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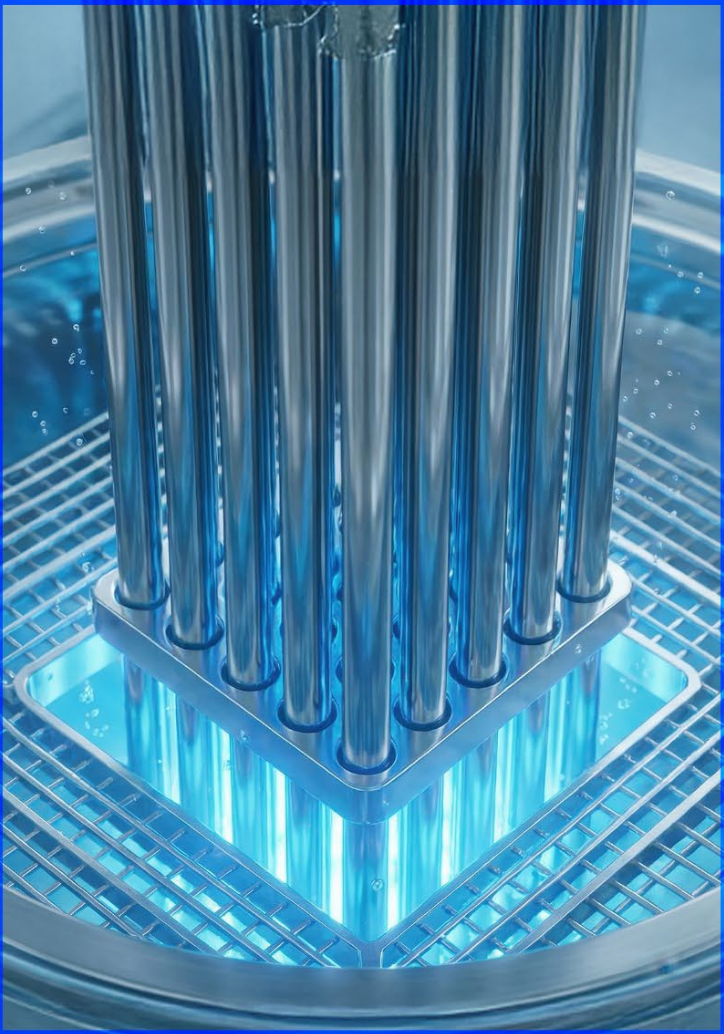
U.S.-India Business Council

Atoms for net-zero

A 100 GW bet on India's nuclear expansion ambitions through private-sector participation

USIBC – KPMG in India report



March 2026

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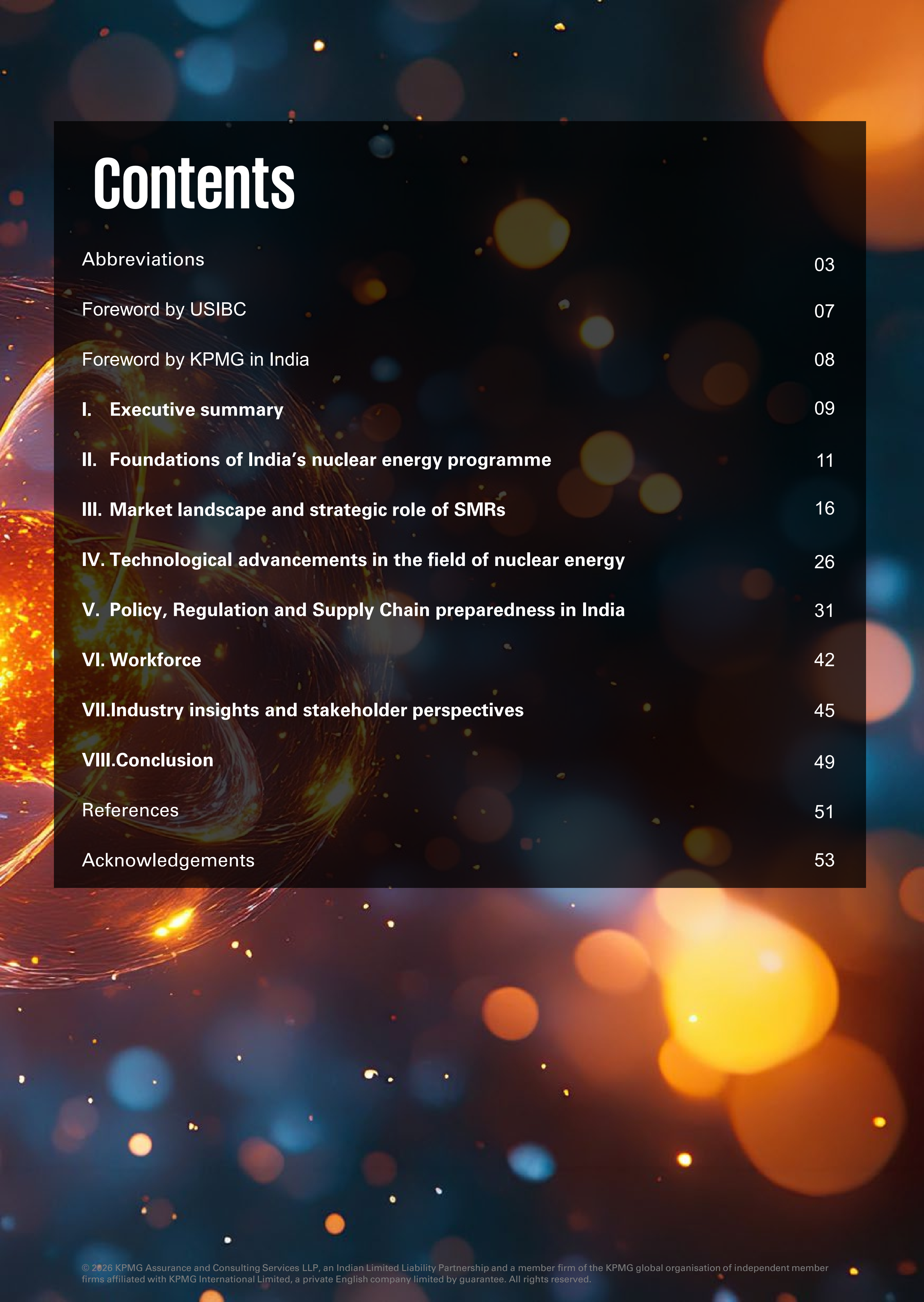

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Abbreviations

AEC	Atomic Energy Commission
AEET	Atomic Energy Establishment, Trombay
AERB	Atomic Energy Regulatory Board
AI	Artificial Intelligence
AMD	Atomic Minerals Directorate for Exploration and Research
ASME	American Society of Mechanical Engineers
BARC	Bhabha Atomic Research Centre
BCM	Billion Cubic Metre
BHAVINI	BHAratiya nabhikiya VIdyut NIgam
BHEL	Bharat Heavy Electrical Limited
BSR	Bharat Small Reactor
BU	Billion Unit
BWR	Boiling Water Reactor
CAGR	Compounded Annual Growth Rate
CANDU	CANada Deuterium Uranium
CEA	Central Electricity Authority
CHTR	Compact High Temperature Reactor
CIRUS	Canada India Reactor Utility Service
CLND	Civil Liability for Nuclear Damage
CO_2	Carbon Dioxide
CSC	Convention on Supplementary Compensation
DAE	Department of Atomic Energy
DGR	Deep Geological Reserve
EIA	Environmental Impact Assessment
EPC	Engineering, Procurement, Construction
EU	European Union
EV	Electric Vehicle
FBR	Fast Breeder Reactor

Abbreviations

FDI	Foreign Direct Investmentect
FDRE	Firm and Dispatchable Renewable Energy
FNPP	Floating Nuclear Power Plants
FOAK	First-of-a-kind
FY	Financial Year
GCNEP	Global Centre for Nuclear Energy Partnership
GE	General Electric
GFR	Gas-cooled Fast Reactors
GW	Gigawatt
GWe	Gigawatt-electric
GWh	Gigawatt-hour
GW$_{th}$	Gigawatt-thermal
HALEU	High Assay Low Enriched Uranium
HCC	Hindustan Construction Company
HLW	High Level Waste
HTSE	High Temperature Steam Electrolysis
IAEA	International Atomic Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IMO	International Maritime Organisation
INIP	Indian Nuclear Insurance Pool
INR	Indian Rupees
IPR	Intellectual Protection Rights
IRRS	Integrated Regulatory Review Service
IS	Iodine-Sulphur
ITER	International Thermonuclear Experimental Reactor
KEPCO	Korea Electric Power Corporation
KT	Kilo-tonnes
LEU	Low Enriched Uranium

Abbreviations

LWR	Light Water Reactor
MEIL	Megha Engineering and Infrastructure Limited
MLD	Million Litres per Day
MMT	Million Metric Tonnes
MoSPI	Ministry of Statistics and Programme Implementation
MSME	Micro, Medium and Small Enterprise
MSR	Molten Salt Reactor
MU	Million Units
MW	Megawatt
MW_e	Megawatt-electric
MWh	Megawatt-hour
MW_{th}	Megawatt-thermal
NDDP	Nuclear Desalination Demonstration Plant
NEMO	Nuclear Energy Maritime Organisation
NFC	Nuclear Fuel Complex
NPCIL	Nuclear Power Corporation of India Limited
NPT	Non-Proliferation Treaty
NSDF	Near-surface Disposal Facilities
NSG	Nuclear Suppliers Group
NWPA	Nuclear Waste Policy Act
PFBR	Prototype Fast Breeder Reactor
PHWR	Pressurised Heavy Water Reactor
PJ	Petajoule
PPA	Power Purchase Agreement
PSU	Public Sector Undertaking
PWR	Pressurised Water Reactor
QA	Quality Assurance
RAPS	Rajasthan Atomic Power Station

Abbreviations

SHANTI	Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India
SSSF	Solid Storage Surveillance Facilities
TAPS	Tarapur Atomic Power Station
TBD	To Be Decided
TIFR	Tata Institute of Fundamental Research
TRISO	TRi-structural ISOtropic (particle fuel)
UCIL	Uranium Corporation of India Limited
U.K.	United Kingdom
U.S.	United States of America
USIBC	United States-India Business Council
U.S.S.R.	Union of Soviet Socialist Republics
WBCSD	World Business Council for Sustainable Development
WITS	World Integrated Trade Solution

Foreword by USIBC

"*Atoms for net-zero*" arrives at a pivotal moment in India's and global discussions on energy security. India is on a strong trajectory of industrialisation, expanding manufacturing, and building resilient infrastructure. These can be fundamental to powering the nation's economic growth. India is also committed to Viksit Bharat 2047, a serious development agenda for the next two decades and beyond. Prime Minister Narendra Modi's government is clearly committed to achieving a net-zero emissions target by 2070. Many different energy technologies and fuels are expected to aid India in achieving this, and civil nuclear energy is envisaged to be a critical and consequential component of the country's energy mix. India's roadmap for nuclear energy is clear: 22 GW of installed capacity by 2032, scaling to 100 GW by 2047. The launch of India's Nuclear energy mission and the dedicated investment of INR20,000 crore (approximately USD2.2 billion) for the development of five indigenous Small Modular Reactors (SMRs) represent an important milestone in India's energy development.

Following the 2025 Budget announcement to open the nuclear energy sector to private participation, this report was developed, based on extensive surveys with industry and experts, to support the actualisation of that goal. A year later, this objective has been further bolstered by India's enactment of the Sustainable Harnessing and Advancement of Nuclear Energy for Transforming India (SHANTI) Act, 2025. This is a genuine legislative breakthrough and a landmark reform that encourages private-sector investment, technology and manufacturing partnerships, and enables the inflow of capital and innovation. We warmly welcome this step and commend the Government of India for aligning its 100 GW ambition with the institutional reforms required to achieve it.

We now have an opportunity to build on the legislation and translate it into real projects and partnerships. Government and business can work together to align safety standards, streamline licensing pathways, and develop long-term power-purchase models that bring certainty and predictability to the sector. We also recognise that this might open conversations on innovative financing structures, including green bonds, blended finance, and credit support, that can de-risk investment and attract institutional capital at scale. At the core of a growing sector like nuclear energy, industry can also play a strong role in supporting the sustained national commitment to build the skilled workforce needed to safely construct and operate 100 GW of nuclear capacity. This can be achieved through dedicated investment in science, technology, engineering, and mathematics (STEM) education, and through knowledge partnerships with globally reputed research institutions.

"*Atoms for net-zero*" is an attempt to support India's nuclear energy mission, encourage business-to-business connectivity, and build on India's priority to open the sector to robust private-sector partnerships. It lays out the policy architecture, potential technology pathways, financing mechanisms, and private-sector models that can advance that mission.

We offer this as an analysis of the current landscape, and as a call for collaboration. The window to partner on India's nuclear-energy renaissance is open.

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Foreword by KPMG in India

India is at a defining point in its clean energy journey. Nuclear power may anchor a reliable and low-carbon system that supports growth in industry, digital infrastructure and mobility while enhancing energy security. The Government has set forth an ambitious target of installing 100 GW of nuclear power capacity by 2047, which is nearly a 11-to-13-fold jump from the current capacity. Private sector is expected to step in and contribute towards helping the country achieve this ambitious target.

A modern legislative framework is expected to translate this ambition into action. The SHANTI Act, passed in December 2025, has been widely hailed for creating the enabling legislative framework. The roles for the Department of Atomic Energy and the Atomic Energy Regulatory Board are envisaged to be clarified, with sovereign control retained over sensitive activities like regulations, approvals, and fuel cycle functions, but wide swathes outside them have been opened to the private sector. The resulting architecture may invite investment and innovation while keeping safety and the environment at the centre.

Technology choice is likely to matter. India's pressurised heavy water reactor heritage offers a dependable platform as the country prepares for the next wave of nuclear reactor installations. SMRs, including indigenously developed Bharat Small Reactors (BSRs), are expected to serve industrial heat, hydrogen, desalination and captive power needs. A measured approach that standardises a few platforms and replicates them across sites may compress schedules, lower financing costs and build deep domestic capability.

Finance might be as important as technology. This report sets out how bankable offtake, viability gap support for first-of-a-kind projects and eligibility within green finance frameworks could unlock capital at scale. It also highlights the value of time-bound licensing, design certification pathways for repeat builds and a predictable back-end regime in which spent fuel is centrally managed. These proposals are expected to align investor confidence with public assurance.

Our industry survey indicates strong interest in conventional reactors for data centres and in small modular reactors for distributed industrial applications. They also flag priorities such as assured access to suitable fuels for advanced designs, vendor qualification to international codes and accelerated approvals. Continued collaboration between government, operators, global technology providers and financiers is expected to be essential to convert intent into projects and projects into operating fleets.

India might need to expand and upskill its workforce across operations, engineering, digital controls, quality assurance and construction. The scale of the target implies tens of thousands of high-quality jobs in plant operations, with many more in the supply chain and construction during the build-out. Investing in skills and safety culture is envisaged to ensure that expansion proceeds responsibly and earns public trust.

Translating the intent and provisions of the SHANTI Act to reality is expected to require calibrated implementation measures. This report aims to offer a practical roadmap from vision to commissioning.

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I. Executive summary

India's nuclear energy sector is entering a transformative phase, marked by a decisive goal to become a more inclusive and dynamic framework that actively encourages private sector involvement and international collaboration. This evolution is driven by the country's urgent need to meet rising energy security demands, reduce dependence on fossil fuels, and achieve its climate commitments. With ambitious targets of reaching 22 GW of nuclear capacity by 2032 and scaling up to 100 GW by 2047, the government has laid out a strategic roadmap that includes the launch of the Nuclear Energy Mission. This also includes a proposed investment of INR20,000 crore (approximately USD2.18 billion) specifically earmarked for the development of five indigenous SMRs.[1] This Mission is envisaged to accelerate the adoption of advanced nuclear technologies, strengthen domestic manufacturing capabilities, and position nuclear energy as a reliable, low-carbon pillar of India's energy mix.

SMRs and the indigenously developed BSRs are central to this vision. Their modular design, passive safety features, and scalability make them particularly well-suited for decentralised deployment across diverse geographies and industrial sectors. Beyond grid power, SMRs offer compelling applications in hydrogen and ammonia production, district heating, desalination, and remote power generation—especially in regions with limited access to conventional energy infrastructure. Their ability to provide high-temperature industrial heat also makes them valuable for decarbonizing hard-to-abate sectors such as steel, refining, and chemicals. Industry stakeholders increasingly view SMRs as a gateway for private sector participation, contingent on government support for first-of-a-kind (FOAK) projects and the establishment of a clear, streamlined regulatory pathway.

However, realising the full potential of nuclear energy in India is expected to require a comprehensive overhaul of the existing legislative and regulatory framework. The SHANTI Act, passed in December 2025, is a step in the right direction, as it now enables private-sector participation in India's nuclear energy sector, subject to regulatory and licensing requirements. The SHANTI Act repeals the erstwhile Atomic Energy Act of 1962 and the Civil Liability for Nuclear Damage (CLND) Act of 2010, both of which restricted private and foreign investment and created barriers to innovation and the inflow of capital.

Survey findings from industry participants, conducted in November 2025 prior to the passage of the SHANTI act, underscored a strong consensus on the need for targeted amendments to these laws to unlock private financing, enable international technology partnerships, and facilitate broader market access. Respondents also emphasise the importance of long-term power purchase agreements (PPAs) to ensure revenue certainty, simplified licensing and approval processes to reduce project lead times, and greater clarity on liability and insurance mechanisms to mitigate investor risk. Some of the industry asks, like enabling private sector participation, have already been addressed by the SHANTI act.

India's nuclear supply chain, although robust in conventional Pressurised Heavy Water Reactor (PHWR) technologies and engineering capabilities, requires significant upgrading to support next generation reactors. Key gaps include the availability of High Assay Low Enriched Uranium (HALEU) fuel, nuclear grade manufacturing infrastructure, and advanced digital control systems. Addressing these challenges might require coordinated efforts across government, industry, and academia, together with strategic partnerships with international players in reactor design, engineering, fuel supply, and safety systems.

This creates a compelling opportunity for global organisations across the value chain: from reactor design and engineering services to fuel supply, digital systems, and safety technologies. As the country moves towards legislative reform and regulatory modernisation, international firms with advanced capabilities in SMRs, fuel enrichment, and nuclear grade manufacturing are well positioned to contribute to India's ambitious expansion goals.

To build a resilient and future-ready nuclear ecosystem, the report advocates for harmonisation of safety standards, joint research and development initiatives, and innovative financing mechanisms such as green bonds, blended finance, and export credit support. These instruments can help de-risk investment, attract institutional capital, and align nuclear projects with global sustainability goals. Public engagement and transparent communication are also emphasised as critical to building societal trust, particularly around issues of nuclear waste management and environmental safety.

The importance of a skilled workforce cannot be understated. As such, the country needs to have a framework to train and hire skilled workforce which can safely construct and handle the 100 GW nuclear power capacity in the country by 2047. There needs to be special emphasis on Science, Technology, Engineering and Mathematics (STEM) branches in India's premier universities and cross-country collaborations are also necessary to accelerate the development of skills in present and prospective workforce.

In conclusion, India's nuclear energy sector stands at a strategic inflection point. With the right mix of policy reform, technological innovation, and investment mobilisation, the country has the potential to emerge as a global leader in nuclear energy. By embracing a collaborative, forward-looking approach, India can not only meet its domestic energy and climate goals but also contribute meaningfully to the global clean energy transition.

II. Foundations of India’s nuclear energy programme

1 Vision, origins and scientific leadership

India’s nuclear energy journey began shortly after independence, driven by the vision of Dr. Homi Jehangir Bhabha, widely regarded as the architect of India’s atomic programme.[2] His establishment of the Tata Institute of Fundamental Research (TIFR) in 1945 laid the groundwork for nuclear science in India. This was followed by the creation of the Atomic Energy Commission (AEC) in 1948 and the Atomic Energy Establishment, Trombay (later renamed Bhabha Atomic Research Centre, BARC) in 1954. These institutions formed the backbone of India’s integrated nuclear research and development ecosystem.

India’s first nuclear reactor, APSARA, a 1 MW_{th} research reactor, went critical in August 1956 and was dedicated to the nation on 20 January 1957, making India the first Asian country outside the Soviet Union to operate a nuclear reactor.[3] Commercial nuclear power generation began with the commissioning of Tarapur Atomic Power Station (TAPS) Units 1 and 2 in 1969, built using Boiling Water Reactor (BWR) technology supplied by General Electric (U.S.).[4,5] Since 1969, India has established several more nuclear power plants, mainly based on indigenous PHWR reactors, and now has a nuclear generation capacity of 8.8 GW as of February 2026.[6] The Honourable Prime Minister, Shri Narendra Modi, has set a target of achieving 100 GW of nuclear power capacity by 2047, and an interim target of 22 GW by 2032 was proposed in a meeting chaired by the Honourable Minister of Power, Shri Manohar Lal Khattar.[7]

2 Historic milestones and reactor development

Under Dr. Bhabha’s leadership, India developed a three-stage nuclear energy programme with the aim of achieving energy self-sufficiency by utilising the naturally available resources of the country.[8] The tenets of the three stages are as follows:

i. The first phase of the programme is based on PHWR design using natural uranium as fuel

ii. The second phase would be based on utilisation of plutonium, generated as by-product from the first phase, in Fast Breeder Reactors (FBRs) for power generation and to enhance India’s fissile material inventory both in terms of plutonium-239 (Pu-239) and uranium-233 (U-233)

iii. The third phase would be based on thorium fuelled thermal reactors.

India’s nuclear reactor fleet is mainly based in indigenously developed PHWR design. About 96 per cent of India’s 8.8 GW nuclear power fleet is based on this design and the remaining 0.32 MW TAPS 1 and 2 is based on BWR design, developed in 1969. Also, reactors 1 and 2 (totalling 2 GW capacity) is based on Russian VVER technology (a form of Pressurised Water Reactor or PWR).[9]

India’s three stage nuclear energy programme relies on the abundant reserves of thorium oxide (ThO_2), which can be bred to produce fissile materials such as U 233 for use as nuclear fuel. India has approximately 1.07 MMT of ThO_2 reserves, which in turn can generate more than 155,500 GWe years of electricity.[10] India has therefore initiated work on establishing pilot FBRs, and the pilot FBR is expected to become operational by September 2026.

Looking ahead, India is also considering the establishment of small modular reactors (SMRs). According to the International Atomic Energy Agency (IAEA), SMRs are nuclear fission reactors with an electrical output capacity of up to 300 MWe.[11] A brief summary of India’s journey in nuclear energy is presented in Figure 1 below.[12]

Figure 1: Brief summary of India's nuclear journey for peaceful, civilian use

Early developments and strategic foundations (1945-1970s)

Founding of nuclear research

India’s nuclear journey began with TIFR in 1945, led by dr. Homi J. Bhabha, establishing foundational research efforts.

Strategic nuclear infrastructure

Between 1950s and 1970s, India developed key reactors like APSARA and CIRUS, and plants for heavy water and plutonium processing.

Resource and fuel development

Uranium discovery in Jaduguda and formation of UCIL strengthened India's nuclear fuel supply and reprocessing capabilities.

International cooperation

India’s peaceful nuclear agreements with France, USA, and U.S.S.R. expanded technological and diplomatic nuclear collaborations.

Expansion, international cooperation, and future goals (early 1980s – present)

Programme expansion and centralisation

The 1980s saw India’s nuclear program expand with RAPS 2 operations and NPCIL formation centralising power operations.

International nuclear cooperation

India signed nuclear agreements with U.S.S.R., Russia, US, Kazakhstan, Australia, UK, and Japan to strengthen global partnerships.

Technological advances and future projects

BHAVINI was formed for PFBR research with fuel loading starting in 2024 and commissioning planned by 2026.

Long-term energy goals

India aims to achieve 100 GW nuclear power capacity by 2047, promoting sustainable development and energy security.

3 Global collaborations and strategic alliances

Since its inception, India’s nuclear programme involved international collaborations with several major partners. These collaborations laid the groundwork for India's nuclear infrastructure.

A. United States of America: Civil nuclear engagement and technology transfer

The U.S. played a crucial role in India's nuclear development, largely through its ‘Atoms for Peace’ programme, which promoted civil nuclear technology globally.

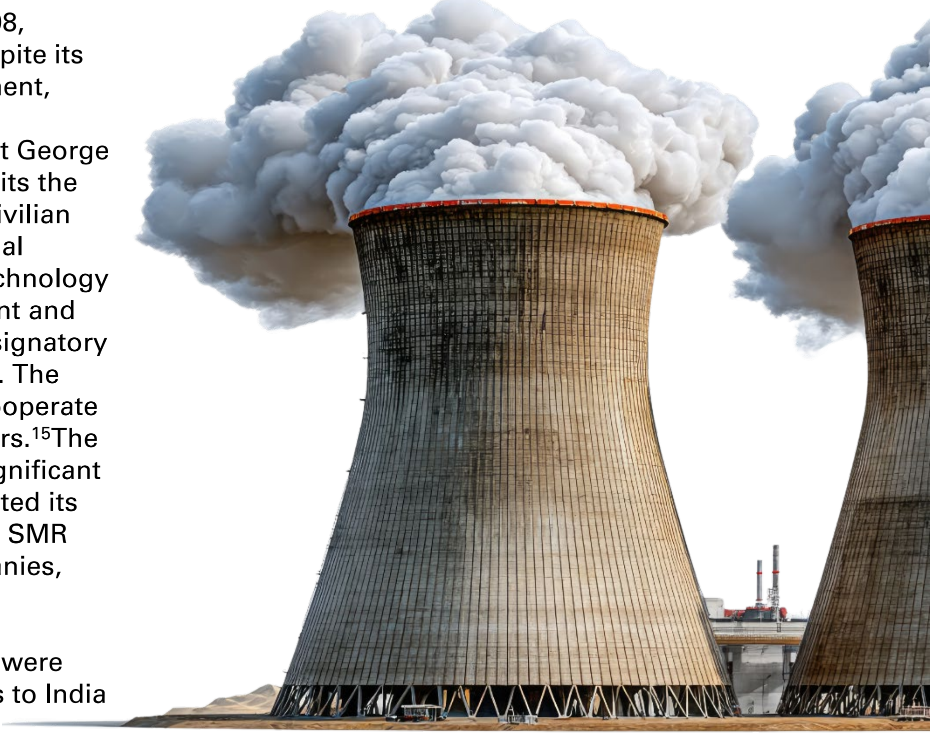
- Tarapur Atomic Power Station (TAPS) (1960s): India's first commercial nuclear power plant at Tarapur was built by the US company GE and began operating in 1969.[13] The plant, consisting of two BWRs, received enriched uranium fuel from the US under a long-term agreement.
- Heavy water supply (1950s): The U.S. also supplied heavy water for the Canadian-built CIRUS reactor.
- Nuclear training (1950s–1960s): Under the Atoms for Peace programme, the U.S. provided valuable training to Indian nuclear scientists.

India and U.S. signed a historic agreement called the “123 Agreement” in 2008 to collaborate on the emerging nuclear power sector in India and aid in technology transfer and fuel supply to India. Post the signing of this agreement, several other countries like France, Japan, Australia and others also showed interest in partnering with India on nuclear power. India also obtained a waiver from the Nuclear Suppliers Group (NSG) in 2008, enabling civil nuclear trade with India despite its non-NPT status, as a result of this agreement, through persistent efforts from the U.S. government under the then U.S. President George W. Bush.[14] The NSG waiver, though permits the trade of nuclear fuel and technology for civilian purposes, is not a “clean and unconditional waiver” as it still places restrictions on technology transfer related to uranium fuel enrichment and spent fuel reprocessing, as India is not a signatory of Nuclear Non-Proliferation Treaty (NPT). The U.S., however, has expressed desire to cooperate with India in obtaining further NSG waivers.[15]The cooperation with U.S. reached another significant milestone in April 2025, when U.S. permitted its company, Holtec International, to transfer SMR related technology to select Indian companies, to enable joint development, design and manufacture of reactors in India.[16] This is significant as previously, U.S. companies were allowed to export equipment and reactors to India but not jointly manufacture them in India. The approval also exists for Holtec Asia (a subsidiary of Holtec International, U.S.) to export Holtec nuclear equipment, manufactured in India, to be exported to U.S., thereby opening up significant opportunities in nuclear equipment exports from India.

B. UK: Early strategic support from United Kingdom

The United Kingdom played a pivotal role in the early stages of India’s nuclear development. It provided the enriched uranium fuel required for APSARA, India’s first nuclear research reactor. Although the reactor was indigenously designed and constructed at the Atomic Energy Establishment Trombay (AEET), British support was essential to its successful commissioning. This achievement marked India as the first Asian nation outside the Soviet Union to operate a nuclear reactor. APSARA served as a vital training ground for emerging Indian nuclear scientists and facilitated research in nuclear physics and materials testing.

The UK and India concluded a civil nuclear cooperation treaty which entered into force on 16 December 2016 and have collaborated around India’s Global Centre for Nuclear Energy Partnership (GCNEP).[17]



C. Canada: Foundational technology transfer and reactor development

Canada's partnership was foundational to India's nuclear power programme, centred on the PHWR technology.

- Canada and India Reactor Utility Services (CIRUS) reactor (1956–1960): In 1956, Canada agreed to provide a 40 MW_{th} research reactor, known as the Canada-India Reactor, U.S. (CIRUS), under the Colombo Plan. Canada supplied the reactor's design and major components, while India managed the construction of the reactor. The reactor became operational on 10 July 1960 and was permanently shut down in December 2010. The CIRUS reactor served as an outstanding training ground for engineers and scientists, offering valuable insights into the complexities of handling natural uranium, heavy water, and reactor systems. These learnings laid the foundation for the development of India’s PHWR programme.[18]
- Rajasthan Atomic Power Station (RAPS) (1960s): This is based on the Canadian Deuterium Uranium (CANDU) reactor design. Canada provided the initial design and equipment for the first unit (RAPS-1), which started operation in 1972.[19] The collaboration was a "mutually beneficial" risk-sharing partnership for developing CANDU technology, where India began localizing manufacturing for the second unit (RAPS-2).

D. Russia: Long-Term reactor deployment and fuel supply partnership

The U.S.S.R., and later the Russian Federation, became a crucial partner in India’s nuclear energy ambitions. The U.S.S.R. provided essential nuclear fuel and technological support throughout the 1970s and 1980s. Some of the reactors established in India through U.S.S.R./Russian support are:

- Kudankulam project (1988 onwards): In 1988, India and the U.S.S.R. signed an agreement to build two VVER-1000 (a form of PWR) reactors at Kudankulam, Tamil Nadu.[20] Despite delays following the collapse of the U.S.S.R., Russia later honoured the agreement and expanded its commitment.
- Continuing collaboration: This partnership has deepened over the years, with Russia currently building additional reactors at Kudankulam and remains a key supplier of advanced reactor technology and fuel. Additionally, TVEL, a subsidiary of Russia’s Rosatom, also supplies fuel pellets—including for Tarapur’s BWRs under specific contracts—alongside PHWR fuel deliveries post-2009.

E. Japan: Peaceful nuclear cooperation and technology exchange

India and Japan entered into a collaboration on peaceful uses of nuclear energy. The agreement focuses on technology and fuel transfer for nuclear reactors using Japanese technologies, for application in power generation, scientific research, training, medicine, industrial use, agriculture etc.[21]

4 Government targets and national ambition

In a bid to achieve energy self-sufficiency and clean energy goals, the Honourable Prime Minister, Shri Narendra Modi, has set up a target of achieving 100 GW of nuclear power capacity by 2047 and an interim target of 22 GW by 2032 was proposed in a meeting chaired by the Honourable Minister of Power, Shri Manohar Lal Khattar.[22]

The targets were outlined as part of the Union Budget announcement for FY2025-26 by the Honourable Minister of Finance, Smt Nirmala Sitharaman. Some salient features of the Union Budget pertaining to the advancement of nuclear energy in India are as follows:[23]

1. Nuclear Energy Mission: The government announced the launch of the Nuclear Energy Mission under the Viksit Bharat initiative. This mission seeks to strengthen domestic nuclear capabilities, encourage greater involvement from the private sector, and expedite the adoption of cutting-edge technologies such as SMRs. The mission is currently being prepared.
2. Financial outlay: An outlay of INR20,000 crore (approximately USD2.18 billion) was allocated to the Nuclear Energy Mission to support research and development activities leading to the establishment of five indigenously developed BSRs by 2032.[24]

3. Legal amendments: Amendments to Atomic Energy Act and CLND Act were announced in a bid to attract private participation in the nuclear energy sector of India. In December 2025, the government passed the SHANTI act, which repealed the Atomic Energy act and the CLND act.

To realise these ambitions, encompassing both capacity expansion and the adoption of advanced technologies such as SMRs, a comprehensive and collaborative effort is required among government, industry, global technology providers, financiers, and academia. This effort must address several critical priorities, including the understanding and deployment of emerging technologies, fostering active multi-stakeholder dialogue, developing skilled human resources, establishing a reliable nuclear fuel supply chain, and creating innovative financing structures and business models, among other essential facets.

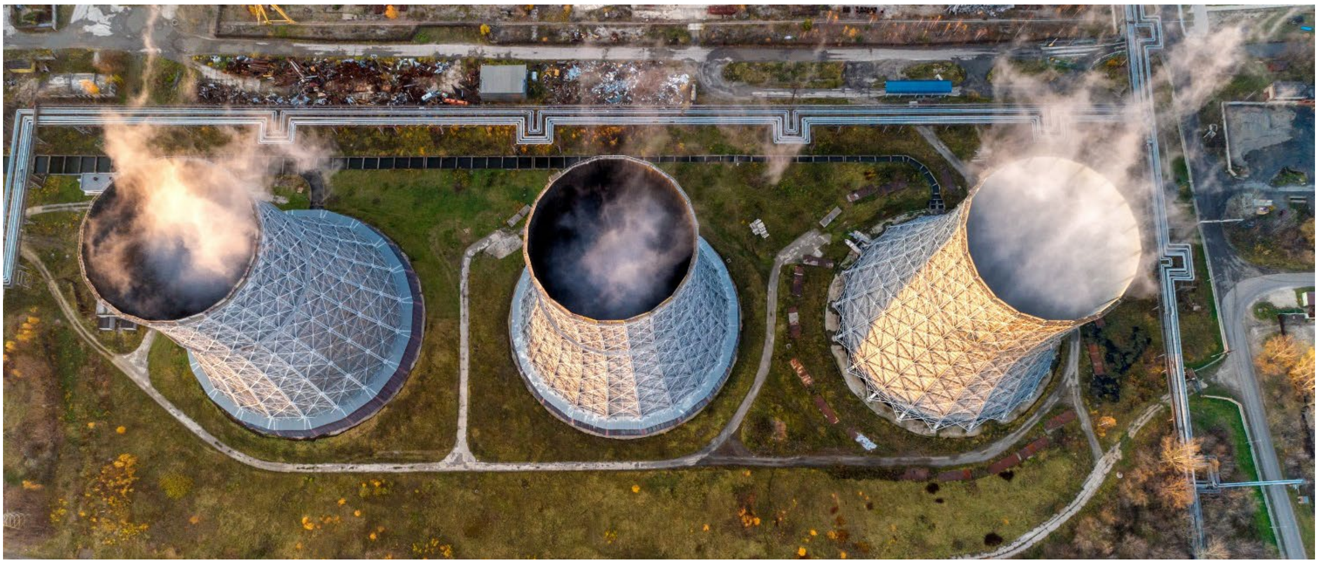
The reference to SMRs, particularly the indigenous design known as the BSR, is of considerable significance, as SMRs are expected to play a pivotal role in the wider deployment of nuclear energy for both power generation and non-power applications. It is noteworthy that SMRs are attracting increasing attention from governments and industry alike, owing to their numerous advantages—chiefly large-scale manufacturability, compactness, safety, flexibility, efficiency and circularity. The benefits of SMRs and their applicability in key industrial sectors have been elaborated in Chapter III.

It is envisaged that the announced proposals, if enacted, could help pave the way for increased private sector participation in nuclear power sector in India and help India achieve its ambitious goals.

5 Objectives of the report

The objective of this study is to derive insights from leading industries in the United States and India regarding the evolving nuclear energy landscape in India. The report seeks to examine the current electricity scenario in India, explore future projections for demand and supply, and assess the applicability of SMRs within the Indian context. It further incorporates perspectives from prominent organisations in both countries engaged in the nuclear energy sector.

This study provides a preliminary assessment of the key enablers required for the expansion of nuclear energy in India to achieve the ambitious target of 100 GW of installed capacity by 2047. These enablers include regulatory and legal frameworks, supply chain readiness, technology selection, the role of SMRs and indigenous BSRs, global collaborations, and other critical considerations. The report aims to equip stakeholders, particularly regulatory authorities and industry leaders, with an understanding of the immediate actions necessary to accelerate the deployment of new nuclear projects. Such acceleration is essential not only to meet the Honourable Prime Minister’s stated target but also to advance India’s energy self sufficiency through the increased adoption of nuclear power.



III. Market landscape and strategic role of SMRs

1 Present capacity

As of 31 March 2025, India has an installed capacity of 475.2 GW. Fossil based thermal power sources like coal, lignite, natural gas and diesel account for about 52 per cent of the installed capacity.[25] The power sector witnessed maximum capacity additions from solar power, accounting to over 72 per cent of the new capacity additions (over 33 GW) in the year FY2024-25. Renewables, comprising of solar, wind, hydro and biomass plants, despite having a share of 45 per cent of the overall installed capacity, still contribute to only 22 per cent to the overall electricity generated in India, highlighting issues of intermittency.[26] The bulk of the power generation capacity is still carried out by fossil-fuel based power generation plants in India.

Nuclear power plants in India have generated 56,681 MUs in the year FY 2024-25 with a plat load factor exceeding 87 per cent annually. The capacity factor and availability factor of nuclear power plants in India has been above 80 per cent consistently for the past five years, indicating reliability and consistent round-the-clock operations of nuclear power plants in India.[27] In April 2025, India added Unit-7 of RAPS plant having a capacity of 700 MWe, bringing the nuclear fleet capacity to 8.8 GW.[28]

India however remains a net-energy importer with significant energy imports coming in the form of oil, natural gas and coal. India imported about 19 per cent of its coal requirements in the year FY 2024-25, although the import dependency is decreasing. Nuclear power plants can help India in further easing reliance on foreign coal imports while simultaneously aiding in the achievement of the country's climate goals.

2 Future projections and demand growth

A. Electricity generation capacity projections

As per Central Electricity Authority (CEA)'s National Electricity Plan 2022-32, the projected electricity demand in India is envisaged to rise from 1907.8 BU (present 1684.2 BU in 2024-25) in 2026-27 to 2473.7 BU by 2031-32, indicating an approximately 30 per cent jump in electricity demand in a 5-year horizon and a CAGR of 5.3 per cent.[29]

To meet the peak power demand of 2026-27, the projected capacity addition is expected to be 211.8 GW, of which 6.3 GW would be nuclear. The bulk of this increased capacity is expected to be led by solar (131 GW) and wind (31 GW). Also, in order to meet the peak power demand of 2031-32, the capacity additions in the period 2027-32 is envisaged to be 291.8 GW, of which nuclear is expected to be 6.6 GW.[30]

As per the CEA's National Electricity Plan 2022-32, approximately 8.7 GW of nuclear power capacity is currently under construction, and a further 7 GW has received administrative approval and financial sanction.[31] All these planned and under construction plants are scheduled to come online by 2031-32. Of this total, 700 MW of capacity at RAPS was commissioned in April 2025.

As India's energy consumption continues to grow, there may be scope for additional nuclear power plants to fulfil the electricity needs of the country. As the country strives ahead in its climate goals, nuclear power is envisaged to play and even bigger role in the Indian energy mix with the phase-out of coal based thermal power plants.

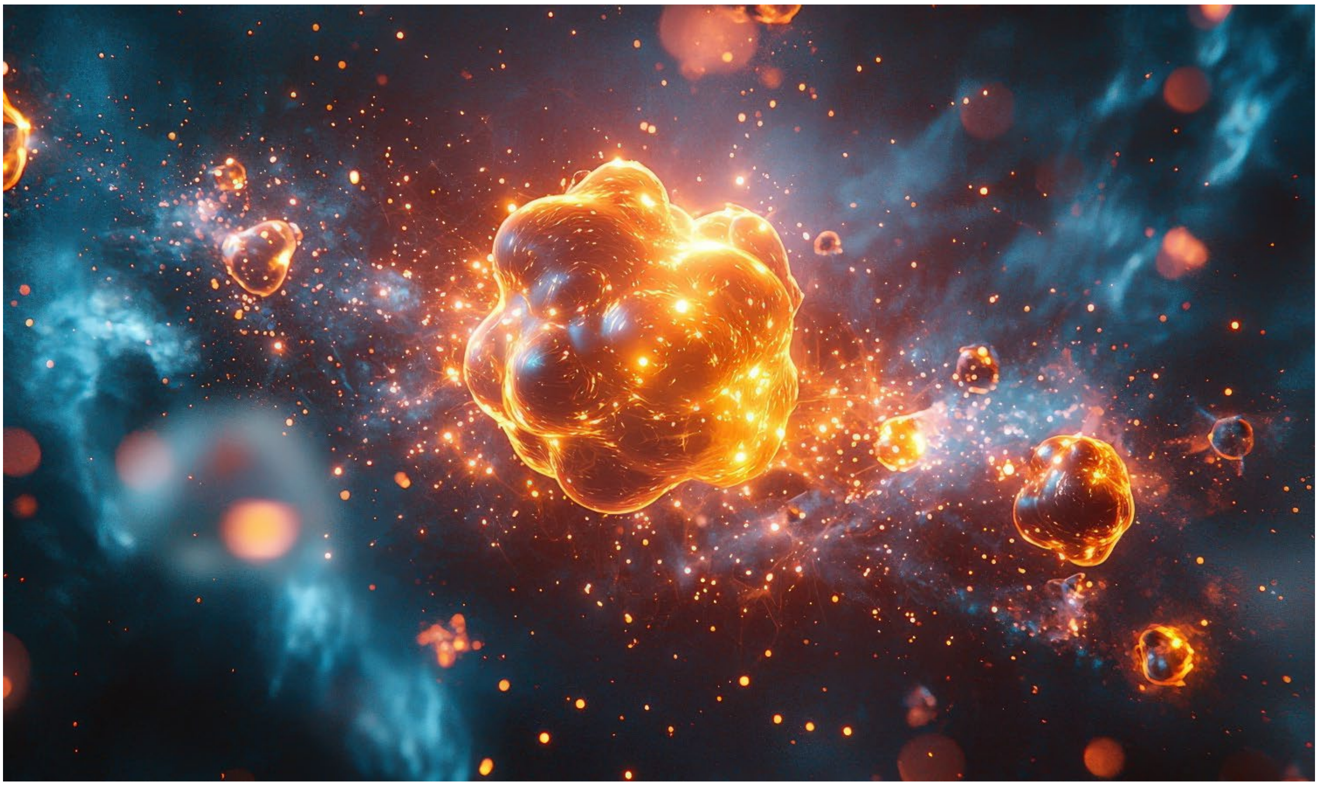
B. Primary energy consumption projections

According to the Energy Statistics India 2025 report published by the Ministry of Statistics and Programme Implementation (MoSPI), Government of India, the country's primary energy consumption has grown at a compound annual growth rate (CAGR) of 3.41 per cent over the past decade (2013–14 to 2023–24).[32] In 2023–24, primary energy consumption stood at 38,479 PJ, with coal (approximately 60 per cent) and crude oil (around 29 per cent) together accounting for nearly 90 per cent of India's total primary energy use.[33] In contrast, energy from clean, abundant, and domestically available source, such as renewables and nuclear, constituted a mere 3.2 per cent of total primary energy consumption during the same period. Notably, about 70 per cent of the coal consumed in 2023–24 was used for electricity generation.[34]

India remains significantly dependent on energy imports. Of the 1,236.48 MMT of coal consumed in 2023–24, approximately 21.4 per cent was imported.[35] Both domestic coal production and imports have grown at similar rates over the past decade, with CAGRs of 11.7 per cent and 11.3 per cent respectively, indicating that import dependency has not materially declined. This reliance is even more pronounced in the case of crude oil and natural gas: in 2023–24, India imported about 88 per cent of its crude oil requirement (263.62 MMT) and 47 per cent of its natural gas demand (67.47 BCM), with import growth rates matching or exceeding domestic production growth, particularly for natural gas.[36]

Utility-scale energy storage projects require lithium as a major raw material for the manufacture of grid-scale batteries. Lithium is also an important commodity for electric vehicle (EV) batteries as the batteries containing lithium offer one of the highest energy densities per unit mass. However, if vehicle electrification and grid-scale energy storage projects are promoted, India's import dependency on lithium may once again come into spotlight. As per World Integrated Trade Solutions (WITS), India imported about 1.18 KT of lithium carbonate and 1.055 KT of lithium hydroxide and oxide in 2023, worth about USD30.5 million and USD38.3 million respectively.[37] Although there were reports of the discovery of 5.9 MMT lithium reserves in India in the Union Territory of Jammu and Kashmir, the reserves are not yet proven or certain and need further investigation.[38]

These trends underscore the urgent need to reduce energy import dependence and substitute imported fuels with clean, domestically available alternatives. In this context, nuclear energy, central to India's three-stage nuclear strategy, can play a transformative role. The second and third stages of this strategy are designed to harness India's abundant thorium reserves, thereby ensuring long-term energy security and sustainability.



C. Commitments from the industry

The projected demand for electricity and primary energy highlights the imperative to diversify energy sources, with a greater emphasis on reliable and domestically available options. Nuclear energy represents one such dependable and clean alternative, capable of advancing India's pursuit of energy self-reliance.

The Government's ambition to expand nuclear power capacity to 100 GW by 2047 is expected to attract a wide array of stakeholders, both public and private, to participate in the generation and utilisation of nuclear energy. As India, along with organisations established within its borders, progresses towards sustainable growth powered by clean and reliable energy such as nuclear, we are poised to witness robust commitments from across the industry.

Table 1 shown below highlights some of the commitments from industry players in India for the establishment of nuclear power plants.

Table 1: Announced nuclear power installations or power purchase intentions of various companies in India

SN	Organisation	Announced commitment (GW)	Type
1	Nuclear Power Corporation of India Limited (NPCIL)	13.8 GW (by 2031-32)[39]	VVER – 4 GW PHWR – 9.8 GW
2	NPCIL	8.8 – 11 GW (40 to 50 units of 220 MWe BSRs) by 2035[40]	PHWR
3	Union Budget FY 2025-26	1.1 GW (5 units of indigenous SMRs)[41]	To Be Decided (TBD), probably PHWR based BSRs
4	NPCIL	7.25 GW (6 units of 1.208 GW each with Westinghouse PWR technology)[42]	AP1000 PWR
5	ASHVINI (National Thermal Power Corporation (NTPC) and NPCIL JV)	2.8 GW (4 units of 700 MWe each)[43]	PHWR
6	NTPC	30 GW (includes JVs)[44]	TBD
7	Holtec	30 GW[45,46]	SMR-300
8	Adani	30 GW[47]	TBD
9	Jindal Steel	18 GW by 2045[48]	TBD, may be a mix of BSRs, Gen-IV reactors, SMRs
10	Indian Railways	2 GW nuclear power purchase from suppliers like NPCIL and others[49]	TBD, may be a mix of BSR-220, BSR-55 conventional PHWR, Rosatom's SMR (RITM-200 PWR)

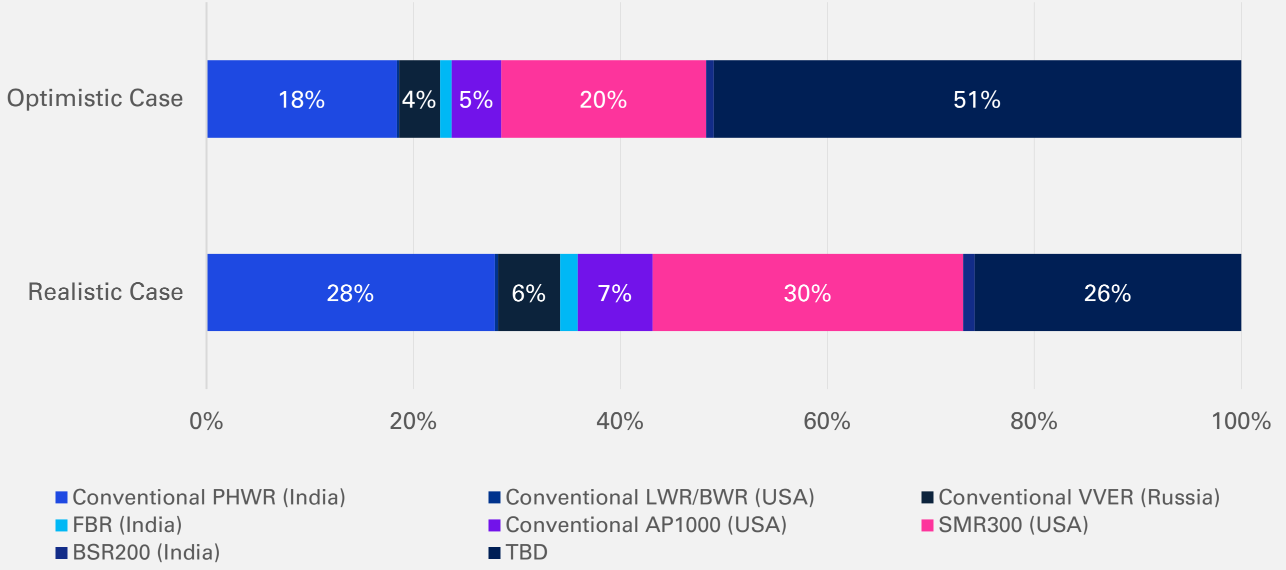
It is worth noting that Holtec's announcement regarding the manufacture of 200 SMRs is not confined solely to India. In an interview, Holtec's CEO, Dr Kris Singh, stated that production would be split between the United States and India, with 4–5 plants proposed in the U.S. alone.[50] More recently, Holtec revealed plans to establish a manufacturing facility in the United Kingdom, aimed at delivering a cumulative 5 GW of SMRs by 2050.[51] Assuming an annual output of six SMRs per plant (based on the SMR-300 design), and considering Holtec's stated intentions for the U.S., U.K., and India, it is estimated that cumulative SMR-300 installations in India could reach 30 GW by 2047.[52]

Table 1 clearly indicates a strong commitment from industry players in India towards nuclear energy, with announced capacities totalling approximately 140 GW—well above the Government's target of 100 GW. Of this, around 63–64 GW has been linked to specific technologies, while the remaining developers with 77–78 GW announced capacity are expected to declare the chosen technologies at a later stage. This scenario may be considered the optimistic case.

In the realistic case, it is assumed that only those players who have specified or announced their intended technologies may proceed with establishing their committed power plants. A cap of 100 GW has been applied to total installations (considering the government's target), leaving a gap of roughly 26–27 GW to be filled by technologies yet to be determined.

This study therefore seeks to estimate the distribution of reactor technologies within India's nuclear energy mix by 2047, under both the optimistic scenario and the realistic scenario (see Figure 2) based on information currently available.[53] Both the scenarios include the existing nuclear power capacity of India at approximately 8.8 GW.

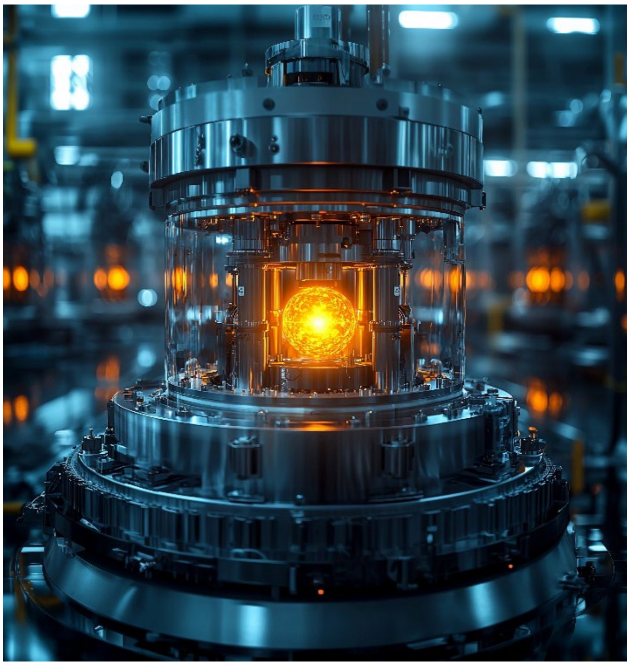
Figure 2: Estimated breakup of technologies in Indian nuclear energy mix in 2047, based on available secondary information



It may be noted that there remains a scope of approximately 26 per cent to 51 per cent for both conventional and emerging technologies that have not yet been announced by developers, translating to a minimum of 26 GWe of additional capacity.[54] Among the emerging technologies are three new SMR models under development in India, which include:[55,56]

1. Bharat SMR having 200 MWe capacity
2. SMR having 55 MWe capacity
3. High-Temperature Gas-cooled Reactor (HTGR) having 5 MW_{th} capacity, meant for clean hydrogen production.

There are several other SMR technologies which are under various stages of commercialisation globally, which may find application in Indian industries.



3 Small Modular Reactors (SMRs) and Bharat Small Reactors (BSRs): Catalysts for expansion

A. Key advantages

The reference to SMRs, particularly the indigenous design known as the BSR, is of considerable significance, as SMRs are expected to play a pivotal role in the wider deployment of nuclear energy for both power generation and non-power applications. It is noteworthy that SMRs are attracting increasing attention from governments and industry alike, owing to their numerous advantages—chiefly large-scale manufacturability, compactness, safety, flexibility, efficiency and circularity. These benefits may be elaborated as follows.

1. **Compactness:** Whereas conventional nuclear reactors typically have capacities exceeding 700–800 MWe, and in some cases even 1,000 MWe, SMRs are considerably smaller, with outputs generally capped at around 300 MWe and, in certain designs, as low as 5–10 MWe. This substantial reduction in size significantly decreases the physical footprint of the power plant, a feature particularly advantageous for remote locations or land-constrained regions—such as archipelagic, forested, or alpine geographies—where land efficiency is of paramount importance.

2. **Modularity and manufacturability:** Unlike conventional nuclear power plants, which necessitate extensive on-site civil construction, SMRs offer a distinct advantage through their modularity. This characteristic significantly reduces construction timelines by minimising the amount of civil work required at the installation site. The compact and modular design of SMRs enables their components—or, in some cases, entire units—to be mass-manufactured in factories and transported to the site for assembly, thereby limiting on-site activities primarily to integration and minimal civil works. Quite notably, certain SMR designs are claimed to fit within a standard 40-foot shipping container, greatly enhancing their modularity and transportability by leveraging existing global logistics infrastructure.

3. **Enhanced safety:** SMRs, particularly those belonging to the Generation IV (Gen-IV) family, incorporate significantly enhanced passive safety features. These designs rely on inherent safety characteristics rather than "active" systems such as sensors, control mechanisms, or human intervention. For instance, certain SMR concepts employ molten fuel salts as the primary energy source; in the event of a leak or accident, these salts can solidify under ambient conditions, thereby limiting the spread of radioactive material. Similarly, some SMRs utilise Tri-structural Isotropic (TRISO) fuel particles, which are inherently resistant to meltdown and remains structurally stable even in the complete absence of coolant. Such features, especially in the post-Fukushima context, position SMRs as highly promising from both an industrial and policy perspective, offering a level of safety that is often described as "accident-proof".

4. **Flexibility:** Owing to their compactness, transportability, and modularity, SMRs are attracting increasing interest across a diverse range of industries, including iron and steel production, coal plant repowering, oil refining, shipping, remote or island-based power generation, cement manufacturing, and hydrogen production. SMRs can capitalise on existing infrastructure in coal-fired thermal power plants, providing a clean and practical pathway for phasing out coal while ensuring the reuse of valuable assets. Their adaptability also makes them particularly suitable for energy-intensive sectors such as steelmaking, metal processing, and oil refining, as well as for deployment in land-constrained environments such as small islands, where energy density and land efficiency are critical considerations. When combined with the inherent baseload capability and reliability of nuclear systems, these attributes position SMRs as a compelling solution for a wide spectrum of industrial applications. The versatility of SMRs is exemplified by the world's first commercially operating floating SMR, Akademik Lomonosov.[57] This unit, with a maximum electrical output of 70 MWe (when heat is not supplied), provides not only electricity but also direct heat and desalinated water to the residents of Pevek, a remote Arctic city in Russia.[58]

5. **Efficiency:** SMRs possess a distinct advantage in their ability to directly supply high-grade, baseload heat to industries that rely heavily on thermal energy for various chemical and physical processes. Such applications include iron extraction and heat treatment in steel production, hydrocracking and fractional distillation in oil refining, calcination in cement manufacturing, district heating in cold climates, and desalination in water-stressed regions. By supplying heat directly rather than converting it first into electricity, SMRs can significantly enhance overall energy efficiency by eliminating the intermediate step of power generation. According to the World Business Council for Sustainable Development (WBCSD), industrial heating remains a largely overlooked area in global decarbonisation efforts, despite accounting for an estimated 18 per cent of global greenhouse gas emissions in 2023, surpassing the combined emissions of the United States and India.[59] In this context, the deployment of clean, high-grade heat sources such as nuclear energy becomes critical to achieving long-term climate goals.

6. **Circularity:** One of the most compelling advantages of SMRs lies in their potential to enable circularity in the nuclear fuel cycle. Certain advanced SMR concepts are designed to utilise high-level waste (HLW)—including spent nuclear fuel from conventional reactors—as a feedstock for energy generation. By extracting residual fissile material from this waste or spent fuel and converting it into usable energy, these reactors not only reduce the volume and radiotoxicity of long-lived waste but also extend the energy value of previously used fuel. Additionally, SMRs can leverage HALEU – (which is enriched to between 5 and 20 per cent U-235 compared to LEU fuel which has 3 to 5 per cent U-235), a range which is usually unsuitable for most existing large light-water reactors (LWRs). This opens the door for advanced fuel cycles where abundant U-238 (which constitutes over 99 per cent of natural uranium) can be converted (or “bred”) into fissile isotopes such as plutonium-239 (Pu-239) or even minor actinides for reuse. Fast reactors using HALEU (like Sodium cooled Fast Reactors (SFRs) or Lead cooled Fast Reactors (LFRs)) promise to maximise HALEU fuel burnup and even utilise the HLW wastes (generated in-situ) comprising of higher actinide series intensely radioactive metals. This capability not only enhances resource efficiency but also reduces the need for fresh uranium mining and minimises the generation of toxic and dangerous HLW wastes, making SMRs a cornerstone for a sustainable, closed-loop circular nuclear economy.

7. **Load following characteristics:** While conventional nuclear power plants may be slow to ramp their outputs up based on ramp up of electricity demand, some SMR designs promise to overcome this deficiency. Some SMR designs based on molten salt reactor technology or sodium cooled reactor technology promise to have ramping rates of nearly 10 per cent per minute.[60] The thermal stresses due to rapid ramp up might be partially minimised by using thermal energy storage systems, employing molten metals or salts, as applicable. The load following characteristics can help in the deployment of SMRs with variable renewable electricity sources like solar and wind to optimise system costs, if needed.

B. Sectoral-use cases

Considering the unique advantages of SMRs, some of the sectors envisaged to utilise SMRs to harness their unique advantages are as follows:

1. **Shipping:** The maritime industry is experiencing renewed interest in nuclear propulsion as it pursues the International Maritime Organisation’s (IMO) goal of achieving net zero emissions by 2050.[61] It is noteworthy that the global shipping sector accounts for approximately 3 per cent of global carbon emissions, a share that is projected to rise as global trade expands and as geopolitical disruptions to maritime routes, such as the Bab-el-Mandeb Strait crisis and drought related constraints in the Panama Canal, become more frequent.[62] Nuclear-powered commercial vessels offer significant advantages over conventional fuel-burning ships, some of which are:
    - Nuclear reactors enable vessels to operate at higher speeds without proportionally increased costs, leading to significantly shorter voyage times and reduction in overall shipping costs.[63] Nuclear ships also need limited refuelling stops, once every 3-5 years, which is significantly lower than conventional ships. This also reduces fuel costs and fuelling time duration, increasing the ship’s uptime.
    - Without fuel tanks and internal combustion engines, nuclear vessels can carry more cargo when compared to conventional ships, which need space to store fuel.

Several international organisations and countries have started research on nuclear propelled ships. The technology is not new as nuclear-powered ships like aircraft carriers and submarines are still in operation. However, the research for the commercial applicability of this technology for civilian use is ongoing. Several countries like USA, Japan, South Korea, China and registers like Lloyd's Register have begun developing prototypes, designs and safety standards for nuclear powered commercial shipping. Several global shipbuilders, SMR manufacturers, EPC companies, government agencies, registers have joined forces to form Nuclear Energy Maritime Organisation (NEMO), which aims to investigate and deploy SMRs for commercial shipping. NEMO has recently gained official status from both IMO and IAEA.[64,65]

It may however be noted that as of October 2025, the vote on the adoption of cleaner fuels for the shipping sector is delayed.[66] This delay for the adoption of net-zero standards and clean shipping fuels might hamper the offtake of clean fuels like green ammonia, methanol and nuclear in shipping sector.

2. **Steel:** The steel sector accounts for 7-9 per cent of the emissions globally and this is set to increase with the increase in the need for steel due to construction activities, expansion of infrastructure projects, automobiles and other such industries.[67] Therefore, there is a pressing need to produce carbon-free steel or "green steel" using clean energy sources and feedstocks. SMRs can become a viable clean alternative for the steel sector.

   - Nuclear SMRs can provide a clean and baseload source of heat and provide consistent high temperatures beyond 1000^{O}C, which is necessary for crucial operations in steel industry like iron extraction, heat treatment, forging etc.
   - Nuclear SMRs can be used to provide clean electricity for steel plant operations.
   - Clean hydrogen, labelled as "pink hydrogen", can also be generated using nuclear produced electricity powering water electrolysers, for the extraction of iron from iron ore by displacing coal and natural gas.

   The steel sector around the world is actively considering nuclear energy for large-scale "green steel" production. Several major steel manufacturers like Tata Steel, Jindal Steel and Power Limited, Danieli, and steel industry associations from Japan, Canada and other countries are considering utilising nuclear power for clean steel production.[68,69,70,71,72]

3. **Desalination:** The emergence of acute water stresses across many parts of the world has prompted the expansion of seawater desalination facilities to meet the growing demand for water. However, seawater desalination itself is an energy intensive process, and the energy requirements are largely being met by carbon-intensive sources like fossil fuels. SMRs can be deployed to provide clean and baseload source of power for such energy intensive processes. The primary advantage of nuclear energy for desalination lies in its ability to provide a consistent and large-scale supply of both heat and electricity, the two main energy inputs for modern desalination technologies. This cogeneration approach makes the entire process highly efficient and reliable. The lack of requirement of frequent fuelling also helps in increasing uptime of the desalination plant, if powered by nuclear energy, and decrease fuel costs, which are otherwise significant in fossil fuel powered desalination plants. The problem of intermittency and additional facilities like batteries is also avoided due to the baseload characteristics of nuclear power plants.

   Several countries and organisations are developing desalination facilities powered by nuclear power plants, by directly utilising heat from the nuclear reactor or by using electricity generated by nuclear power plant. India's BARC had established Nuclear Desalination Demonstration Plant (NDDP) at Kalapakkam which produces 4.5 Million Litres per Day (MLD) freshwater using thermal energy and 1.8 MLD through reverse osmosis.[73] Efforts are underway to increase the capacity of these plants. Other countries like Egypt, China, and Saudi Arabia are also investigating the use of nuclear energy for water desalination facilities.

4. **Oil refining and petrochemicals:** The oil refining industry is one of the most energy-intensive sectors globally. Oil refineries consume vast amounts of thermal energy and electricity to convert crude oil into downstream products like petrol, diesel, and jet fuel. The downstream petrochemical industries also require the use of baseload heat and steam generation and hydrogen consumption for the synthesis of various important chemical feedstocks. This reliance on fossil fuels for process heat and power makes refining a significant source of greenhouse gas emissions. As the world moves towards decarbonisation, a growing number of governments, research institutions, and energy companies are exploring the use of advanced nuclear reactors to provide a clean, reliable, and cost-effective energy source for refining operations.

   Some of the most energy intensive processes of the oil refining and petrochemical industry are as follows:

   - **Distillation:** Large distillation units must be heated to high temperatures between 315° C and 400° C to enable the separation of various commodities from the crude oil extracted. This process thus consumed a lot of thermal energy, obtained by burning fossil fuels.

   - **Cracking:** To produce more high-value products like gasoline, heavier fractions from distillation are "cracked" into smaller molecules. This is a major energy consumer, with thermal cracking processes requiring temperatures over 800° C.

   - **Steam generation:** Steam is an essential intermediate commodity in an oil refinery, used for heating, distillation, power generation for pumps and compressors, and as a reactant in processes like hydrogen production. Generation of a large amount of steam for so many chemical processes requires the availability of baseload thermal energy, which again necessitates the use of fossil fuels.

   - **Hydrogen production:** Oil refining and petrochemical processes require hydrogen as an important feedstock for desulphurisation, hydrocracking processes. Nuclear energy can generate hydrogen either through water electrolysis or direct thermal dissociation of water. This has been explained in greater detail in the next section.

   The key to decarbonising oil refineries lies in replacing fossil-fuelled furnaces and boilers with a clean energy source capable of providing both high-temperature heat and electricity reliably. This is where advanced nuclear reactors, particularly High-Temperature Gas-cooled Reactors (HTGRs), offer a viable solution. Several oil and petrochemical companies like Shell, Dow Chemicals, Indian Oil and others are investigating the utilisation of SMRs in their own refineries to help decarbonise their processes.[74]

5. **Hydrogen production:** Production of emission-free clean hydrogen is being actively explored by several organisations and policymakers around the world. Clean hydrogen is an important energy vector and clean feedstock which can be used in several end-use industries like fertilisers, oil refining, steel, automotive, shipping, chemicals etc. Many of these industries, like oil refining and steel, can offer sector coupling options for the combined use of hydrogen and nuclear power. Hydrogen production via High-Temperature Steam Electrolysis (HTSE) using Solid Oxide Electrolysers (SOECs) can achieve higher efficiency when coupled with nuclear heat sources. This technology can potentially reduce hydrogen production costs significantly compared to conventional water electrolysis techniques. Additionally, Generation IV are also particularly suitable for thermochemical hydrogen production without using any electricity, usually via Iodine-Sulphur (IS) or Copper-Chlorine (Cu-Cl) cycles. Gen-IV reactors like Gas-cooled Fast Reactors (GFR), Lead-cooled Fast Reactors (LFR), Molten Salt Reactors (MSR), and HTGRs can be suitable for generating hydrogen via thermochemical water splitting. Countries like India, Japan, EU, USA, China are investigating the production of clean hydrogen using nuclear reactors. A major USD4 billion project involving 1 GW SMR powered clean hydrogen project has been announced in Indonesia, which aims to deploy 25 SMRs (each having 40 MWe capacity) supplied by Copenhagen Atomics, SOECs by Topsøe among others to produce clean hydrogen and clean ammonia to ultimately produce clean fertilisers and eliminate CO_2 intensive natural gas for fertiliser production.[75]

6. **Data Centres / Artificial Intelligence (AI):** The growth of AI and cloud computing has created an unprecedented demand for energy. Data centres, the physical infrastructure of cloud computing, data storage and AI, are consuming electricity at a staggering rate. This surge is placing immense pressure on existing power grids and challenging the sustainability goals of the world's largest technology companies. In response, major tech firms are turning to nuclear energy as a clean, reliable, and scalable solution to power their operations. The energy density of nuclear power, prospect of clean and emission free power and the most crucial advantage offered due to the baseload characteristics have prompted several major AI and digital technology organisations like Google, Meta and Amazon to turn to nuclear to power their expanding fleet of data centres meant for mission critical solutions like AI and cloud computing. Nuclear plants may also offer extremely low land footprint, which becomes a critical factor in land-constrained areas. The digital technology companies are signing several PPAs with major nuclear power companies and are even restarting mothballed nuclear power plants for their surging electricity needs.

7. **Power generation in remote locations /islands:** SMRs present a highly practical solution for supplying power to land-constrained and isolated areas, such as small islands, mountainous regions, Arctic zones, and arboraceous territories. These locations often lack the space required for large-scale solar or wind installations and face significant challenges in establishing grid connectivity due to their geographical isolation. At present, most of these regions rely on expensive and polluting diesel generators. SMRs, being compact, modular, and factory-built, can be deployed with relative ease in such environments. Their flexibility extends to marine-based configurations, where reactors can be mounted on floating platforms or barges—an approach demonstrated by Russia's Akademik Lomonosov, the world's first floating nuclear power plant, which now provides electricity and heat to the remote Arctic port of Pevek. This concept is gaining global traction, with initiatives led by Rosatom in Russia, NuScale Power in partnership with Prodigy Clean Energy in North America, and South Korean consortia including Samsung Heavy Industries, Korea Electric Power Corporation (KEPCO), and Seaborg Technologies, which are developing advanced floating SMR designs. In fact, leading industries from Japan, USA, UK and others are actively investing and developing offshore SMRs as Floating Nuclear Power Plants (FNPPs) as an earthquake-proof, tsunami-proof, detachable and land-efficient power source suitable for remote islands.[76,77] These innovations promise decentralised, low-carbon, and resilient energy solutions for remote communities, offshore industrial hubs, and island nations, while also enabling cogeneration for desalination and hydrogen production.

These and more such emerging use cases present a compelling case for conventional nuclear power projects and SMRs, which is also evident in several companies' growing interest in this reliable and clean form of energy.

4 Industry acceptance of conventional nuclear reactors and SMRs

As part of this study, a survey was conducted among leading industrial stakeholders in the nuclear energy sector in the United States and India. The findings reveal that, at a global level, a significant majority of respondents view SMRs as highly suitable for clean hydrogen and ammonia production, followed by captive heat and power generation in remote locations.

In the Indian context, industry participants expressed a preference for indigenous BSRs for power generation in remote areas and for captive industrial applications. This inclination is partly attributable to the presence of numerous energy-intensive industries in India, which require substantial and reliable power supplies. Securing grid connectivity often involves lengthy approval processes and may entail unfavourable tariffs, while many industries—such as steel—already operate captive thermal power units. Consequently, BSRs present a viable alternative for reducing coal imports, ensuring baseload power without grid dependency, and maintaining cost competitiveness.

The survey further indicates that LWRs and PHWRs are the preferred technologies for indigenous SMRs, reflecting India's existing expertise and operational familiarity with these designs. This also highlights opportunities for international collaboration with countries that either utilise or are actively developing SMRs based on LWR and PHWR technologies.

The industry also desires financial cost sharing with the government to kickstart the introduction of SMRs in India, especially for the FOAK SMR project in India. Such a cost sharing mechanism can be beneficial for initial projects and help handhold the industry till the market matures in this direction in India.

In addition to SMRs, the industry has also expressed interest in conventional reactors, particularly PHWRs and LWRs. There is strong industry acceptance of conventional LWRs for data centre applications in India. The preference of conventional reactors for data centre applications in India can be attributed to the fact that such applications usually do not involve the utilisation of process heat and rather focus on the reliability of the power supplied. Moreover, conventional large-scale power plants based on LWRs or other technologies can offer the scale which is necessary for a typical hyperscaler data centre. Hence, data centre customers might be alright with reliable nuclear power from large, conventional power plants which might offer greater benefits due to economies of scale and distance from load centre, as such, might not be an important consideration. It may be noted that the average tariff of power generated from nuclear power plants in India during FY2023-24 stood at INR3.83/kWh (approximately USD0.0418/kWh), as per the answer to the starred question 226 asked in the parliament of India, answered by the Honourable Minister of State for Personnel, Public Grievances and Pensions and Prime Minister's Office, Dr. Jitendra Singh, on 11 December 2024.[78,79] This is nearly 23 per cent lower than INR4.98/kWh (approximately US¢5.43/kWh) Firm and Dispatchable Renewable Energy (FDRE) tariff discovered by Solar Energy Corporation of India (SECI) in August 2025.[80,81] This demonstrates the economic advantage of power generated from India's conventional nuclear power plants, which is still substantially higher than any renewable and energy storage plant combination, for 100 per cent baseload operation (without any diurnal or seasonal variation). For newbuilt nuclear power plants, this cost may be marginally higher and is envisaged to continue being competitive against intermittent renewable and energy storage hybrid systems.

For other industrial applications, such as captive power generation and clean hydrogen production, both PHWRs and LWRs are preferred, according to the findings of the industry dipstick survey. Respondents also indicated that the majority of India's nuclear power generation by 2047 is likely to be delivered by conventional reactors such as PHWRs and LWRs, primarily due to the maturity of these technologies.

However, the industry has highlighted the need to address challenges related to fuel availability, domestic fuel enrichment and fabrication facilities, as well as regulatory mandates concerning power consumption from nuclear power plants.

IV. Technological advancements in the field of nuclear energy

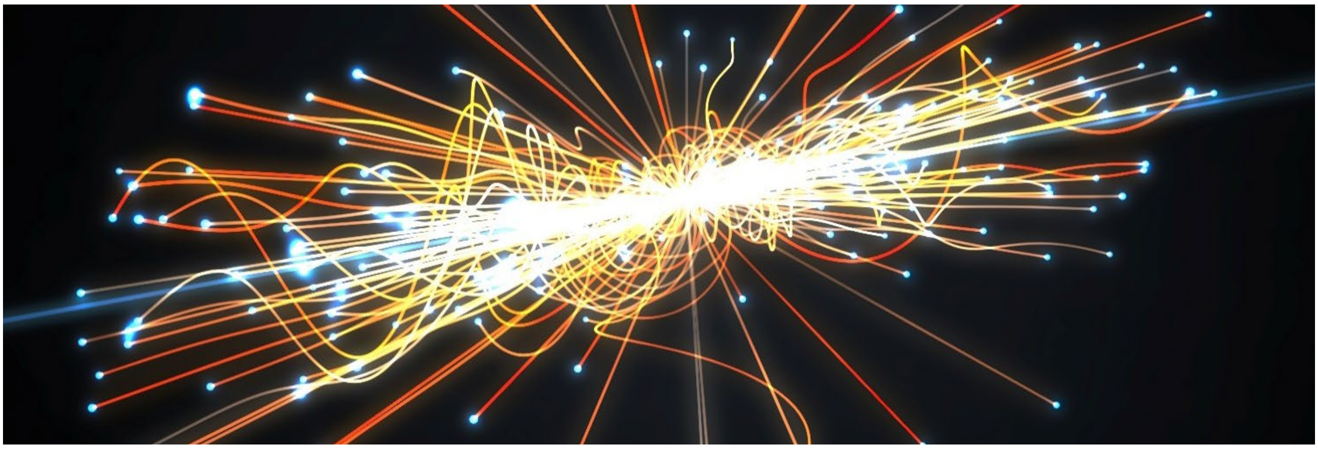
Global nuclear technology is entering a new era shaped by remarkable innovations across the entire value chain, from fuel design and enrichment to reactor construction and safety systems. The most prominent among these are SMRs and advanced Generation-IV (Gen-IV) reactors, which promise higher safety, efficiency, and flexible deployment. Several SMR designs are in various stages of development globally, led by firms such as NuScale, TerraPower, Holtec, Westinghouse, GE Hitachi, Rolls-Royce, and Rosatom. These reactors often use advanced coolants—such as liquid metal, helium, or molten salt—and employ passive safety systems, enabling them to offer cost-effective, scalable solutions for both grid and off-grid settings. Gen-IV reactors, featuring variants like sodium-cooled fast reactors and high-temperature gas reactors, are also designed for enhanced thermodynamic efficiency and the ability to utilise alternative fuel cycles, including thorium and spent fuel.

Innovation in nuclear fuels is another area undergoing rapid change. Accident-tolerant fuels (ATFs) like HALEU and its derivatives like TRISO particles are being introduced to improve fuel performance, safety and efficiency. TRISO particles, which encapsulate fuel in strong carbon and ceramic layers, greatly enhance containment and safety under extreme conditions, including complete loss of coolant. The commercial production of TRISO fuels and development of fertile fuels like thorium-based and commonly available uranium (U-238) based fuels, especially in countries like India, hold promise for reducing nuclear waste by enhancing fuel burnup and reducing proliferation risks by making it harder to extract fissionable materials from nuclear spent fuel. 3D printing and advanced modelling are being utilised for creating new fuel geometries and predicting their performance, accelerating the pace of innovation in this field.

The pain points of the conventional nuclear industry or technologies can broadly be summed up as follows, which drive most of the innovations in the nuclear industry:

1. Need for passive safety, to reduce dependence on active elements like humans or sensors and computation devices which are prone to errors
2. Waste reduction, to minimise the creation of HLWs like higher actinides, which have dangerous levels of radioactivity and long half-lives, necessitating the need for complicated storage mechanisms
3. Sustainability and circularity, through the usage of earth abundant materials or even nuclear spent fuel (especially higher actinides) for energy generation
4. Resistance to proliferation, making it economically unviable or physically difficult to extract fissionable materials from nuclear spent fuel
5. Reducing construction time, an issue which plagues most of the conventional nuclear power plants

Some of the areas of innovation in the nuclear industry can be bucketed into the following broad categories, spreading across the nuclear energy value chain. These innovations attempt to address one of multiple pain points mentioned above.



1 New fuels and fabrication techniques

Nuclear fuel technology is undergoing its most consequential refresh in a generation. Driven by stronger safety margins, longer refuelling intervals, industrial co-generation demands and supply-chain resilience, developers and operators are advancing beyond conventional uranium oxide – zirconium alloy combinations. ATF fuels like HALEU, TRISO and others are moving from laboratory programmes into early commercial deployment. Parallel work on metallic and high-temperature fuels seeks to raise burnup, improve availability and reduce waste generation compared to conventional PHWR or BWR/LWR reactors.

The common thread in this domain is to pragmatically solve the following issues:

1. Reduce or eliminate in-situ hydrogen production due to reaction of steam in reactor with heated zirconium alloy – a phenomenon which caused explosion in Fukushima-Daiichi nuclear power plant which in turn happened due to complete loss of circulating water coolant.
2. Reduce shutdowns by enabling multi-year or even cartridge-style cores
3. Deliver high-grade heat for metals, chemicals, hydrogen and desalination, as the case may demand
4. Diversify fuel supply by using earth abundant materials like U-238 and Th-232 (through in-situ breeding) and reduce pressure on the already constrained and highly regulated fuel enrichment facilities

Developers are responding—most notably with initiatives on increased enrichment and higher burnup—while industry scales new enrichment and fabrication, including domestic HALEU, TRISO manufacturing, and coated-cladding production lines. The result is a suite of fuels and fabrication methods that target longstanding pain points in conventional nuclear operation without sacrificing the disciplined safety case expected by modern regulators.

Some of the pathways adopted for further research and commercialisation, with regards to fuel selection and fuel fabrication are as follows in table 2:[82]

Table 2: Key emerging methodologies being trialled in fuel and fabrication technologies

SN	Methodology adopted	Pain point reduction / Speculated gains
1	HALEU enrichment from 5 per cent to 20 per cent	• Compact core design • Higher fuel burnup • Lower fuel replacement cycles → Lesser reactor downtime • May accommodate fertile materials like U-238 or Th-232 for in-situ breeding and subsequent consumption
2	TRISO fuel particles	• Acts as a containment vessel for radioactive wastes → Effective waste disposal • Allows in-situ fuel pellets monitoring and replacement → Limited downtime • Immune to mechanical shocks and extreme events including total loss of coolants → Passive safety • May accommodate fast spectrum fuels and fast neutron reactor designs → Higher fuel burnup and efficiency • Allows for extreme temperature operations → Increased efficiency

SN	Methodology adopted	Pain point reduction / Speculated gains
3	ATF fuel designs and cladding for existing LWR reactors	• Near drop-in fuels to enhance the efficiency and safety of existing LWR reactors • Higher fuel burnup due to higher enrichment (upto 20 per cent) • Lower fuel replacement cycles → Lesser reactor downtime • Reduces in-situ hydrogen formation due to some claddings used → Passive safety
4	Innovative and new fuels like liquid salts, fast spectrum fuels like U-238 and Th-232, negative temperature coefficient fuels	• In-situ fuel breeding and consumption → Reduced downtime • Negative temperature coefficient reduces fission if temperature increases → Passive safety • Liquid fuels can behave as coolants → Lesser complexity and fewer moving parts • Higher burnup due to consumption of wastes like higher actinides owing to fast spectrum of neutrons → Reduced HLW wastes

2 Emerging cooling and moderation techniques

Emerging innovations in nuclear reactor coolants are driven by the need to enhance safety, improve thermal efficiency, and support advanced fuel cycles. Traditional water-based systems face challenges such as hydrogen generation during severe transients and high-pressure operation, which increase accident risks. Advanced coolants—including helium, liquid metals (sodium, lead, lead-bismuth), molten salts, and supercritical water—address these limitations by operating at low pressure, mitigating risks due to extreme events like total loss of coolant, and enabling higher outlet temperatures for efficient power generation and industrial heat applications.

The current generation of coolants, predominantly heavy water or light water, present challenges which are being resolved through advancements in coolant and moderation technologies. Some of those pain points can be summarised as follows:

1. Improve neutron economy by eliminating or reducing moderation or neutron capture as much as possible (or pushing reactions towards the fast neutron spectrum)
2. Allow wider range of operating temperatures to help provide higher output temperatures from reactors
3. Depressurise the reactor core as much as possible to allow atmospheric pressure operations, thereby reducing the need for complex pressure vessels and avoiding the risk of overpressure
4. Provide passive safety mechanisms allowing walk-away safety even with total loss of coolant, to help avoid incidents or situations which may lead disasters like Fukushima Daiichi nuclear plant disaster in 2011

Each coolant family offers distinct advantages: helium provides chemical inertness and high-temperature capability; sodium and lead-based coolants support fast neutron spectra (by minimising moderation and neutron capture) and low-pressure operation; molten salts deliver high heat capacity and inherent safety features; and supercritical water offers evolutionary improvements in efficiency. Cross-cutting innovations in materials, chemistry control, and system architecture further mitigate corrosion, oxidation, and reactivity challenges. Collectively, these developments aim to improve reactor safety margins, enable flexible deployment in SMRs and microreactors, and support long-term sustainability through advanced fuel-cycle strategies.

Some of the pathways adopted for further research and commercialisation, with regards to fuel selection and fuel fabrication are as follows in table 3:[83]

Table 3: Key emerging methodologies being trialled in cooling and moderation technologies

SN	Methodology adopted	Pain point reduction / Speculated gains
1	Gas cooled reactors, especially helium cooled with TRISO fuel particles	• Very high-grade heat availability → Useful for chemical industry, hydrogen production, metal extraction and refining • Inert and offers minimal moderation and higher neutron economy → Useful for fast spectrum reactions offering higher fuel burnup and reduced wastes • TRISO particles can allow in-situ removal, testing and replacement of fuel particles → Limited reactor downtime
2	Liquid metal or molten salt coolants like sodium (Na), lead (Pb) or lead-bismuth (Pb-Bi) eutectic mixture, lithium beryllium fluoride salt (FLiBe), molten uranium chloride fuel	• Allows operation at atmospheric pressure → Less risk of pressure caused explosion • Inert and offers minimal moderation and higher neutron economy → Useful for fast spectrum reactions offering higher fuel burnup and reduced wastes • Wide temperature operability due to extreme boiling point of metal coolants used → Higher quantum of heat capture and transfer • Liquid fuels can behave as coolants → Lesser complexity and fewer moving parts • Use of earth abundant materials like lead, sodium, bismuth for coolant → Less vulnerability to geopolitical supply chain shocks • High heat capacity (especially molten salts) allows heat retention for extended periods → Useful for energy storage and flexible peak power operations for grid stability
3	Supercritical CO_2 as heat exchange medium and working fluid	• Wide range of temperature and pressure in supercritical region → High efficiency and lower phase-change heat losses • Waterless operations → Useful for even dry and arid regions with limited water access • Allows for compact design of turbines for power generation

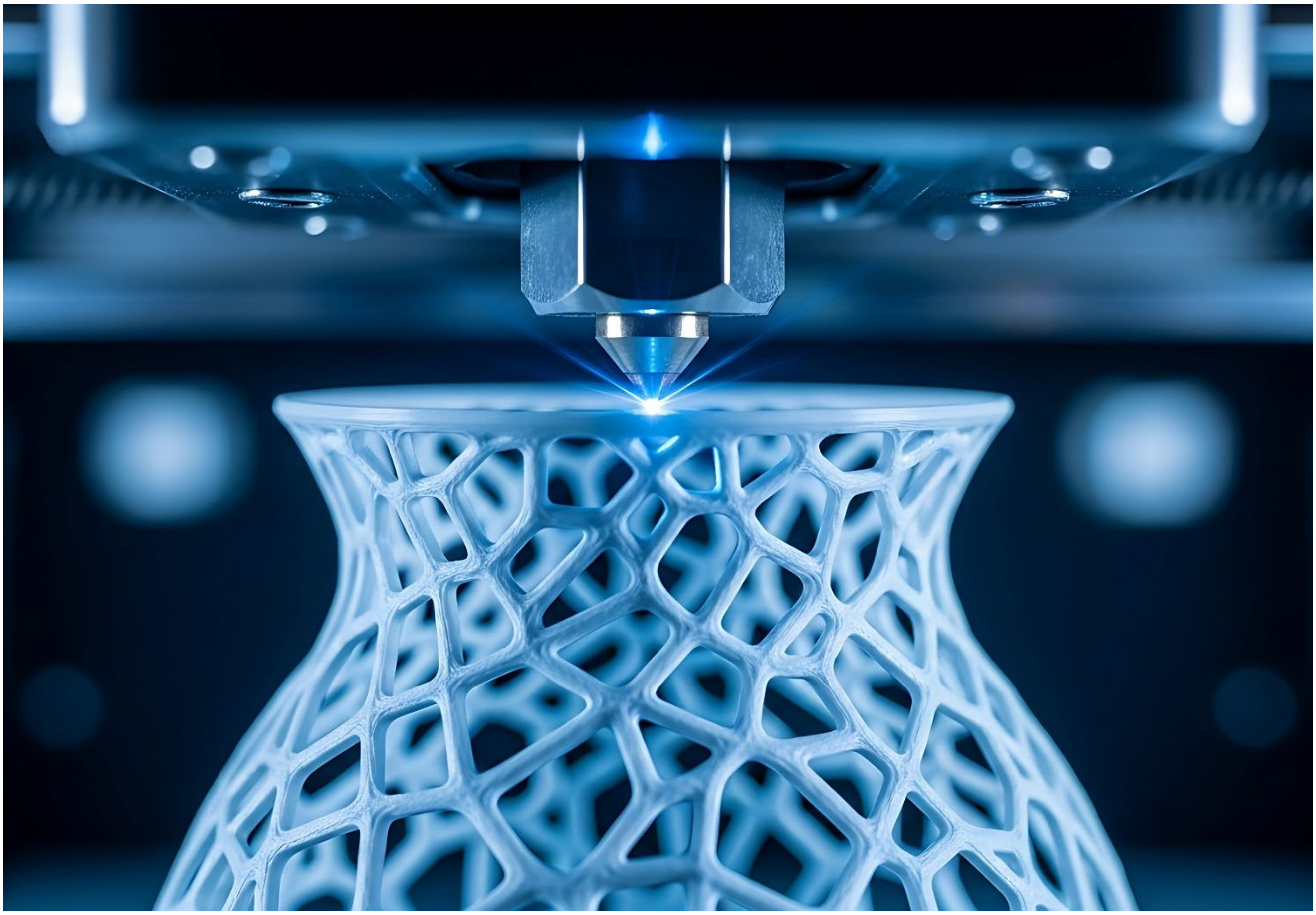
3 Emerging construction and manufacturing techniques

Nuclear construction is transitioning from bespoke, FOAK gigawatt-scale projects toward standardised, modular, and factory-enabled approaches aimed at improving cost and schedule certainty. This shift is evident in programmes such as BWRX-300 at Darlington, Rolls-Royce SMR's UK fleet, and TerraPower's Natrium demonstration in Wyoming, USA. Advanced methodologies—such as underground siting, seismic base isolation, heavy modularisation, and digital-first delivery—are being adopted to reduce on-site complexity, enhance safety, and accelerate deployment. Regulatory collaboration across the USA, UK, and Canada further supports multi-country licensing efficiency.

The broad objectives the emerging construction and manufacturing technology trends are trying to achieve can be summarised as follows:

1. Minimising on-site construction by focusing more on modularisation and mass-manufacturability to reduce construction time
2. Allowing passive safety mechanisms by incorporating construction designs which possess elements like underground placement of reactors, isolation of fuel in case of total loss of coolant etc.
3. Integrated or "fused" reactors and fuel designs to allow isolation and safe disposal of fuel and reactors, economically, when the fuel has been spent
4. Allowing reuse of existing cooling and power infrastructure to allow conversion of baseload coal-based power plants to clean nuclear based power plants

Emerging construction strategies span a spectrum from containerised microreactors enabling rapid deployment to integral and fused primary systems that simplify civil works. Modularisation and digital twins are central to reducing field labour risk and improving quality assurance, while hybrid thermal-storage islands and staged demonstration programmes aim to de-risk FOAK builds and enable fleet learning-curve benefits. Collectively, these innovations target fewer critical lifts, reduced on-site labour, and repeatable series production, positioning nuclear as a more predictable and competitive option for future low-carbon energy systems.



V. Policy, regulation and supply chain preparedness in India

India's nuclear power programme has evolved into a self-reliant supply chain covering fuel, technology, construction, and operation of reactors. The vast majority of commercially operating reactors in India are based on indigenous PHWR design, which itself is a variant of Canada's CANDU reactor technology. Nuclear Power Corporation of India Limited (NPCIL) is a state-owned public sector undertaking (PSU) is the owner and operator of all nuclear power plants in India. The country also has a stable supply of uranium to fuel its nuclear fleet. This section attempts to examine the key segments of the supply chain for India's conventional nuclear sector (specifically PHWRs and BWRs), identifying major Indian and foreign players in each and assessing the potential for indigenisation of each segment.

1 Emerging construction and manufacturing techniques

India's nuclear fuel supply has both domestic and foreign suppliers. The domestic fuel supply chain is handled by the state-owned PSU Uranium Corporation of India Limited (UCIL). There are also foreign suppliers, with Kazakhstan and Russia handling a significant chunk of foreign uranium supply for India's power plants. India also has its own domestic enrichment facilities to process and convert U-238 into the more fissionable U-235 isotope for power plants.

A. Elements

1. *Domestic fuel suppliers:* UCIL is the state-owned miner and processor of uranium ore. UCIL operates several mines (Jaduguda, Tummalapalle, etc.) The Atomic Minerals Directorate (AMD) explores new deposits; as of 2021 India had ~293,000 tU identified in situ, but much of it is low-grade and costly to extract.[84] Domestic production currently meets only a portion of fuel needs in India, and the country has to rely on foreign suppliers as well to provide the balance of the fuel needs.
2. *Foreign Fuel Suppliers:* To compensate for domestic uranium shortfall, India has diversified suppliers abroad since the Nuclear Suppliers Group (NSG) trade restrictions were lifted in 2008. Major uranium exporters have entered the Indian market via long-term contracts. Notable players include:
    - Kazatomprom (Kazakhstan) – Supplied 2,100 tonnes of uranium oxide concentrate (U_3O_8) to India by 2014 under an initial agreement, later extended with 5,000 tU over 2015–2019. Kazakhstan has become a key supplier in India's fuel mix.[85] In February 2026, Kazatomprom signed a long-term agreement with India for the supply of uranium and this contract accounted for approximately 50 per cent of Kazatomprom's book value.[86]
    - TVEL (Russia) – Under a February 2009 contract, Russia's TVEL provided 2,000 tonnes of natural uranium pellets for PHWRs over 10 years, and 58 tonnes of enriched uranium for Tarapur's BWRs.[87] TVEL continues to supply fuel: a USD700 million deal in 2008 and a 2015 renewal for reactor fuel pellets (fabricated into assemblies at NFC) ensured Tarapur's operation.[88]
    - Cameco (Canada) – After India-Canada nuclear cooperation resumed, Cameco signed in 2015 to deliver 3,200 t U_3O_8 by 2020.[89] On 2 March 2026, Canada's Cameco signed an agreement to supply approximately 11,000 tonnes of uranium to India. The contract, spanning from 2027 to 2035, is valued at approximately USD1.9 billion.[90]
    - Others: France's Areva (now Orano), Uzbekistan's Navoi Mining & Metallurgy Company (NMMC) are also key suppliers of uranium to India. India also signed agreements with Australia (2014) and Namibia, Mongolia (2009) to enable future uranium imports.

3. *Fuel fabrication and enrichment:* India has established the state-owned Nuclear Fuel Complex (NFC) in Hyderabad to refine, process and fabricate uranium fuel useful for the indigenous fleet of PHWRs. There are plans to establish more NFCs in India to cater to the growing fleet of nuclear reactors in India. The proposed NFCs are envisaged to be built using technological assistance from US, France and Russia. Fuel fabrication and enrichment have limited scope of indigenisation owing to technological restrictions and IAEA oversight, as the new NFC facilities would be mapped with the power plants for whom the fuel is intended.
4. *Prototype Fast Breeder Reactor (PFBR):* A fast breeder reactor (FBR) is one which is able to breed fertile nuclear materials like Th-232 and U-238 to fissile nuclear fuels like U-233 and U-235. The fissile materials can then be used in conventional nuclear reactors to generate heat and electricity. PFBR is quite crucial in achieving energy self-reliance in India as the technology is envisaged to make use of the abundant Thorium reserves in the country instead of depending on foreign supplied conventional or nuclear fuels. PFBR, once online, can help generate domestically bred nuclear fuel for conventional nuclear power plants in India.

B. Key challenges and industry expectations

India’s nuclear fuel supply chain is evolving rapidly, with a mix of domestic production and international procurement. While the elements of the supply chain, such as UCIL’s mining operations and NFC’s fabrication capabilities, form the backbone of India’s nuclear infrastructure, the sector faces several pressing challenges that must be addressed to enable private sector participation and scale deployment.

A key challenge lies in the bifurcation of fuel sources: while PHWRs benefit from indigenous fuel fabrication, safeguarded LWRs and BWRs remain dependent on imported enriched uranium. This reliance may introduce vulnerabilities in long-term fuel security, especially for advanced reactor designs like SMRs and BSRs. Although India has matured in heavy engineering capabilities, scaling up to meet future demand requires certified nuclear-grade vendor development and robust Quality Assurance (QA) systems.

Industry stakeholders, as reflected in the dipstick survey, have voiced concerns over fuel supply risks, particularly the availability of HALEU fuel. Approximately 83 per cent of respondents emphasised the need for long-term HALEU procurement agreements with IAEA-approved suppliers, while 33 per cent highlighted the lack of domestic enrichment infrastructure. To mitigate these risks, the industry recommends a three-pronged strategy: securing international HALEU contracts, investing in domestic enrichment capabilities, and adopting reactor technologies compatible with Low-Enriched Uranium (LEU).

Furthermore, the push for localisation of nuclear-grade manufacturing also present opportunities for private sector engagement. However, these must be accompanied by clear regulatory frameworks, risk-sharing mechanisms, and investment in certification and testing infrastructure to ensure supply chain resilience and project viability.

2 Engineering, Procurement and Construction (EPC), reactor technology and design

A. Elements

Over the past few decades, India has developed a robust and indigenous EPC (Engineering, Procurement, and Construction) ecosystem for the nuclear power sector, comprising both private enterprises and state-owned companies. These entities have played a pivotal role in the domestic development of nuclear reactors.

Among the most prominent heavy engineering and EPC firms in India are Larsen & Toubro (L&T), Bharat Heavy Electricals Limited (BHEL), Hindustan Construction Company (HCC), and Megha Engineering and Infrastructure Limited (MEIL). The growth of these major EPC companies has also fostered the emergence of a large number of Micro, Small, and Medium Enterprises (MSMEs), which supply specialised equipment and components for nuclear power plants.

Organisations such as L&T have even developed advanced heavy engineering capabilities, enabling them to secure prestigious international EPC contracts—such as the cryostat for the International Thermonuclear Experimental Reactor (ITER) fusion project.[91]

India's EPC ecosystem for nuclear power can therefore be considered to have achieved a high degree of indigenisation.

Closely related to EPC is the reactor technology and design landscape. The technology landscape in India's conventional nuclear power sector remains varied, with significant scope for further indigenisation. BARC, a leading state-owned institution, plays a central role in providing reactor designs and technologies for indigenous PHWRs, which constitute the majority of India's nuclear power fleet. Russia's Rosatom is a key technology provider for the VVER reactors at Kudankulam, while legacy support from Canada—through the CANDU reactor design—has been instrumental in shaping India's indigenous PHWR technology. Additionally, the United States-based company GE supplied technology and served as the EPC contractor for the Tarapur nuclear power plant, which is based on the BWR design.

Looking ahead, India has successfully developed the PFBR, a critical component of its three-stage nuclear power programme. Research is also underway on an indigenous LFR design, known as the Compact High Temperature Reactor (CHTR).[92] This reactor is envisioned to be fuelled by TRISO, which is considered inherently safe against thermal meltdowns.[93] The CHTR is expected to support clean hydrogen production and desalinated water generation, making it a vital element of India's long-term nuclear strategy.

B. Key challenges and industry expectations

India's nuclear industry has identified a series of critical supply chain challenges that must be addressed to unlock private sector participation and scale reactor deployment. The dipstick survey highlights persistent procurement difficulties for key components such as reactor pressure vessels, forged equipment, heat exchangers, and steam generators—items essential for expanding nuclear power capacity. Compounding this is the limited access to proprietary technologies and licensing, particularly for core design and coolant systems, which are vital for deploying advanced Gen-IV SMRs.

The survey also indicates that these challenges may be exacerbated by a lack of qualified vendors, long lead times, and high dependence on imports for enriched fuel and control systems. Domestic manufacturers often fail to meet international nuclear-grade standards, and the absence of a robust certification ecosystem further weakens supply chain resilience. Infrastructure gaps in spent fuel handling and decommissioning services, coupled with fragmented vendor networks, hinder coordinated scaling—especially for modular and advanced reactor technologies.

The industry expects the government to take some actions to mitigate the EPC and technology related hurdles. This includes investing in vendor qualification programmes, enabling joint ventures with global OEMs, and establishing a dedicated nuclear manufacturing ecosystem under the "Make in India" initiative. Vendors, especially Micro, Small and Medium Enterprises (MSMEs) form a significant chunk of orders from the EPC company. Policy support may also focus on strengthening Intellectual Protection Rights (IPRs) and easing export control restrictions, expanding domestic enrichment capabilities, and creating risk-sharing mechanisms to de-risk supply chain development. These steps are essential to build a resilient, future-ready nuclear supply chain that can support India's ambitious energy and climate goals.

3 Ownership models and developer ecosystem

Nuclear power development in India is state-driven at present. The erstwhile Atomic Energy Act of 1962 and its 2016 amendment permitted only government-owned entities or JVs (with government holding of minimum 51 per cent) to set up nuclear power plants.[94] Accordingly, the NPCIL, a public sector enterprise under the Department of Atomic Energy (DAE), was the primary owner, operator, and developer of all commercial nuclear reactors in India. NPCIL is responsible for the design, construction, commissioning and operation of thermal nuclear plants. Another government company, Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), was tasked with FBR projects and the PFBR is yet to be commissioned. The plant operations, ownership and maintenance were all governed by NPCIL and was thus fully indigenous.

It is envisaged by the industry, as a part of the industry survey, that an important lever to encourage private sector participation for nuclear projects in India is by amending the Atomic Energy Act and CLND Act. These acts have been repealed by the SHANTI Act, 2025, which permits the participation of private entities in the development and ownership of nuclear power plants in India.[95]

4 Spent fuel management and disposal framework

A. Elements

Disposal of spent fuel or wastes is an integral part of the nuclear power supply chain in India owing to the fact that nuclear reactors produce both HLWs and Low-Level Wastes (LLWs), both of which contain radioactive elements which are extremely hazardous. The HLW wastes stay radioactive for thousands of years due to their long half-lives. In India, an integrated spent fuel disposal system is followed for safe disposal of nuclear spent fuel. The regulations are to be provided by AERB under the SHANTI Act. The entirety of HLW and LLW nuclear waste disposal in India is controlled by the central government or the AERB.

Operational wastes at the plant level are to be managed by the licensee in accordance with licence conditions and AERB safety authorisations, including treatment, conditioning and disposal at AERB-approved facilities, supported by the licensee's obligation to maintain financial security for safe disposal, repatriation (if applicable) and decommissioning

Spent fuel must be first cooled at the installation for a period specified by the regulator and then delivered to the Central Government for subsequent management, including reprocessing/recycling, vitrification and interim storage, or repatriated to the country of origin wherever applicable. The costs of delivery and subsequent management/repatriation must be borne by the licensee, under the SHANTI act. The management of spent fuel and HLW is reserved exclusively to the Central Government under the SHANTI act.

Research and development for final disposal of spent fuel or wastes shall remain under the Central Government's purview. AERB is expected to set the applicable safety framework.

B. Key challenges and industry expectations

Industry feedback, prior to the passage of the SHANTI act, highlighted the need for a single, Centre led back end that is predictable, transparent and financeable. Under the SHANTI act, the Central Government already holds exclusive responsibility for the licensing and regulatory aspects. Licensees under the SHANTI act are required to cool spent fuel on site for the regulator specified period and then deliver it to the Central Government. Management of spent fuel and HLWs, including reprocessing, recycling, vitrification and interim storage, remains exclusively with the Central Government.

Post the passage of the SHANTI act, some of the gaps which might need to be addressed are as follows, which can aid in offering regulatory clarity regarding spent fuel management, recycling and safe disposal:

1. Publication of a comprehensive National Policy for Spent Fuel and Radioactive Waste (which might be issued at a later stage by the Central Government, as indicated in the SHANTI act)
2. Continued investment in advanced waste treatment/partitioning and in scaling interim storage capacity as India's nuclear power capacity expands
3. Codified tracking and inventory systems (SHANTI act enables the Central Government to maintain a national registry of radioactive substances)

5 Regulatory landscape and legal reform priorities

Prior to the passage of the SHANTI act, India's nuclear regulatory framework was anchored by the Atomic Energy Act, 1962, and was supplemented by comprehensive safety regulations like CLND act, 2010. The regulatory framework has evolved to ensure nuclear safety while facilitating peaceful uses of atomic energy and achieving energy self-sufficiency. The regulatory structure, with AERB as the independent safety regulator and DAE overseeing policy and development, had received positive international assessment while identifying areas for continuous improvement. Current reform initiatives aim to address liability concerns and encourage greater participation in nuclear power development, crucial for India's clean energy transition and climate commitments. The SHANTI act, which supersedes the Atomic Energy act and CLND act, is a step in this direction.[96]

The regulatory landscape is governed by domestic laws and international regulatory authorities like IAEA. The key legislations are summarised as follows:

A. Core domestic Laws

I. Atomic Energy Act, 1962:

The Atomic Energy Act, 1962, provides the foundational legislation governing India's nuclear sector. The act provides for the development, control and use of atomic energy for the welfare of the people of India and for other peaceful purposes.

i. Key Provisions:

1. Section 3(a) and (b) confers the Central Government with the power of producing, manufacturing, using, and disposing of atomic energy and radioactive substances.
2. Section 3(c) empowers the government to declare as "restricted information" any information relating to location, quality and quantity of prescribed substances and nuclear technology.
3. Sections 16 and 17 refer to control over radioactive substance and special provisions for safety.
4. Section 22 empowers the Government to fix rates for and regulate the supply of electricity from atomic power stations.

ii. Major Amendments:

1. The Atomic Energy (Amendment) Act 1987 introduced the concept of "Government Company" defined as a company with at least 51 per cent paid-up share capital held by the Central Government.
2. The 1962 Act was amended in 2016 to enable NPCIL to form joint ventures with public companies, though these amendments do not extend to private sector companies.

II. Civil Liability for Nuclear Damage (CLND) Act, 2010:

The CLND act was enacted to provide prompt compensation to victims for damage caused by nuclear incidents through a no-fault liability regime and to facilitate India becoming a State Party to the Convention on Supplementary Compensation.

i. Key Provisions:

1. Establishes strict liability on nuclear operators for nuclear damage, ensuring compensation for victims and defining responsibility for nuclear accidents.
2. Unique provision under Section 17(b) introducing supplier liability, enabling operators to seek recourse against suppliers for defective equipment or sub-standard services.
3. Section 46 preserves the application of other laws while not exempting operators from any proceedings under other statutes.
4. Liability provisions more stringent than international standards, potentially imposing unlimited liability on foreign suppliers.

ii. International Context: India signed the Convention on Supplementary Compensation (CSC) on October 29, 2010, ratified it on February 4, 2016, and became a State Party. Unlike the CSC framework which places liability solely on operators, India's CLND act broadens supplier accountability.

III. Sustainable Harnessing and Advancement of Nuclear energy for Transforming India (SHANTI) Act, 2025:

The SHANTI act creates a single, modern statute for India’s civil nuclear sector, opening the door to regulated private participation while centralising regulatory responsibilities, updating civil liability, and giving statutory footing to AERB. It repeals the Atomic Energy Act, 1962 and the CLND Act, 2010.

i. Key provisions:

1. Market access & licensing: Besides Government entities, any private player may apply for licences to build, own, operate or decommission nuclear power plants.
2. Activities reserved exclusively for the Central Government: Enrichment/isotopic separation; spent fuel management (including reprocessing, recycling, separation of radionuclides, and HLW management); production/up gradation of heavy water remain solely with the Central Government.
3. Constitution of AERB as the regulatory authority: AERB is deemed constituted under SHANTI act, with a Chairperson, a whole-time member and up to seven part time members. The AERB is expected to issue regulatory guidelines (codes/standards/guides), grant safety authorisations and monitor implementation.
4. Civil liability framework (operator centric) & financial protection: Overall a maximum of 300 million Special Drawing Rights (SDRs) (or higher if notified by the Central Government) and graded operator caps by installation category has been provided in the SHANTI act. Operators are however expected to maintain financial security to honour the liability obligations. The SHANTI act also empowers the Central Government to take up the liability beyond the operator’s cap and establish a National Liability Fund for this purpose.
5. Central Government to establish tariffs: Under the SHANTI act, the Central Government is expected to establish tariffs of electricity generated from nuclear power plants, by taking into consideration critical parameters like fuel cost, decommissioning cost, spent fuel management cost etc. The tariffs set shall be independent of the Electricity Act, 2003.

B. International regulations

I. IAEA Review Findings:

i. IAEA Integrated Regulatory Review Service (IRRS) peer review in 2015 concluded that AERB is an “experienced, knowledgeable and dedicated” regulator protecting public and environment. A 2022 extended follow up by IAEA found that AERB had acted on all recommendations and suggestions from 2015, closed 11 of 13 recommendations and 20 of 21 suggestions, and made significant improvements, with no new findings on the topics covered in 2015.[97] The expanded 2022 scope (radiation sources) also noted opportunities to further strengthen oversight.

ii. Clause 17 of SHANTI act “deems” the AERB to have been constituted under the SHANTI act. It thus carries the legacy of AERB forward and gives it an express statutory footing within the new umbrella law. In parallel, Clause 91 of SHANTI act repeals both Atomic Energy act and CLND act but saves existing bodies, licences, rules and instruments so that everything continues seamlessly under the SHANTI act.

iii. The latest review of IAEA thus stands valid for AERB, even under SHANTI act.

II. U.S.-India Civil Nuclear Agreement

i. Section 123 of the U.S. Atomic Energy Act requires conclusion of peaceful nuclear cooperation agreements for significant transfers of nuclear material or equipment from the United States. The Indo-US nuclear agreement, known as the 123 Agreement, was signed following requirements of Section 123 of the U.S. Atomic Energy Act, 1954.

ii. The then Prime Minister Shri Singh and the then US President George W. Bush announced agreement to enter civil nuclear deal. In December 2006, the U.S. Congress approved legislation changing U.S. law to allow nuclear exports to India for first time in 30 years. On October 8, 2008, President Bush signed the U.S.-India Nuclear Cooperation Approval and Non-Proliferation Enhancement Act into law.[98]

C. Regulatory bodies

I. Atomic Energy Regulatory Board (AERB)

i. Pursuant to the SHANTI Act, AERB is designated as the competent authority for granting, renewal, withdrawal and revocation of consents for nuclear and radiation facilities and enforcing regulations on players in nuclear energy space in India.

ii. The AERB shall comprise of a Chairperson, one Whole time Member, and up to seven Part time Members, appointed by the Central Government on the recommendation of a search cum selection committee of the Atomic Energy Commission (AEC).

iii. AERB may also engage consultants/experts as needed.

iv. Primary Functions:

1. Develop safety policies, codes, guides and standards for siting, design, construction, commissioning, operation and decommissioning of nuclear and radiation facilities.
2. Ensure compliance through review, assessment, regulatory inspection and enforcement.
3. Prescribe acceptance limits of radiation exposure to workers and public and environmental release limits.
4. Review emergency preparedness plans and training programs for nuclear facility personnel.
5. Notify the public of nuclear incidents as mandated by the SHANTI act, 2025.

II. Department of Atomic Energy (DAE):

DAE was set up under the direct charge of the Prime Minister through a Presidential Order on August 3, 1954. It comprises six research centres, three industrial organisations, five PSUs and three service organisations. Under Section 2, clause 6 of the SHANTI act, 2025, the Central Government would automatically mean DAE itself. The AERB is designated as the regulatory authority, while DAE assumes the responsibility of granting licenses, settling disputes, assuming control over mining, enrichment of fuel, management of heavy water and spent fuel and even overall control of facilities if deemed necessary keeping in mind the safety or emergency conditions.

ii. Key Provisions:

1. DAE is responsible for granting licenses to players in the nuclear energy sector (public or private) as per the SHANTI act.
2. DAE shall, grant/refuse, extend/renew licenses for players in the nuclear energy space in India. The department may also, alter conditions, suspend/cancel licenses, and may issue composite licences as necessary. DAE assumes exclusive responsibility of areas in the nuclear energy domain reserved for the Central Government under the SHANTI act, namely enrichment or isotopic separation of fuel, spent-fuel management (reprocessing, recycling, radionuclide separation, HLW management), production/upgradation of heavy water and any other notified activities.
3. DAE is also responsible for accounting and maintaining registry of nuclear materials, heavy water and spent fuel. Licensees of the nuclear power projects must hand over the spent fuel and heavy water to DAE after storing the spent fuel within the licensee's own facility for cooling as per DAE's rules. Costs for storage of spent fuel and heavy water within the licensee's premises and transportation to designated AERB / DAE facilities are to be borne by the licensee.
4. As per SHANTI act, DAE assumes exclusive vesting of acquisition rights in prescribed substances, mines/minerals/equipment/plant. DAE may acquire abandoned plants/reactors free from encumbrances and levy costs for safe operation/waste/spent-fuel/decommissioning if deemed necessary as per the provision of the act.
5. DAE is expected to establish the Atomic Energy Redressal Advisory Council to hear review applications against AERB/DAE orders and facilitate reconciliation/settlement.

III. Other key entities under DAE

i. NPCIL: Responsible for the construction, operation and maintenance of nuclear power plants in India. Until the passage of SHANTI Act, NPCIL was the sole authority entrusted with nuclear power plants development and operations. As of January 2026, all operational nuclear power plants in India are under NPCIL's control (totalling to a generation capacity of nearly 8.8 GWe).

ii. BHAVINI: Established for fast breeder reactor development.

iii. NFC: Responsible for nuclear fuel fabrication.

iv. UCIL: Manages uranium mining and processing.

v. Indian Rare Earths Limited (IREL): Responsible for mining and processing of rare earths, including radioactive elements like thorium (useful for fast breeder reactors).

vi. Heavy Water Board (HWB): Responsible for the production, supply and management of heavy water – a neutron moderator used in PHWR reactors.

vii. Electronics Corporation of India Limited (ECIL): Responsible for indigenous development of controls and instrumentation requirements of nuclear power plants in India. However, as on date, the corporation now develops controls and instrumentation requirements of other industries as well like banking, aviation, defence, telecom, agriculture, coal, steel etc.

D. Regulatory bodies

India's nuclear energy sector is governed by a centralised legal and regulatory framework that significantly limited private sector participation until the passage of SHANTI act in 2025. The erstwhile Atomic Energy Act, 1962, particularly Sections 14(1A) and 14(1B), restricted licensing for nuclear power generation to the Central Government or government-owned entities. Additionally, Section 22 of the same Act empowers the Union Government to set tariffs for electricity from atomic power stations, bypassing the standard regulatory mechanisms under the Electricity Act. The CLND Act, 2010, further entrenched this limitation by confining operator liability to government-controlled entities, with NPCIL and its majority-owned JVs being the de facto operator.

Industry stakeholders, as reflected in the survey responses, are desirous of urgent legislative reform to address these constraints. As of November 2025, there was a strong consensus on the need to amend both the Atomic Energy Act and the CLND Act to enable private and foreign participation, clarify supplier liability, and introduce market-based models such as power purchase agreements (PPAs). Section 17(b) of the CLND Act, which granted the operator a right of recourse against suppliers for defects or substandard services, was viewed as overly punitive and atypical by international standards. While the establishment of the Indian Nuclear Insurance Pool (INIP) in 2015 was a step forward, its INR1,500 crore (approximately USD170 million) capacity remains modest, and suppliers continue to seek statutory certainty or liability caps to mitigate risk.[99]

The regulatory landscape also presented procedural and institutional challenges. The Atomic Energy Regulatory Board (AERB), though functionally independent, operated under DAE, raising concerns about its statutory autonomy. Multiple layers of permitting like siting, environmental clearance under the EIA Notification (2006), coastal zone approvals, and land acquisition, added complexity and delay. Industry respondents emphasised the need for a more agile, transparent, and digitally enabled regulatory regime that engages continuously with developers and adapts to advanced reactor technologies. Harmonisation with international standards such as ASME, RCC-M, and IEEE was also essential to facilitate procurement and financing for private entrants.

To unlock the full potential of nuclear energy in India, the government needed to take decisive action. This included amending restrictive sections of the Atomic Energy Act and CLND Act, streamlining regulatory processes, and establishing SMR-specific guidelines and pre-approved nuclear zones. A national policy that explicitly promotes nuclear energy, incentivises innovation, and fosters international collaboration is critical. These reforms are not merely desirable; they are essential to achieving India’s ambitious nuclear targets and positioning the country as a global leader in clean energy innovation.

The SHANTI act in 2025 was thus a major step in the right direction. It enabled private sector participation in nuclear power plant operation, development and maintenance, which is crucial to achieving the target of 100 GW installed capacity by 2047. Additionally, the functions of AERB and DAE were separated and streamlined. Liability was also capped for the operator, with central government stepping in to take up additional liability for damages beyond 300 million SDRs, if needed. The act also provides a simplified legal pathway for resolution of disputes and redressal as the parties dissatisfied with Atomic Energy Redressal Advisory Council’s ruling and Appellate Tribunal’s ruling may directly approach the Supreme Court of India. The act however does not clarify about SMR specific regulations, nor does it open up other nuclear value chain activities like mining, enrichment, spent fuel recycling and disposal to private sector.

6 Opportunities for international players and technology providers

The fact that about 15-16 GW of new nuclear power plants are now in various stages of approval and construction in India and are scheduled to be online by 2031-32 presents an immediate investment opportunity in the country for nuclear power.[100] The opportunities are envisaged to increase as the country has undertaken a massive target of establishing 100 GW of nuclear power facilities by 2047, up from 8.8 GW as of 2025. Some of the short-term investment opportunities are as follows, basis industry dipstick survey:

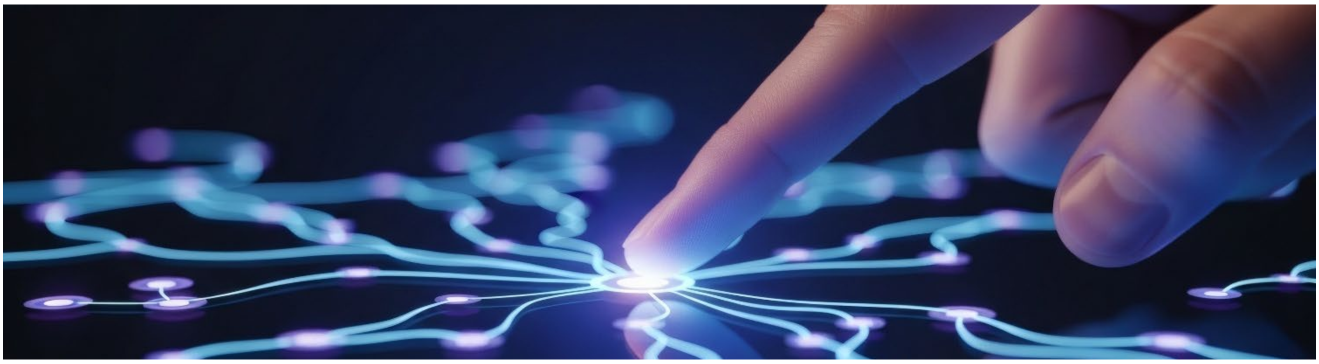


Table 4: Immediate investment opportunities in Indian nuclear energy sector

SN	Value Chain Component	Offerings	Rationale
1	Power plant development	Civil EPC services, including sub-components and sub-services like: 1. Heavy forging (especially for pressure vessels) 2. Heat exchangers 3. Steam turbines 4. Plant and machinery 5. Heavy casting 6. Specialised construction 7. Electrical power stations 8. Control units	The announced capacity till 2031-32 is envisaged to be based on the conventional PHWR technology developed by India, indicating standardised offerings and play for large-scale EPC service providers.
2	Fuel fabrication	1. Specialty metals and alloys 2. Fuel supply (mining and enrichment) 3. PHWR fuel-bundle lines 4. Zircaloy tubes 5. Technology license	Establishment of new NFCs for newbuilt nuclear reactors might necessitate technology licensing for engineered fuel tubes and pellets. The offerings can be either indigenous or foreign, depending on the reactor technology being used.

Further opportunities are expected to emerge with the introduction of FBRs, SMRs, and indigenously developed BSRs into the Indian market. The proliferation of these advanced technologies is likely to pave the way for large-scale reactor manufacturing. Some SMR designs are intended to be standardised and modular, enabling them to be transported over long distances in commercial 40-foot containers. This approach could significantly streamline deployment and shorten construction timelines. International firms have a strong record in delivering major projects, implementing digital and steam-cycle upgrades, supplying qualified components, diversifying BWR fuel portfolios, and providing export-backed financing. Some envisaged plays for global companies in the immediate future may be summarised as follows:

Table 5: Key immediate term opportunities for global players in Indian nuclear energy sector

SN	Category	Key global players	Applicability in India
1	Reactor design and technology	1. Westinghouse 2. GE-Hitachi 3. Global Nuclear Fuel (GNF) 4. Holtec 5. Rosatom 6. BWXT 7. Rolls Royce 8. Framatome 9. Korea Electric Power Corporation (KEPCO)	Availability of new reactor designs and licensing is essential as India gradually adopts not only SMRs but also opens up to foreign investment in new nuclear projects in India
2	EPC / Heavy Engineering	1. Bechtel 2. Samsung 3. HD Hyundai 4. KEPCO E&C 5. Sargent & Lundy (through its Indian JV with L&T) 6. GE	India has a mature EPC ecosystem and several of the major global EPC firms already have a foothold in India.
3	Steam turbines	1. EDF / Arabelle 2. Siemens Energy	India has both indigenous and global players manufacturing steam turbines for thermal power plants. However, the market can expand significantly and bring variability upon the proliferation of new nuclear technologies and SMRs as the market is opened up.
4	Control systems	1. Honeywell 2. Emerson 3. Westinghouse 4. Siemens 5. Framatome	India's PHWR/BWR fleet has a steady digital-upgrade backlog. Modern control systems are relevant for technology upgrades, faster and safer controls and derisk from emerging cyber threats to power plants.

1. **Policy opening & liability reform:** India has announced its intention to **amending the CLND Act and Atomic Energy Act** to permit private/foreign stakes and to **cap supplier exposure**, long the chief deterrent for U.S. OEMs.[101]
2. **Top-cover from leaders & regulators:** US President Donald Trump and Indian Prime Minister Shri Narendra Modi met on February 2025 and reiterated their commitment towards the realisation of the "123 Agreement" by moving ahead with US designed nuclear reactors and enabling technology transfer. The USA welcomed the budget announcements and India's intention to amend the Atomic Energy Act and CLND Act to enable increased private and foreign participation in Indian nuclear energy sector.[102]
3. **Bharat Small Reactors:** NPCIL's maiden RfP for the establishment of 220 MWe PHWR based BSR reactors can also offer an opportunity to US project developers. The successful conclusion of the current RfP might substantially increase opportunities in the emerging SMR space in India.[103,104]

VI. Workforce

Expanding nuclear capacity, whether through conventional plants or advanced SMRs, requires national coordination in workforce skill development. A country must not only attract a wide spectrum of scientific and engineering talent but also cultivate a culture of safety, innovation, and operational excellence. The skills needed span nuclear engineering, systems integration, digitalisation, regulatory compliance, project management, cybersecurity, and advanced manufacturing. Nations pursuing large nuclear programmes require both depth in specialist fields and breadth in interdisciplinary competencies, including reactor and fuel cycle technologies, risk analysis, maintenance, and stakeholder communications.

Countries that lead in nuclear technology and construction, such as France, South Korea, Japan, China, and Russia, demonstrate several best practices. They invest in dedicated nuclear education and training institutes, including France's Institut National des Sciences et Techniques Nucléaires (INSTN), South Korea's KEPCO International Nuclear Graduate School, and Russia's Rosatom Corporate Academy. These nations embed nuclear topics within university curricula, operate robust vocational programmes, and promote dual track pathways for both technicians and advanced researchers. Continuous professional development is strongly encouraged, often involving simulation-based training, international exchange programmes, and collaborative research with technology vendors. Skills in digital control systems, modular construction, and licensing have become central, reflecting the sector's transition towards standardised designs and greater operational flexibility.

Through such multifaceted strategies, a country can not only support its immediate workforce needs but also strengthen the foundation for safe, innovative, and sustainable nuclear expansion well into the future.

1 Estimation of manpower requirement in a typical nuclear power plant in India

In India, indigenous PHWR technology-based reactors form the backbone of the current nuclear power plant fleet. A joint report, "Measuring Employment Generated by the Nuclear Power Sector", estimates that approximately 380 direct jobs are created per GW of nuclear power capacity.[105] Applying this figure to India's ambitious target of 100 GW of nuclear installations by 2047 suggests a requirement for around 38,000 skilled workers to develop and operate these plants.

The same study highlights that first-order indirect employment—comprising the supply chain ecosystem providing products and services directly to nuclear plants—is also significant compared to direct employment. Indirect jobs are typically estimated using a multiplier ranging from 0.912 to 1.38, according to the report. Based on these multipliers, indirect employment from India's target could range between 34,000 and 55,000. In total, the country may need a workforce of approximately 93,000 to support a 100 GW fleet.

The construction of nuclear power plants is anticipated to generate a significant number of temporary jobs, primarily associated with the building of the facilities. According to estimates by EDF, a 10 GW installation could create approximately 25,000 construction-related jobs in India, equating to around 2,500 jobs per gigawatt of plant capacity.[106] Based on this projection, the construction of 100 GW of nuclear power capacity could result in roughly 250,000 temporary construction jobs nationwide.

Currently, India has only 8.8 GW of nuclear capacity, meaning the existing workforce is likely just a fraction of what might be required by 2047. This underscores the considerable challenge India faces in building the skilled workforce necessary to achieve its nuclear ambitions.

2 Estimation of team roles, responsibilities and skills

A nation must build specialist depth and interdisciplinary breadth in nuclear engineering, digital systems, cybersecurity, risk analysis, advanced manufacturing, and operational management. These skills are critical to managing both conventional reactors and modular, flexible SMR designs.

Some of the skills which are expected to be in demand as the country progresses to realise its ambitions in nuclear energy are as follows:

1. **Plant Leadership and Management:** A small team of senior managers (e.g. Station Director, Operations Superintendent, Maintenance Superintendent) oversees overall plant safety, regulatory compliance, and performance. These roles require decades of experience, strong leadership, and in-depth knowledge of nuclear regulations and reactor technology.
2. **Reactor Operations Team**: This team is typically responsible for the safe operation of a nuclear reactor core at all times. Its members typically hold engineering degrees in disciplines such as mechanical, electrical, or nuclear engineering, or possess technical diplomas supplemented with specialised training, for example through the BARC Training School or NPCIL's operator training programmes. Reactor operators must gain a strong command of reactor physics, systems control, and emergency procedures, and they often undergo several years of intensive instruction before being permitted to work independently. They operate in rotating shifts to monitor and control the reactor, turbines, and cooling systems, ensuring safe and reliable power generation.
3. **Maintenance and Technical Support:** A large fraction of the staff are maintenance engineers and technicians in mechanical, electrical, instrumentation & control (I&C) disciplines. Their role is to keep the plant equipment in good working order through preventive maintenance, inspections, and repairs. For example, mechanical fitters and welders service pumps, valves, heat exchangers, etc., electricians maintain motors and switchgear, and I&C technicians calibrate sensors and control systems. These personnel typically have relevant trade certifications or engineering diplomas, along with plant-specific training in working under nuclear quality and safety standards. They must be skilled in troubleshooting complex systems and adhering to rigorous procedural and safety protocols.
4. **Safety, Security and Environment Staff**: Nuclear plants employ specialists focused on health physics (radiation protection), industrial safety, environmental monitoring, and physical security. Health physicists and radiation protection officers continuously monitor radiation levels, implement contamination controls, and ensure worker doses remain below limits – requiring expertise in radiation science and safety regulations. Quality assurance (QA) personnel and regulatory compliance officers develop and enforce procedures that meet Atomic Energy Regulatory Board (AERB) standards. Additionally, a substantial security force is deployed to protect the facility – often armed security officers drawn from paramilitary backgrounds (in India, often the CISF), trained in nuclear security protocols. Security personnel work in shifts to guard the plant's perimeter and sensitive areas, and while they may not be "technical" nuclear workers, they form an important part of the permanent headcount.
5. **Engineering & Support Staff**: These include nuclear scientists/engineers and other professionals who provide technical oversight and support to operations. For example, reactor engineers and fuel engineers plan refuelling outages and monitor core performance; systems engineers analyse plant performance and design modifications for improvement. There are also chemists managing the water chemistry in the reactor and secondary systems, which is vital for corrosion control.

6. **General support functions:** These teams help supervise and provide support functions to the core operations, maintenance, and engineering groups. They include IT specialists who maintain computer systems, training instructors who continually upskill personnel, and administrative staff in areas such as human resources, finance, procurement, and materials management who oversee the site's day to day activities. Roles such as accountants, communications specialists, and lawyers may also form part of a nuclear facility's organisational structure. Although these professionals do not work directly with the reactor, they play a vital role in ensuring the smooth functioning of the organisation. Each position requires relevant qualifications, such as finance degrees for accountants, alongside a sound understanding of working in a high security, safety focused environment.

It is envisaged that a proper skill development framework or strategy needs to be in place to ensure that not only the government sector but also the private players are able to train, develop and hire specific skilled teams to ensure the successful construction and safe operations of their nuclear fleets.

VII. Industry Insights and Stakeholder Perspectives

Survey Findings and Industry Sentiment: The USIBC-KPMG survey captures a comprehensive pulse of the Indian nuclear energy ecosystem, revealing critical enablers and barriers across policy, market, technology, supply chain, financing, and community engagement.

The line of questioning seeks to understand whether India's nuclear programme can scale reliably and affordably through innovation, regulatory modernisation, and global collaboration—without compromising safety or public confidence. It probes eight interlocking domains: market needs and the role of modular reactors; fuel security and enrichment; construction and design practices; ownership and finance; waste stewardship; regulation and liability; international collaboration; and stakeholder sentiment. Across categories, the questions seek hard evidence—quantified costs and schedules, fuel and component lead times, bankable offtake structures, and measurable safety outcomes—while mapping dependencies such as HALEU availability, vendor qualification, and regulatory throughput. The overarching objective is to identify the minimum set of reforms, risk sharing mechanisms, and technology choices that enable near term demonstrations and repeatable fleet deployment.

It may be noted that the responses from the industry were sought till November 2025, post which the survey results were compiled, as a part of this report. Some of the industry asks, especially related to private sector entry in nuclear energy space, have been addressed post the passage of the SHANTI act, 2025 in December 2025. As mentioned previously, the SHANTI act 2025 repeals the Atomic Energy act and CLND act and their respective amendments.

Market landscape and role of modular reactors: The questions interrogate how modular and advanced reactors address India's specific demand profile: rising peak loads, regional imbalances, and the need for firm, low carbon capacity alongside variable renewables. They probe use cases beyond grid power, like industrial heat, hydrogen, desalination, data centres, repowering of retiring thermal sites, and remote or coastal deployments. The probe subsequently asks for quantification of heat grades, capacity factors, ramping capability, footprint, and water use. Respondents are encouraged to compare FOAK and fleet economics, articulate grid integration requirements and offtake models, and show how serial manufacturing shortens schedules. The aim is to prioritise configurations that can be standardised, licensed once and replicated, with clarity on siting constraints, balance of plant reuse, and options for thermal storage coupling.

Fuel supply chain and enrichment infrastructure: The line of questioning examines resilience of the back end and front end fuel cycle: adequacy of domestic uranium resources, diversification of imports, and realistic timelines for enrichment and fabrication expansion. It tests readiness for accident tolerant fuels and advanced enrichments, including the availability of HALEU, and asks how supply risk is mitigated through long term contracts, stockpiles, dual sourcing, and international safeguards. Respondents are asked to quantify throughput (tonnes per year), quality assurance regimes, inspection intervals, and transport logistics, and to demonstrate compatibility between near term reactor choices and fuel forms that can be fabricated domestically. The questions also probe synergies with indigenous programmes (such as fast reactors) to close the fuel cycle, reduce waste burdens, and align with non proliferation and traceability expectations.

Engineering, procurement and construction; reactor technology and design: Here the questions pursue schedule certainty and constructability. They seek an understanding of key aspects of EPC like vendor qualification status for nuclear grade forgings and heat exchangers, and alignment with international codes. Respondents are urged to present critical path maps, factory readiness levels, and FOAK to Nth learning curves, including quantified targets for labour hours and rework reduction. Technically, the questions explore technology readiness levels for candidate designs, passive safety claims, decay heat removal strategies, and interfaces with Brayton or steam cycles, insisting on test data and pilot milestones rather than aspirational statements.

Ownership models and developer ecosystem: The questionnaire probes which ownership and delivery structures are truly bankable under current law: utility owned, public–private partnerships, or special purpose vehicles with sovereign participation. It asks how risks across construction, fuel, operations, and back-end liabilities are allocated, and which instruments—capacity payments, contracts for difference, availability based PPAs—unlock competitive finance. There is emphasis on lender safeguards, step in rights, and revenue certainty for industrial co location customers. Respondents are asked to outline roles for domestic EPCs, operators, and O&M providers; the extent of localisation feasible without schedule penalty; and the path from single unit demonstrations to repeatable fleets. The overall intent is to identify models that minimise cost of capital, maintain accountability for nuclear safety, and attract long horizon investors.

Waste management and disposal framework: The questions seek clarity on responsibilities and timelines from spent fuel removal to ultimate disposal, distinguishing near surface facilities for low and intermediate level wastes from deep geological solutions for vitrified high-level wastes. They examine whether a central authority, funding mechanism, and tracking system exist to manage waste across a growing fleet, and how standardisation of fuel forms and canisters can reduce lifecycle costs. Respondents are asked to describe interim storage strategies, transport packages, monitoring regimes, and emergency preparedness, and to set out realistic siting and community engagement plans based on consent and benefits sharing. For modular and advanced designs, the line of enquiry tests claims about waste minimisation, burnup, and recycling, insisting on measurable reductions in radiotoxicity and on credible end points rather than deferral.

Regulatory landscape and legal reform priorities: This category interrogates the specific statutory changes needed to enable private participation while preserving sovereign oversight of nuclear safety. It asks for a concrete blueprint: amendments to core Acts (Atomic Energy Act and CLND Act), clarification of liability and recourse, and creation of design certification pathways and SMR specific rules. The questions test whether the regulator’s processes can be digitised and time bound, how multi site fleet licensing might work, and how domestic codes can be harmonised with international standards to ease procurement and finance. They also probe cross border regulatory cooperation for technology reviews, and readiness for modern risk domains for example, cyber security, seismic commonality, and beyond design basis events. The desired outcome is a predictable, transparent regime that reduces lead times, avoids duplicative reviews, and supports safe, repeatable deployment.

Opportunities for international collaboration and technology access: The line of questioning is intentionally company agnostic yet rigorous on substance: what technology building blocks, manufacturing know how, and workforce training can be localised quickly; how intellectual property is protected while enabling licensed production; and which export credit and blended finance tools can bridge FOAK risks. It invites proposals for co development, joint testing, and shared qualification of modules and materials, alongside long-term fuel assurances and take back options where relevant. Respondents are asked to map supply chains, identify bottlenecks in heavy forgings and control systems, and present phased transition plans from imported assemblies to indigenous manufacture. The aim is to couple global best practice with domestic capacity, accelerating learning curves and securing resilience against geopolitical or logistics shocks.

Industry insights and stakeholder perspectives: Finally, the questions consolidate market signals: appetite for long term offtake, willingness to co site with industrial heat loads, and thresholds for acceptable levelised and contracted costs. They probe perceived bottlenecks—fuel availability, vendor qualification, certification backlogs, financing costs—and ask which risk sharing measures (cost share for FOAK, viability gap support, green finance eligibility) would unlock decisions. The survey design seeks not endorsements but decision grade inputs: timelines to first concrete and first power, availability and capacity factor targets, outage strategies, and staffing plans. Public acceptance is addressed through expectations for transparent communication, environmental baselining, and community benefits. The intended outcome is a prioritised set of actions—legal, regulatory, financial, and technical—that converts interest into investable projects and, ultimately, a repeatable nuclear build programme.

The key insights from the survey are presented as follows:

A. Policy Expectations and Reform Recommendations

1. There is a strong consensus among the respondents on the **need for proactive regulatory approvals** (63 per cent of the respondents) and **accelerated licensing** (83 per cent of the respondents) to speed up nuclear project timelines.
2. **Legislative Reform is Critical:** Amendments to the Atomic Energy Act and Civil Liability Act are essential to unlock private and foreign participation. This has already been actioned through the passage of SHANTI act, 2025.
3. **Dedicated SMR specific regulations are needed:** A separate legal and regulatory pathway for SMRs is necessary, recognizing their unique characteristics.
4. **Speedier approvals and licensing:** Proactive, transparent, quick and digitally enabled regulatory processes are needed to accelerate licensing and approvals.
5. **Clarity and Predictability:** Investors and developers seek clear timelines, criteria, and expectations across licensing, fuel supply, and environmental approvals.
6. **Public-Private Collaboration:** Legal recognition of PPPs, FDI, and market-based models may catalyse private sector entry and innovation.
7. **Land and Environmental Reforms:** Streamlined land acquisition and EIA processes, including pre-approved nuclear zones, are vital to reduce project risk.

B. Market Dynamics and Technology Choices

1. **Assured markets is desired by the industry** in the form of Long-term PPAs (50 per cent of the respondents), demand aggregation or mandates are essential to de-risk nuclear investments.
2. SMRs are seen as highly attractive for industrial applications, especially **Gen-IV** designs.
3. **Lack of technology access** (83 per cent), **high financial costs or lack of access to cheap capital** (67 per cent), H**ALEU fuel supply** and **enrichment infrastructure** (50 per cent) and **lack of sufficient domestic manufacturing capacity for nuclear-grade components** (50 per cent) are identified as major bottlenecks for Indian nuclear power industry.
4. There is a consensus among the respondents towards **preference for LWR reactors** (50 per cent) to carry the bulk of India’s 100 GW nuclear power generation capacity by 2047.

C. Global Collaboration and Capacity Building

1. The industry wishes to establish bilateral G2G frameworks for technology transfer, fuel supply guarantees, and harmonised regulatory standards.
2. There is a need for increased B2B partnerships for joint ventures, local manufacturing, and co-development of SMR technologies.
3. There is again emphasis on facilitating access to U.S. reactor designs, operational data, and certification programs to build technical capacity, creation of joint R&D centers and pilot projects to demonstrate feasibility and build trust between stakeholders.
4. Alignment of safety and licensing standards is necessary to reduce duplication and accelerate deployment timelines.

D. Financing, Risk Mitigation and Business Models

1. The industry views that public-private partnerships and utility-owned models are seen as viable business models for SMR deployment in India.
2. U.S. support is crucial in areas such as joint ventures, technical assessments, and regulatory coordination to adapt successful SMR models.
3. The industry re-iterates that derisking mechanisms like long-term offtake agreements and cost-sharing with government or global agencies are top priorities for securing SMR financing.
4. Inclusion of nuclear in green financing and access to concessional loans can significantly improve financial viability.
5. Business model co-development workshops and study tours are valued for knowledge transfer and capacity building.
6. Insurance guarantees and risk-sharing frameworks are essential to attract private investment in nuclear projects.

The survey reveals a clear roadmap for enabling private sector participation and accelerating nuclear energy deployment in India. Through the passage of the SHANTI act, the government has taken the first major step of allowing private investment and international collaboration. The SHANTI act also splits responsibilities between licensor (DAE) and regulatory authority (AERB). Regulatory modernisation for emerging technologies like SMRs- and time-bound clearances, is essential. India may consider investing more in domestic manufacturing, fuel infrastructure (including HALEU), and vendor certification to reduce import dependence and build supply chain resilience. Other than plant ownership, operation, maintenance, construction, other critical areas of the nuclear energy value chain like mining, enrichment, heavy water production, decommissioning and safe disposal / recycling of spent fuel lie firmly within the control of DAE as per the SHANTI act, 2025. Some of these areas might need to be opened up to the private sector to help in the proliferation of emerging technologies, especially Generation-IV reactors which promise to be safer, fuel efficient and circular. Financing mechanisms such as long-term PPAs, green financing, and sovereign-backed guarantees are critical to de-risk projects. Finally, proactive community engagement, transparent environmental processes, and deployment of inherently safe reactor technologies are expected to be vital to securing public trust and ensuring sustainable growth. These insights are envisaged to help guide targeted policy interventions across technology, market, and governance domains.

VIII. Conclusion

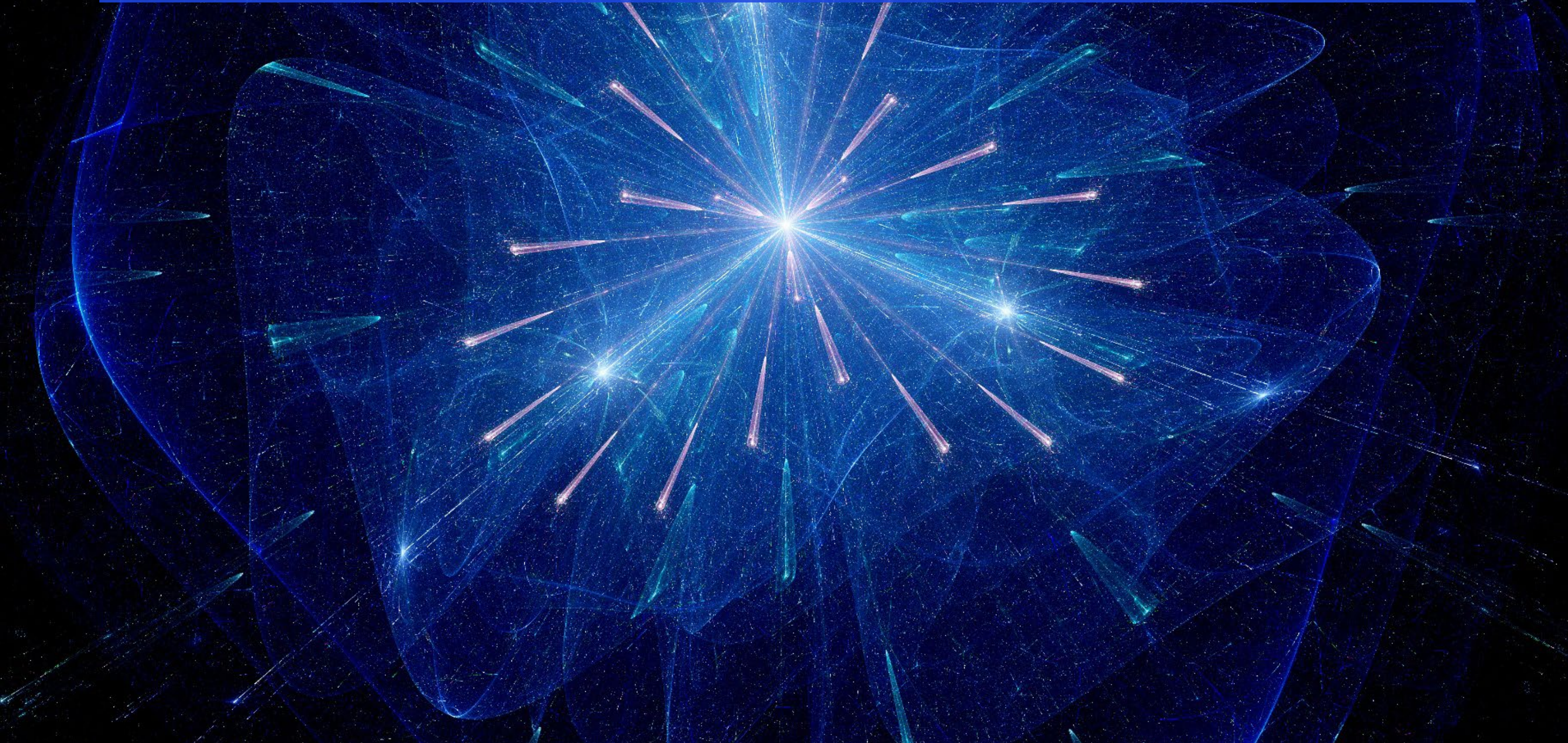
India's nuclear energy sector stands at a pivotal juncture, poised to transition from a state-dominated model to a more inclusive, innovation-driven ecosystem. The report highlights a strong convergence between government ambition and industry readiness, with stakeholders calling for legislative reform, regulatory clarity, and targeted investment to unlock private and foreign participation. The much-needed step of allowing private sector entry in nuclear plant operations has been taken by the government through the passage of SHANTI act in 2025. This step might go a long way towards helping the country achieve its ambitious goal of 100 GW installed nuclear power capacity by 2047.

The industry survey revealed some useful takeaways from the industry. The industry desires that India must move decisively to create a conducive environment for private and foreign participation in nuclear energy. Though the passage of the SHANTI act addresses some of the industry asks and provides licensing and regulatory clarity, new frameworks are still needed to address new technologies like SMRs and Gen-IV reactors.

On the commercial front, the government may attempt to institutionalise bankable offtake mechanisms through long-term PPAs and demand aggregation models, supported by sovereign guarantees and viability gap funding for FOAK SMRs. Inclusion of nuclear energy in India's green taxonomy and access to concessional finance might significantly improve project economics. Parallel efforts to develop a robust domestic supply chain, including vendor qualification programmes and HALEU fuel strategies, are essential to reduce import dependence and ensure self-sufficiency.

Quite notably, an integrated national radioactive waste management policy is required alongwith the creation of a dedicated spent fuel authority may provide clarity on back-end responsibilities, to boost private sector confidence. The SHANTI act empowers the Central Government to formulate National Policy for Management of Spent Fuel and Radioactive Waste, which might offer further clarity on waste management and address this important industry ask. Coupled with proactive community engagement and transparent risk communication, these measures are envisaged to build public trust in nuclear energy.

In summary, India's nuclear ambitions can be realised through a coordinated policy push that combines legal reform, regulatory agility, financial innovation, and international collaboration. By acting on these priorities, India can position itself as a global leader in clean energy while unlocking significant opportunities for domestic industry and strategic partners such as the United States.



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Acknowledgment

The report "*Atoms for net-zero: A 100 GW bet on India's nuclear expansion ambitions through private-sector participation*" provides the industry landscape of India's journey to expand nuclear energy deployment. Nuclear energy is envisaged to play a significant role in supporting India's energy security and resilience objectives of Viksit Bharat 2047. The report reflects the collective contributions of individuals at KPMG in India, USIBC and industry experts, whose views were instrumental throughout its development. Valuable insights across research, analysis, and editorial refinement enriched the narrative and supported a balanced perspective on the future of nuclear power in India. From shaping key themes to polishing the final draft, each contributor played a significant role in bringing this piece to completion. The final work stands as an example of shared thinking to catalyse investment, innovation and partnerships with the private sector.

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