for the 15th unit from \$ 90/MWh to approximately \$ 72.7/MWh, which is below the \$ 80/MWh cost competitiveness benchmark.

CHAPTER - X

CRITICAL BARRIERS

The key challenge lies in the fact that India's private sector will be entering the nuclear domain for the first time since the enactment of the SHANTI Act. To succeed, companies must build robust supply chains, establish technology transfer partnerships, and align with clear standards while receiving fiscal support to make the sector viable. Compounding this, Small Modular Reactors (SMRs) have yet to see commercial deployment in India and remain limited worldwide, which means the initial learning curve will be steep and demanding.

1. Fuel Security and Industrial Scaling Constraints

India depends on imports for safeguarded enriched uranium for its civilian reactor programme. The BSMR-200 is based on PWR technology and uses SEU, which creates specific fuel cycle and scaling challenges. Although it does not require highly enriched fuels like HALEU used in some global SMR designs, enrichment remains a key constraint. India's existing enrichment capacity has primarily been developed for strategic purposes but not yet scaled for large commercial civilian use. (International Panel on Fissile Materials [IPFM], 2025)

Expanding enrichment capacity for SMRs will require building safeguarded facilities, ensuring compliance with international nuclear oversight requirements, and establishing a reliable long term domestic fuel supply framework.

India's upstream uranium sector continues to play a key role in meeting strategic requirements. As nuclear capacity expands, however, ensuring adequate and cost effective fuel supply for growing civilian demand will require a diversified procurement approach, alongside domestic production, including imports from countries such as Kazakhstan, Canada, Uzbekistan, and Russia (CEA, 2025). Consequently, even if enrichment capacity is expanded domestically, dependence on safeguarded uranium imports exposes the programme to external supply vulnerabilities,

underscoring the need for strategic stockpiling and diversified procurement models. This is even more critical due to the volatility around nuclear supply globally.

Beyond fuel supply, industrial scaling gaps persist within the BSMR supply chain. Although India has developed indigenous heavy forging capability for reactor pressure vessels (RPVs), scaling these components for modular, factory-based SMR production requires optimisation of fabrication techniques, supply chain standardisation, and manufacturing streamlining. The transition from large, site built reactor components to modular, serially manufactured units represents a critical industrial shift that is yet to be fully institutionalised. Additionally, long lead times in manufacturing critical components such as steam generators, turbines, and high precision forgings can significantly extend project timelines.

2. Legacy Constraints and Emerging Reforms

India's three stage nuclear programme was conceived to utilise its limited domestic uranium and abundant thorium reserves. While the first stage based on indigenous PHWR technology has reached commercial maturity, the transition to the second stage has historically faced significant legacy constraints. The PFBR's recent criticality at Kalpakkam marks India's formal entry into the second stage; the learning curve from this FOAK experience informs the case for standardised, modular deployments going forward.

Beyond technological development, the legacy single operator model, appropriate for its time, is being complemented under SHANTI Act 2025 by licensed private participation to expand delivery bandwidth. Furthermore, existing regulatory frameworks are tailored for large, site built reactors. Current mandates for a 1.6 km exclusion zone and 5 km sterile zone but SMR developers claim SMRs as "walk away safe" designs, not requiring exclusion

zones (Holtec, 2014). Applying these legacy requirements restricts siting flexibility, particularly for deployment near industrial clusters or brownfield sites where land is at a premium. Further, since harmonised standards and a single window clearance mechanism are still emerging, FOAK projects may face regulatory ambiguity during deployments, leading to approval delays and increased complexity.

A significant institutional constraint also exists regarding market integration: currently, nuclear power pricing and regulatory oversight vest exclusively with the AERB, with no formal institutional role assigned to the Central Electricity Regulatory Commission (CERC). This arrangement was appropriate when nuclear capacity was limited and largely insulated from competitive electricity markets. However, as India targets 100 GW of nuclear capacity by 2047, nuclear power will be increasingly integrated into the grid. Consequently, CERC's involvement in areas such as grid code compliance, scheduling protocols, and market participation frameworks for nuclear power will become operationally necessary.

Additionally, the lack of harmonised standards and a single window clearance mechanism creates regulatory uncertainty, particularly for FOAK SMR units. Nuclear liability remains another critical barrier to private participation; uniform liability requirements often render smaller, lower output reactors economically unviable. While the SHANTI Act introduces a graded liability framework, further calibration is required to accurately reflect the reduced risk profile of SMRs and micro reactors.

Finally, social acceptance remains a persistent challenge. Large scale conventional projects have historically triggered public resistance due to extensive land acquisition and displacement. In contrast, SMRs with their modular design, minimal land requirements, and potential for localised employment, offer a strategic opportunity to improve public perception through targeted engagement and a lower impact physical presence.

3. Financial Barriers

The commercial viability of SMRs remains uncertain due to limited global deployment experience. Early estimates suggest that the cost of FOAK projects can be as high as \$ 120/MWh, 50% higher than the grid level production cost. With only 2 SMRs currently in commercial operation, reliable cost benchmarks have yet to be established. FOAK SMR projects are particularly exposed to cost overruns, often incurring premiums of 20% or more, especially when entirely new reactor designs are introduced. These FOAK risks increase upfront capital requirements and complicate financing.

Global experience underscores these challenges. SMR projects in Russia, China, and Argentina have recorded significant cost escalations, with capital costs rising by 300 to 600% compared to original estimates. Similarly, NuScale's flagship SMR project in Utah was cancelled after projected cost of construction increased by 75% between 2021 and 2024 (IEEFA, 2024).

These experiences highlight the importance of careful planning and risk management. Accordingly, the proposed national level mission adopts a coordinated approach that addresses enrichment capacity expansion, modular manufacturing optimisation, regulatory adaptation, and risk mitigation mechanisms for FOAK projects. India's mission mode approach, combining the clarity provided by the SHANTI Act with calibrated fiscal support, is designed to proactively manage these risks and avoid similar cost escalation challenges.

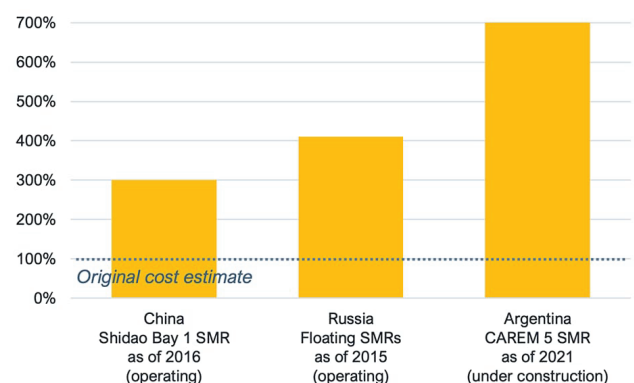


Figure 7: Cost Escalation Experienced by SMRs In or Under Operation; Source : IEEFA Calculations

CHAPTER - XI

GLOBAL BENCHMARKING

SMRs are only deployed in Russia and China. However, SMR development is currently emerging in the United States, Canada, United Kingdom, France, China and Russia, with over 120 SMR designs identified globally (NEA, 2025). International experience demonstrates that SMR deployment does not emerge organically from market forces alone; rather, it is enabled through coordinated fiscal support, regulatory innovation, fuel security programmes, and manufacturing ecosystem development. The proposed roadmap will draw structured lessons from these global frameworks.

Policy Dimension	Country	Key Measure
Fiscal Incentives	USA	Zero Emission Nuclear Production Tax Credit
	UK	Regulated Asset Base (RAB)
	Canada	Strategic Innovation Fund (~CAD 20 million) supporting SMR roadmap deployment
Fuel Security and Supply Chain	UK	Rolls Royce SMR supply chain portal
	USA	DOE HALEU Availability Program; Gateway for Accelerated Innovation in Nuclear (GAIN) support via DOE labs
Regulatory Harmonisation and Clearance	USA & Canada	NRC–CNSC Memorandum of Cooperation
	USA	NRC Standard Design Approval (SDA) framework
	UK	Generic Design Assessment (GDA) for site independent approval
	South Korea	Standard Design Approval (SDA) for repeat deployment; shift to safety function based regulation under NSSC
Sustainable Finance	European Union-France	Green Taxonomy

Deployment Strategy	China	Integration of SMRs into clean heating strategy (replacing coal in northern regions)
	South Korea	Special Act on SMR Promotion; mandatory 5 year Basic Plan for SMR system development
	Canada	National SMR roadmap guiding deployment strategy

Table 6: Global Benchmarking of SMR Support Frameworks

1. Fiscal Support Mechanisms

- a. The United States provides a Zero Emission Nuclear Production Tax Credit to existing nuclear power facilities. The subsidy is the highest when a facility's receipts from electricity sales are low and gradually phases out as revenues rise, preventing premature plant closures while avoiding over subsidisation during periods of high profitability (US Congress, 2025).
- b. The Regulated Asset Base (RAB) model is used in the United Kingdom to finance large scale infrastructure projects, including new nuclear power plants, by allowing regulated cost recovery from consumers during the construction phase (GOV UK, 2022).

2. Fuel Security and Supply Chain

- a. The U.S. Department of Energy's HALEU Availability Program demonstrates proactive state intervention in securing advanced fuel supply by aggregating demand and supporting domestic enrichment and fabrication capacity. Under this, the federal government acquires HALEU through purchase agreements with domestic industry partners and makes conditional allocations to selected private developers to support reactor testing, prototype development and establishment of domestic advanced fuel fabrication lines (Department of Energy, 2025).
- b. USA's Gateway for Accelerated Innovation in Nuclear (GAIN) initiatives provides private companies access to the Department of Energy's (DOE) national laboratories and technical expertise to facilitate commercialisation (DOE, 2025)

- c. The UK's Rolls Royce SMR programme has established a dedicated supply chain portal to integrate domestic manufacturers into a fleet-based, factory-built production model (Rolls Royce SMR, 2023).

3. Regulatory Harmonisation and Clearance

- a. The US Nuclear Safety Commission (NRC) and Canadian Nuclear Safety Commission (CNSC) have institutionalised regulatory cooperation to reduce duplication in design reviews, including collaborative assessment of BWRX 300 design (GOC, 2022).
- b. In Canada, the CNSC's prelicensing Vendor Design Review enables reactor developers to demonstrate understanding and compliance with Canadian licensing requirements and seek detailed feedback ahead of a formal license application (X Energy, 2024).
- c. Similarly, the US NRC's Standard Design Approval Framework enables faster siting and licensing of SMRs by allowing previously approved reactor designs, such as Nu Scales's US460, to be reused across multiple projects without redundant safety reviews (NRC, 2025).
- d. The UK is decoupling the design of a reactor from its physical location to speed up the licensing process. Under the GDA framework, the Office of Nuclear Regulation reviews a reactor design generically, independent of any site. Once a Design Acceptance Certificate (DAC) is issued, the same design can be used at multiple locations, with only site specific checks needed, reducing time and duplication (UK, 2024).

4. Sustainable Finance and Taxonomy

The European Union has officially classified nuclear energy as a transitional sustainable activity under its taxonomy in 2022. This has enabled France to mobilise green bond financing for nuclear projects (BGEN, 2023).

5. Gauging public confidence

To achieve higher public acceptance and less resistance, French municipalities such as Avoine which host nuclear plants, receive 12 times more subsidies and benefits, while residents pay just 0.1% property tax compared to a 12% national average, financed through a share of business taxes from nuclear facilities. (De Chambrier, 2024)

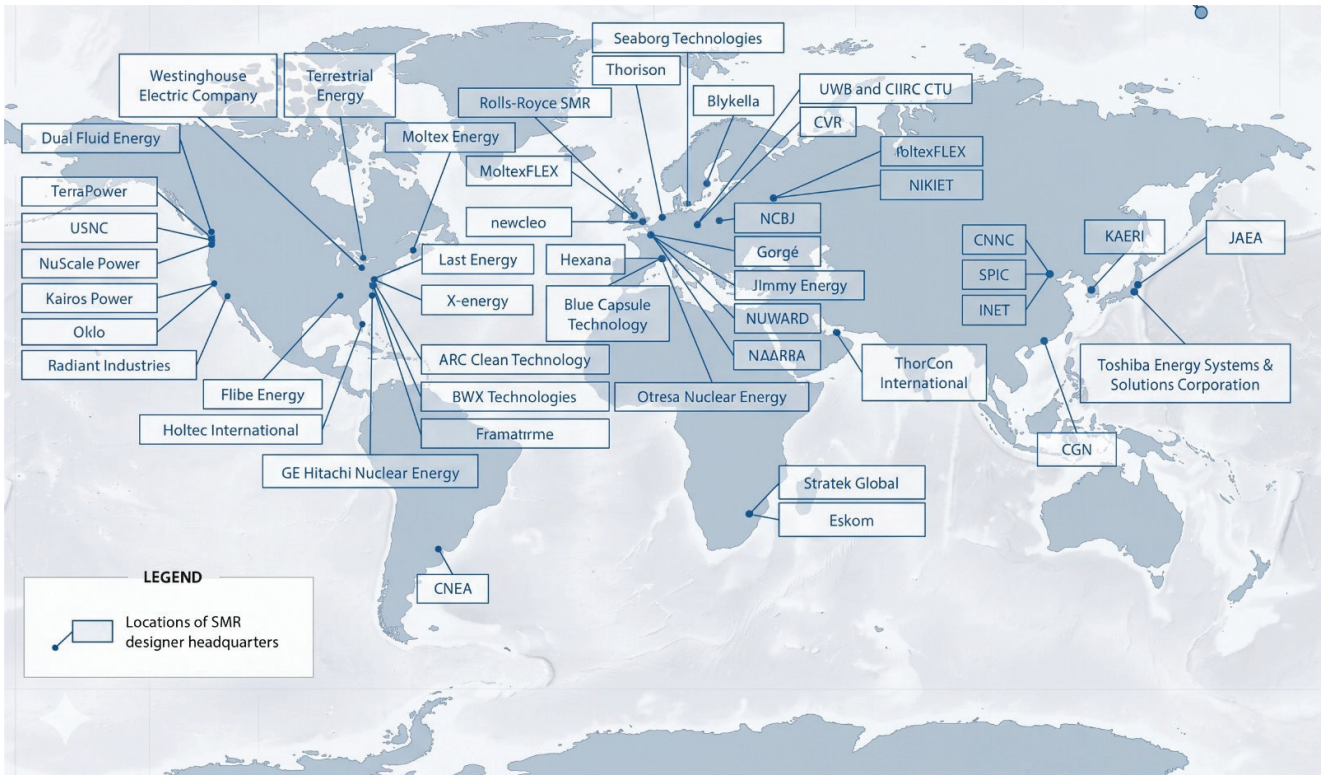


Figure 8: Global SMR designs (Source: IAEA)

CHAPTER - XII

ROADMAP FOR DEPLOYING SMRS THROUGH PRIVATE SECTOR PARTICIPATION

Translating India's SMR ambitions into deployable projects requires a coordinated policy architecture that simultaneously addresses financing constraints, regulatory barriers, and institutional gaps. This section outlines the comprehensive policy framework recommended under the roadmap, structured across four interconnected pillars: capital support and fiscal incentives, demand side mandates, regulatory reform, and institutional governance.

1. Capital Support and Incentive Framework

From the alternatives outlined in Section IX, this study recommends Scenario 2, which adopts a hybrid financing framework combining capital support and tax rebates for the first 10 units and just tax rebates for the subsequent 15 units. This approach significantly reduces the overall fiscal burden while ensuring project viability. As deployment scales and costs decline in the NOAK stage, reliance on direct subsidies and tax rebates can be progressively phased out.

Phase No	Number of SMR Units	Policy Instrument	Required VGF	Total Fiscal Support (\$)
Phase 1	10	Partial VGF + Fiscal Incentives	17% of Capex	1.09 billion
Phase 2	15	Fiscal Incentives Only	Not Required	0

Table 7: Financial Allocation Summary under Recommended Scenario 2

The effectiveness of the proposed fiscal framework is contingent upon complementary cost reduction measures, particularly in relation to the import of high value nuclear components. In this context, it is recommended that the Government of India extend the existing zero customs duty regime, currently applicable to critical equipment for Light Water Reactors (LWRs) established with foreign cooperation, to include analogous components required for SMRs (PIB, 2026). The scope of such a regime should cover capital intensive and safety critical equipment, including reactor pressure vessels, steam generators, pressurisers, turbines, and associated systems.

2. Research & Development

A dedicated R&D effort, leveraging existing funding mechanisms such as the Anusandhan National Research Foundation (ANRF), allocations under the Nuclear Energy Mission, and the Research, Development, and Innovation (RDI) Fund, can accelerate indigenous nuclear technology development. Support should be channelled through competitive grants prioritising projects with clear commercial pathways, strong technology transfer potential, and significant domestic value addition.

The fund will support four strategic areas: reactor design optimisation for Indian conditions, including ANEEL fuel integration with PHWR reactors and MSR development to leverage India's

thorium reserves; advanced safety systems featuring passive cooling and digital instrumentation; fuel cycle innovations; and modular manufacturing processes that reduce construction timelines and costs.

To build long term scientific capacity, Centres of Excellence could be established in partnership with premier technical institutions, fostering deep expertise in reactor physics, nuclear materials science, 3S (safety, security and safeguard), modular construction techniques, and digital twin technology for predictive maintenance. This dual approach targeted funding for near term innovation and institutional partnerships for foundational research will derisk new reactor designs while creating a sustainable pipeline of indigenous nuclear technology capabilities.

3. Other Incentives

part from capital incentives, a number of non-fiscal incentives can be provided to SMRs at central and state levels to improve project feasibility and improve investor attractiveness. As SMRs are a part of the Climate Finance Taxonomy, DAE can work with the Ministry of Finance and SEBI to improve access to concessional finance such as green bonds, sustainability linked financing, and ESG focused investments. This policy directive will unlock substantial pools of climate finance currently unavailable to nuclear projects, potentially reducing borrowing costs by 25-50 basis points through green bond issuances. Taxonomic inclusion will enable SMR projects to access concessional financing from the Green Climate Fund, World Bank Clean Technology Fund, Asian Development Bank climate finance facilities, and bilateral development finance institutions.

Additionally, the Government of India should designate Railway Energy Management Company Limited (REMCL) as an anchor demand aggregator for FOAK SMR projects, enabling bankable long term procurement of clean, firm power by Indian Railways.

Incentive Category	Specific Measure	Duration/Eligibility	Estimated Impact
Network Charges	Inter/Intra State Transmission System charge waiver	Up to debt tenor (15-20 yrs)	₹0.30-0.50/kWh reduction
Dispatch Priority	Must run status	Project lifetime	Revenue certainty, high PLF
Grid Flexibility	30 day power banking	Project lifetime	Enhanced revenue optimisation
Land & Water	Priority allocation	Development phase/lifetime	Reduced timelines and costs

Table 8: Other Incentives Matrix

4. Demand Side Mandates

The roadmap proposes to introduce a Clean Firm Power Obligation mandating large industrial consumers and data centers to procure clean, dispatchable baseload power, with nuclear energy explicitly recognised as qualifying zero carbon energy. The CFPO will be implemented through a progressive three phase approach voluntary (1-3 years), partial (4-6 years) and mandatory (7 or more years). For new and emerging loads like Semiconductor Fabrication industry and Data Centers, tax holidays up to 7 years can be provided on consuming SMR power electricity.

Phase	Timeline	Obligation	Target Entities	Penalty
Voluntary	Years 1-3	Voluntary	All large consumers	None (incentive based)
Partial	Years 4-6	3-5%	Energy intensive industries, Data centers, PSUs	Yes
Mandatory	Year 7+	5% → 15% progressive	All obligated entities	yes

Table 9: CFPO Implementation Roadmap

5. Minimum Eligibility Criteria

Historically, all nuclear power projects in India have been developed, owned, and operated exclusively by NPCIL, a public sector undertaking wholly owned by the Department of Atomic Energy. This monopolistic structure meant that no regulatory standards or minimum threshold criteria existed for private sector participation in nuclear power generation, as such participation was neither envisaged nor permitted under the prevailing legal and institutional framework.

The enactment of the SHANTI Act 2025 marks a watershed moment by enabling private sector participation for the first time. While the Act establishes a foundational framework, including requirements such as mandatory incorporation under Indian law, majority domestic ownership, escrowed decommissioning funds, nuclear liability insurance coverage, and long term fuel supply arrangements with NPCIL. Building on this foundation framework of the SHANTI Act, this roadmap proposes complementary minimum participation criteria, drawing on global best practices to strengthen and operationalise private sector involvement.

Analysis of global frameworks across established nuclear jurisdictions, including the United States, United Kingdom, France, Canada, South Korea, and China, reveals that successful private sector participation requires qualification standards across five critical dimensions: ownership and control safeguards, financial health and sustainability, technical competence and experience, manufacturing and supply chain localisation, and safety and regulatory readiness. Drawing from these international precedents, this roadmap presents a comprehensive minimum participation criteria that build upon the SHANTI Act foundation whilst incorporating best practices adapted to India's deployment objectives. (Refer to Annexure-II for details)

- a. **Ownership and Control Safeguards** ensure that control over SMR facilities remains within entities subject to Indian jurisdiction (51% Indian Ownership) and security oversight while allowing scope for foreign investments.
- b. **Financial Health Standards** establish thresholds for balance sheet strength, liquidity, operational efficiency, and long term capital mobilisation capability to minimise project abandonment risk and ensure sustained operations through economic cycles.
- c. **Technical Competence Requirements** mandate specialised capabilities in nuclear engineering, quality assurance, and safety management, including reactor technology partnerships and prerequisite experience in complex, safety critical industries.
- d. **Manufacturing and Supply Chain Localisation** establishes progressive local content requirements that balance initial technology access with long term industrial sovereignty objectives aligned with "Make in India" policy.

- e. **Safety and Regulatory Readiness** codifies explicit pre qualification standards for safety culture, emergency preparedness, cybersecurity, and public engagement to maintain the highest safety standards whilst enabling efficient private sector entry.

6. Proposed Regulatory Reform Plan

a. Rationalisation of Exclusion Zone

Since current nuclear siting norms are incompatible with SMRs, a shift to a dose-consequence-based-approach is recommended. Under this framework, the size of the Exclusion Zone and Emergency Planning Zone (EPZ) should be determined based on the reactor's actual radiological risk rather than fixed distances. For SMRs with a thermal power <300 MWh and proven passive safety, the EPZ may be restricted to the site boundary, provided it is demonstrated that no off site radioactive release would occur under design basis accidents. This would enable siting within industrial parks or near cities for district heating.

Accordingly, the AERB Safety Code on Site Evaluation of Nuclear Facilities should be amended to replace the current fixed EPZ norm (16 km radius) with a risk informed range of approximately 400–800 meters for SMRs (Aswal & Chandra, 2025). Similarly, the current 1.6 km Exclusion Zone may be reduced to 400 meters, while the Sterilised Zone (up to 5 km) may be significantly reduced or eliminated.

These reforms would align India's regulatory approach with performance based, risk informed practices adopted by leading regulators such as the U.S. Nuclear Regulatory Commission and the Canadian Nuclear Safety Commission.

It is further recommended that Annexure II of AERB Safety Code titled "Site Evaluation of Nuclear Facilities" be amended to include SMRs/Micro reactors specific screening distances for external human induced events like proximity to chemical plants. The lower radioactive inventory of an SMR reduces the potential consequence of an external hazard, allowing for siting in brownfield industrial hubs that would otherwise be rejected for large NPPs.

b. Institutional Framework

To implement the roadmap effectively, a three-tier governance structure is proposed. At the apex, an Inter Ministerial SMR Council chaired by the Prime Minister's Office will provide strategic direction and resolve cross cutting fiscal and regulatory issues. The SMR Mission Directorate within the Department of Atomic Energy will function as the nodal implementation body responsible for coordination, monitoring, and execution. The AERB will operate independently to conduct licensing and safety oversight. Project execution will follow a hybrid model combining NPCIL led Special Purpose Vehicles and qualified private developers.

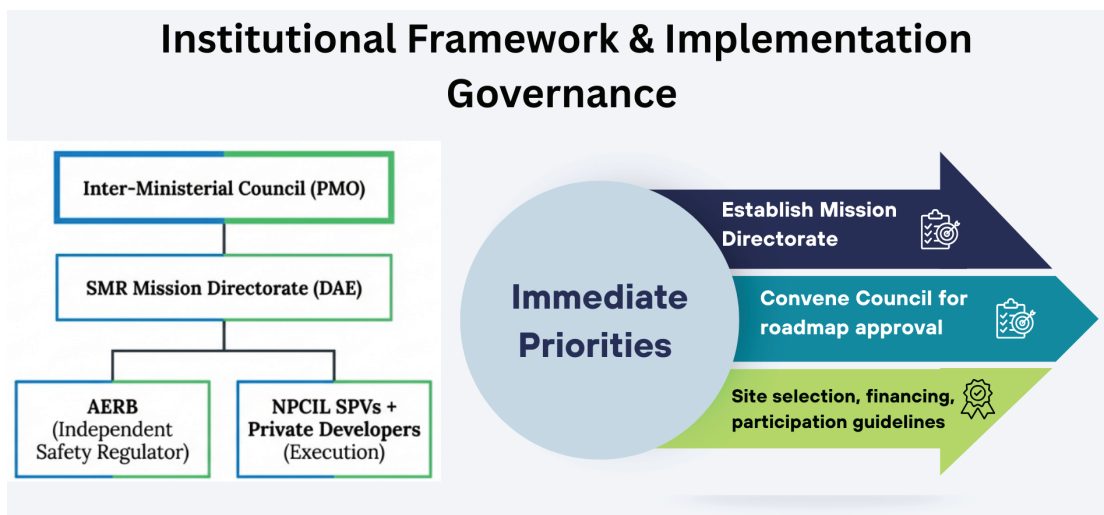


Figure 9: Proposed Institutional Framework for SMR deployment

Immediate implementation priorities include establishing the SMR Mission Directorate with appropriate technical and coordination mandates, and convening the Inter Ministerial SMR Council to approve a detailed roadmap covering site selection, financing instruments, and private sector participation guidelines.

Further, to address the growing integration of nuclear power into the competitive electricity market, the following institutional reforms are recommended:

i. Inter-Regulatory Protocol:

A formal protocol should be established between the AERB and the CERC to delineate jurisdictions. Under this framework, the AERB retains exclusive authority over nuclear safety, while the CERC assumes jurisdiction over grid integration, dispatch scheduling, and tariff determination for nuclear generated electricity sold in open markets.

ii. Regulatory Representation:

The CERC should develop a dedicated nuclear power market participation framework ahead of the first SMR achieving commercial operation. This framework must cover must run status, ancillary services eligibility, and long term Power Purchase Agreement (PPA) structuring specific to SMR projects.

c. Long Term Enriched Fuel Supply Security Framework

i. Technology transfer should be integrated with long term fuel supply assurances:

The government can negotiate fuel supply agreements of up to 20 years with countries from which SMR designs are sourced. Structuring these arrangements within bilateral government to government frameworks, alongside partnerships between Indian firms and international technology providers, will reduce upstream supply risks and ensure continuity of operations over the project lifecycle.

ii. A Sunset Clause tied to Domestic Enrichment Capacity be embedded within this framework, whereby the guarantee and pricing regulation are progressively wound down as India scales up its indigenous enrichment infrastructure to commercially sufficient levels. This ensures the mechanism functions as a transitional bridge rather than a permanent subsidy, incentivising parallel investment in domestic fuel cycle capabilities.

d. Global Design Harmonisation & Mutual Recognition

SMRs rely on economies of multiples rather than economies of scale. For a vendor to be profitable, they must sell dozens of identical units globally. If every country requires a unique, ground up design review, the cost of customisation can make the business unviable. It is therefore recommended that India should shift from a purely national licensing model to a more globally integrated framework to attract international vendors and accelerate the deployment of indigenous designs.

India should formally align with the International Atomic Energy Agency's (IAEA) 'Nuclear Harmonisation and Standardisation Initiative' (NHSI) by inserting a deemed approved clause: "where an SMR design has successfully completed the IAEA's Generic Reactor Safety Review (GRSR) or has been certified by from an IAEA recognised Tier 1 nuclear nation, the AERB shall dispense with a de novo technical design review. In such cases, the regulatory oversight shall be restricted exclusively to local site specific clearances." This will ensure that the international safety benchmarks are leveraged without administrative duplication.

e. Performance-based Licensing

Following the NITI Aayog recommendation (NITI Aayog, 2023) to adopt licensing for innovative SMR designs, the AERB should transition from prescriptive rules to performance based outcomes. The traditional regulations mandate specific hardware whereas the SMRs use passive safety and so may

not need those hardwares at all. In order to address that, it is suggested that a dedicated SMR Specific Safety Code that focuses on safety results may be established. It will tailor safety requirements based on the actual risk profile of smaller cores and passive cooling systems, similar to the US NRC Part 53 framework. (Refer to Annexure-II).

f. Decoupled Site Clearances and Single Window

In traditional nuclear projects, the site and the reactor are licensed together in a linear, slow process. Because SMRs are factory built, the reactor is essentially a product that arrives at a site. Waiting for a specific design to be finalised before clearing a site leads to massive construction delays. Addressing this requires two distinct but complementary reforms: decoupling site approval from reactor design assessment and streamlining inter agency coordination through a dedicated single window.

i. Decoupling Site Approval from Reactor Design

Under the current approach, a developer cannot advance site clearance until a reactor design is substantially finalised, which introduces significant lead time delays that are particularly ill suited to the SMR model. To address this, AERB should enable early Site Permits, certifying locations as "nuclear ready" independent of the final reactor design, similar to practices followed by the U.S. Nuclear Regulatory Commission. Site assessment under this framework would evaluate geology, seismicity, hydrology, emergency planning zones, and grid proximity, factors that are design agnostic and can be assessed well in advance of design selection. This would significantly reduce project timelines and improve bankability for private investors, since a pre certified site de risks the development pipeline at the stage when financing decisions are being made.

ii. Streamlining Inter Agency Coordination

It is recommended that the AERB, in coordination with the DAE, establish a Nuclear Energy Single Window (NESW) as a dedicated vertical within the National Single Window System. NESW would digitally integrate approvals across key ministries and agencies, including environmental clearance (MoEFCC), state pollution control boards, Ministry of Power (grid connectivity), Ministry of Heavy Industries (manufacturing certification), and state level land and construction authorities.

NESW should function as a fast track interface for non-safety approvals. It should enable seamless sharing and pre validation of compliance documentation (such as ISO 19443, ISO 9001, and BIS standards) across agencies to eliminate duplication. Non-safety clearances including environmental approvals, land acquisition, water allocation, construction permits, and grid connectivity should be time bound (e.g., within 180 days), with deemed approval provisions supported by digital tracking systems.

Safety approvals, however, must remain fully independent under AERB and should not be subject to deemed clearance. These should follow a structured stage gated process covering site approval, construction consent, commissioning, and operation while being prioritised within the NESW framework through pre screening of vendor certifications, quality assurance records, and compliance documentation.

g. Graded Liability and Insurance pool

It is recommended that a separate liability tier be introduced for microreactors and portable power modules, with caps in the range of ₹10–50 crore. This makes SMRs a competitive and insurable alternative to diesel generators and small scale fossil fuel plants. In addition, penalty provisions should be made proportional to project scale, with lower penalties for minor administrative violations in smaller reactors. Extend the Indian Nuclear Insurance Pool (INIP) to SMRs for financial security.

h. Financial Inclusion of Nuclear Energy in India's Sovereign Green Bond and FDI framework

As the Climate Finance Taxonomy has already recognised nuclear, a logical next step is harmonising the Sovereign Green Bond Framework, bringing India in line with the UK, France, South Korea and the EU taxonomy. It is recommended that nuclear energy be included as an eligible green project by either creating a separate category or adding under 'Renewable Energy' category. Further, expedite inter-ministerial consultations and amend FEMA to permit 49% FDI in nuclear power via Indian-majority joint ventures. Given the capital intensive nature of nuclear projects, such inclusion will allow the private players to tap into a global pool of Environmental, Social, and Governance funds.

CONCLUSION

Deployment of SMRs should be positioned as a strategic pillar of India's long term growth framework, aligned with both Viksit Bharat and national energy independence commitments. Anchored in the enabling reforms of the SHANTI Act, the mission can crowd in private capital, accelerate standardised SMR deployment, and catalyse a competitive domestic nuclear manufacturing ecosystem. By repurposing retiring coal assets, powering industrial clusters and data centres, and enabling green hydrogen production, SMRs can deliver reliable, low carbon energy at scale. With fiscal support and regulatory certainty, the roadmap can unlock sustainable economic growth while strengthening energy sovereignty.



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ENDNOTES

1. Fiscal projections assume a stable 8% learning rate and do not account for the extreme cost escalation outliers seen in some international FOAK projects.
2. A 7-year PTC targets the period of significant financial stress, when debt servicing and operational risks are highest. It provides enough support to make projects bankable and bridge the residual cost gap. Beyond this phase, SMRs are expected to operate efficiently and competitively without subsidies. For Nuclear projects after 2005, the US gives tax credits for 8 years. Given the smaller scale and modular nature of SMRs, we use a more conservative estimate of 7 years.
3. Import duty exemptions are calculated for 45% indigenisation, including basic custom duty waiver and social welfare duty waiver, and freight and insurance which make up 6-8% of the SMR. (Nuclear Business)
4. The assumed 3% interest subvention is in line with Gol's incentive package in schemes like Assistance in Deploying Energy Efficient Technologies in Industries and Establishments (ADEETIE), which provides a 3% interest subvention for Medium Enterprises (Bureau of Energy Efficiency) leading to a cost reduction of 5-8%.

ANNEXURE-I: CANDIDATE COAL TO SMR TRANSITION SITES

Note: Multiple rows at the same plant indicate separate generating units

Candidate Coal to SMR Transition Sites			
Sr. No.	Name	State	District
1	Anpara	Uttar Pradesh	Sonbhadra
2	Anpara	Uttar Pradesh	Sonbhadra
3	Barauni	Bihar	Begusarai
4	Bhusawal	Maharashtra	Jalgaon
5	Chandrapur_Coal	Maharashtra	Chandrapur
6	Chandrapur_Coal	Maharashtra	Chandrapur
7	Chandrapur_Coal	Maharashtra	Chandrapur
8	Chandrapur_Coal	Maharashtra	Chandrapur
9	Chandrapur_Coal	Maharashtra	Chandrapur
10	Durgapur	West Bengal	Paschim Bardhaman
11	Farakka Stps	West Bengal	Murshidabad
12	Gandhi Nagar	Gujarat	Gandhinagar
13	GHTP (Leh.Moh.)	Punjab	Bathinda
14	Khaperkheda li	Maharashtra	Nagpur
15	Khaperkheda li	Maharashtra	Nagpur
16	Kota	Rajasthan	Kota
17	Nashik	Maharashtra	Nashik
18	Nashik	Maharashtra	Nashik
19	Nashik	Maharashtra	Nashik
20	Neyveli St li	Tamil Nadu	Cuddalore
21	North Chennai	Tamil Nadu	Tiruvallur
22	North Chennai	Tamil Nadu	Tiruvallur
23	Obra-A	Uttar Pradesh	Sonbhadra
24	R_Gundem - B	Telangana	Peddapalli
25	R_Gundem Stps	Telangana	Peddapalli
26	R_Gundem Stps	Telangana	Peddapalli
27	Raichur	Karnataka	Raichur
28	Raichur	Karnataka	Raichur
29	Raichur	Karnataka	Raichur
30	Raichur	Karnataka	Raichur
31	Raichur	Karnataka	Raichur

Candidate Coal to SMR Transition Sites

Sr. No.	Name	State	District
32	Raichur	Karnataka	Raichur
33	Royal Seema	Andhra Pradesh	YSR Kadapa
34	Ropar	Punjab	Rupnagar
35	Ropar	Punjab	Rupnagar
36	Ropar	Punjab	Rupnagar
37	Ropar	Punjab	Rupnagar
38	Southern Repl.	West Bengal	Kolkata
39	Southern Repl.	West Bengal	Kolkata
40	Suratgarh	Rajasthan	Sri Ganganagar
41	Tuticorin	Tamil Nadu	Thoothukudi
42	Ukai_Coal	Gujarat	Tapi
43	Ukai_Coal	Gujarat	Tapi
44	Unchahar	Uttar Pradesh	Rae Bareli
45	Unchahar	Uttar Pradesh	Rae Bareli
46	Wanakbori	Gujarat	Kheda
47	Wanakbori	Gujarat	Kheda
48	Wanakbori	Gujarat	Kheda
49	Wanakbori	Gujarat	Kheda

ANNEXURE-II: MINIMUM ELIGIBILITY

Table 10 delineates the minimum participation criteria across these five dimensions, distinguishing between requirements already established under the SHANTI Act and additional standards necessary to ensure robust private sector participation aligned with global best practices.

Minimum Participation Criteria for Private Sector Players		
Category	Existing requirements for Nuclear Projects	Additional Requirements to be Incorporated
Ownership & Control Safeguards	<ol style="list-style-type: none"> 1. Company incorporated in India under Companies Act, 2013. 2. Majority Indian ownership ($\geq 51\%$ beneficial ownership). 	<ol style="list-style-type: none"> 1. Board level security clearance for key directors and senior management. 2. For Captive Consumers: Minimum baseload offtake agreement for at least 51% of power generated, in alignment with captive power regulations.
Financial Health	<ol style="list-style-type: none"> 1. Escrowed decommissioning fund from Day 1. 2. Mandatory nuclear liability insurance coverage. 	<ol style="list-style-type: none"> 1. Current Ratio >1 2. Demonstrated balance sheet resilience ($1:2 \leq \text{debt equity ratio} \leq 1:1.5$). 3. EBITDA margin of at least 14% 4. Proven ability to raise long tenure capital (minimum 15 year debt profile).
Technical Competence & Experience	<ol style="list-style-type: none"> 1. Long term partnership with Nuclear Power Corporation of India Limited (NPCIL) under Department of Atomic Energy for receiving enriched nuclear fuel supply. 	<ol style="list-style-type: none"> 1. Certified nuclear quality assurance systems (ASME NQA-1 or equivalent) and independent safety review committee. 2. Technology partnership with internationally certified reactor vendors (IAEA Technical Support Organisation recognition or equivalent). 3. Demonstrated experience in large infrastructure or power projects (minimum ₹5,000 crore project value). 4. Preferred experience in strategic industrial sectors (oil & gas, defence, heavy engineering, process industries).
Manufacturing & Supply Chain Localisation	(Not explicitly covered under SHANTI Act)	<ol style="list-style-type: none"> 1. Phased targets for Local Value Addition (LVA): <ol style="list-style-type: none"> a. Minimum 45% LVA at project outset b. Rising to 60% by 2035 c. Advancing to 80% by 2047. 2. Commitment to develop domestic supply chain for critical reactor components (pressure vessels, steam generators, control systems).

Safety &
Regulatory
Readiness

*(Safety oversight delegated to
AERB; no private sector specific
pre qualification under SHANTI
Act)*

1. ISO 9001 and ISO 19443 (nuclear sector quality management) certification.
2. Pre licensing site evaluation capability (hydrological, seismic, demographic studies).
3. Comprehensive Emergency Preparedness Plan aligned with AERB guidelines and IAEA Safety Standards (GS-R-2).
4. Cybersecurity framework compliant with AERB/NPC-18 and IEC 62645 standards for nuclear instrumentation and control systems.
5. Full compliance with Atomic Energy Regulatory Board (AERB) or successor Nuclear Safety Authority standards.
6. Mandatory public consultation and transparency framework (environmental impact assessment, stakeholder engagement plan).



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