4. India's Nuclear Energy Roadmap - Economy

According to the TERI report 'India's Nuclear Energy Vision - Strategic Pathways for SMR Deployment', achieving 100 GW by 2047 will require investments of nearly ₹23–25 lakh crore, major regulatory reforms, rapid project execution, and deployment of Small Modular Reactors.

1.Background

Nuclear energy has been part of India's energy portfolio since the establishment of the Atomic Energy Commission in 1948 and commissioning of the first nuclear power plant at Tirupur in 1969, guided by Dr. Homi J. Bhabha's visionary three-stage nuclear programme designed to utilize India's vast thorium reserves for long-term energy security. India currently operates 25 nuclear reactors with installed capacity of around 8.8 GW across 7 nuclear power sites, contributing approximately 3% to total electricity generation, a relatively modest share compared to countries like France where nuclear provides over 70% of electricity. India's economy and population are expanding rapidly, increasing demand for clean energy, reliable baseload electricity, industrial power supply, and energy security, while renewable energy capacity is growing through solar and wind installations, but these sources remain intermittent unable to provide continuous power during non-solar hours requiring complementary baseload sources. Nuclear energy provides continuous baseload power operating at high-capacity factors exceeding 80%, low-carbon electricity with minimal greenhouse gas emissions during operation, grid stability during non-solar hours when solar generation drops, and support for green hydrogen and green ammonia production through dedicated nuclear power for electrolysis. According to the Central Electricity Authority, nuclear energy will become increasingly important as renewable penetration rises requiring stable baseload to balance grid fluctuations. The government has announced ambitious target of achieving 100 GW nuclear capacity by 2047 as part of Viksit Bharat vision and Net Zero 2070 commitment, representing more than tenfold increase from current 8.8 GW. Ongoing and planned projects may increase capacity to nearly 22 GW by 2032, but reaching 100 GW by 2047 requires much faster expansion strategy necessitating deployment of Small Modular Reactors alongside conventional large reactors.

The TERI report 'India's Nuclear Energy Vision - Strategic Pathways for SMR Deployment' estimates achieving this target will require investments of nearly ₹23–25 lakh crore, major regulatory reforms streamlining licensing procedures and creating SMR-specific regulations, rapid project execution reducing construction timelines through factory-based manufacturing and modular construction, overcoming financing constraints through sovereign support and private investment participation, ensuring fuel security through domestic uranium production expansion and international partnerships, building skilled workforce through training programmes and institutional coordination, addressing public acceptance concerns through transparency and community engagement, and leveraging India's indigenous capabilities under Atmanirbhar Bharat framework developing 200 MWe Bharat Small Modular Reactor, 55 MWe reactor, and 5 MWth High Temperature Gas-Cooled Reactor with budgetary allocation of ₹20,000 crore for SMR research and deployment in Union Budget 2025–26 targeting operationalization of 5 indigenous SMRs by 2033.

2.Why Nuclear Energy Matters for India

Growing Energy Demand

1. India's economy and population are expanding rapidly, increasing the demand for clean energy, reliable baseload electricity, industrial power supply, and energy security.
2. Electricity demand is projected to grow at 6-7% annually over the next two decades requiring massive capacity additions.
3. Industrial sectors including steel, cement, chemicals, and data centers require uninterrupted power supply that intermittent renewables cannot guarantee alone.
4. Urbanization and rising living standards drive increased per capita electricity consumption requiring diverse energy sources.

Role of Nuclear Power

1. Nuclear energy provides continuous baseload power operating at capacity factors exceeding 80% unlike solar and wind which have capacity factors of 20-25%.
2. Low-carbon electricity with minimal greenhouse gas emissions during operation supporting India's Net Zero 2070 commitment.
3. Grid stability during non-solar hours when solar generation drops maintaining frequency and voltage stability.
4. Support for green hydrogen and green ammonia production through dedicated nuclear power for electrolysis providing clean industrial feedstock.
5. According to the Central Electricity Authority, nuclear energy will become increasingly important as renewable penetration rises requiring stable baseload to balance grid fluctuations.

3.Current Status of Nuclear Energy in India

Existing Infrastructure

1. India currently operates 25 nuclear reactors with installed capacity of around 8.8 GW across 7 nuclear power sites.
2. Nuclear contributes approximately 3% to total electricity generation, relatively modest compared to global leaders.
3. Existing reactors include Pressurised Heavy Water Reactors using natural uranium and light water reactors using enriched uranium.
4. The Prototype Fast Breeder Reactor at Kalpakkam achieved criticality in April 2026 marking progress in Stage 2 of three-stage programme.

Future Pipeline

1. Ongoing and planned projects may increase capacity to nearly 22 GW by 2032 through construction of new units.
2. However, reaching 100 GW by 2047 requires a much faster expansion strategy beyond conventional large reactors.
3. Fleet mode construction approach being adopted for standardized reactor designs reducing costs and timelines.
4. International cooperation with countries like France, Russia, and USA for technology transfer and joint ventures.

4.Small Modular Reactors (SMRs)

Definition and Characteristics

1. SMRs are compact nuclear reactors with smaller generation capacity typically under 300 MW, factory-based manufacturing, modular construction, and faster deployment timelines.
2. They are considered more flexible and cost-effective than conventional large reactors that typically exceed 1000 MW capacity.
3. Modular design allows components to be manufactured in factories and transported to sites reducing construction time and quality issues.

Advantages of SMRs

Faster Construction - Factory manufacturing reduces delays and cost overruns common in conventional nuclear projects that often face multi-year delays.

Lower Initial Investment - Phased investments reduce financial risk allowing utilities to add capacity incrementally based on demand growth.

Flexible Deployment - SMRs can be installed in industrial hubs providing dedicated power, remote regions without strong transmission infrastructure, smaller grids unable to absorb large plants, and data centers requiring reliable power.

Multi-purpose Applications - Apart from electricity generation, SMRs can support hydrogen production through high-temperature electrolysis, desalination providing fresh water in coastal areas, industrial process heat for manufacturing, and district heating for urban areas.

India's Indigenous SMR Programme

1. India is currently developing a 200 MWe Bharat Small Modular Reactor, 55 MWe reactor, and 5 MWth High Temperature Gas-Cooled Reactor.
2. Budgetary Support - The Union Budget 2025–26 allocated ₹20,000 crore for SMR research and deployment.
3. Target - Operationalise 5 indigenous SMRs by 2033 demonstrating technical feasibility and economic viability.
4. It reflects the government's push toward indigenous nuclear technology development under the Atmanirbhar Bharat framework.

5.India's Three-Stage Nuclear Programme

Strategic Vision

1. India's long-term nuclear vision follows the strategy proposed by Dr. Homi J. Bhabha designed to utilize India's limited uranium but vast thorium reserves.
2. India possesses one of the world's largest thorium reserves estimated at over 25% of global deposits, making Stage 3 strategically important.

Three Stages

Stage 1 - Pressurised Heavy Water Reactors (PHWRs) using natural uranium producing plutonium as byproduct.

Stage 2 - Fast Breeder Reactors using plutonium from Stage 1 breeding more plutonium than consumed while producing Uranium-233 from thorium.

1. The Prototype Fast Breeder Reactor at Kalpakkam achieved criticality in April 2026 marking milestone in Stage 2 implementation.

Stage 3 - Thorium-based reactors using Uranium-233 for long-term fuel sustainability providing virtually unlimited energy from abundant thorium resources.

Global Developments in SMRs

1. More than 120 SMR designs are under development globally representing diverse technologies and approaches.
2. Countries leading SMR development include the United States with NuScale and other designs, Canada with CANDU-based SMRs, China with operational floating nuclear plants, Russia with operational KLT-40S reactors, France with NUWARD design, and the United Kingdom with Rolls-Royce SMR.
3. Only a few SMRs are currently operational, but global investment is increasing rapidly with billions committed by governments and private sector.

6.Key Challenges in Achieving 100 GW Target

Regulatory Bottlenecks

1. India's nuclear regulatory system was designed mainly for large reactors requiring adaptation for SMR characteristics.
2. Required reforms include streamlined licensing procedures reducing approval timelines, SMR-specific regulations recognizing different risk profiles, faster environmental clearances without compromising safety, and public-private partnership frameworks enabling private sector participation.
3. The Atomic Energy Act and related frameworks may require modernization to accommodate private participation currently restricted.

Financing Constraints

1. Nuclear projects involve high upfront capital costs exceeding ₹5-7 crore per MW, long gestation periods of 5-7 years, and financial risks due to delays and cost overruns.
2. TERI estimates investments of ₹23–25 lakh crore by 2047 requiring massive capital mobilization.
3. It requires sovereign support through budgetary allocations and guarantees, international partnerships bringing foreign capital and technology, and private investment participation through innovative financing mechanisms.

Fuel Security Concerns

1. India produces only around 600 tonnes of uranium annually, despite having substantial reserves around 425,000–433,800 tonnes of U_3O_8.
2. Import Dependence - Between 2008–09 and 2024–25, India imported 18,842.60 tonnes of uranium products demonstrating reliance on foreign supplies.
3. Thus, long-term fuel security remains a major concern requiring accelerated domestic uranium mining, processing capacity expansion, and diversification of import sources.
4. Thorium fuel cycle development is essential for utilizing indigenous thorium reserves reducing dependence on uranium imports.

Workforce and Technological Gaps

1. Rapid expansion requires skilled nuclear engineers, safety experts, and advanced manufacturing ecosystems currently insufficient for ambitious targets.
2. India needs institutional coordination between research organizations, regulatory bodies, and industry, training programmes at universities and technical institutions, and research collaboration with international partners for technology transfer.
3. Manufacturing ecosystem development for nuclear components, quality assurance systems, and supply chain resilience are critical.

Public Acceptance and Safety Concerns

1. Public concerns after incidents like Fukushima in Japan 2011 and Chernobyl in Ukraine 1986 continue to affect nuclear expansion globally.
2. There is a need for public outreach programmes explaining safety features and emergency preparedness, transparency in safety mechanisms and incident reporting, and community participation in site selection and environmental impact assessments.
3. Local opposition has delayed several nuclear projects in India requiring better stakeholder engagement.

7.Way Forward - TERI's Recommended Roadmap

Phase 1 - Foundation Building

1. Regulatory reforms streamlining approval processes and creating SMR-specific frameworks, pilot SMR projects demonstrating technical and economic viability, and institutional strengthening building regulatory capacity and industry ecosystem.

Phase 2 - Rapid Deployment

1. Large-scale deployment of proven SMR designs achieving economies of scale, industrial ecosystem development creating domestic manufacturing capabilities, and public-private collaboration leveraging private sector efficiency and capital.

Phase 3 - Advanced Technologies

1. Integration of advanced reactors including Generation IV designs with enhanced safety, Thorium-based systems implementing Stage 3 of three-stage programme, and deep decarbonisation of industry providing clean energy for hard-to-abate sectors.

Conclusion

Nuclear energy is emerging as a crucial pillar of India's long-term energy transition strategy providing continuous baseload power, low-carbon electricity supporting Net Zero 2070 target, grid stability during non-solar hours, and support for green hydrogen production. India currently operates 25

nuclear reactors with 8.8 GW capacity with ongoing projects potentially reaching 22 GW by 2032, but achieving ambitious target of 100 GW nuclear capacity by 2047 requires coordinated action across regulation, financing, fuel security, technology, and public engagement. Small Modular Reactors can play transformative role through faster construction via factory manufacturing, lower initial investment reducing financial risk, flexible deployment in industrial hubs and remote regions, and multi-purpose applications including hydrogen production and desalination. India's indigenous SMR programme developing 200 MWe Bharat Small Modular Reactor with ₹20,000 crore budgetary allocation targeting 5 operational SMRs by 2033 under Amenabar Bharat framework. Key challenges include regulatory bottlenecks requiring Atomic Energy Act modernization, financing constraints needing ₹23-25 lakh crore investment, fuel security concerns with India producing only 600 tonnes uranium annually while importing 18,842.60 tonnes between 2008-25, workforce and technological gaps, and public acceptance issues following Fukushima and Chernobyl incidents. TERI recommends phased roadmap with Phase 1 regulatory reforms and pilot projects, Phase 2 large-scale deployment and industrial ecosystem development, and Phase 3 integration of advanced reactors and thorium-based systems achieving deep decarbonisation.
Source - https -//www.downtoearth.org.in/energy/india-will-need-rs-25-lakh-crore-sweeping-reforms-to-achieve-100-gw-nuclear-target-by-2047-teri-report