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India's Nuclear Energy Ambitions: Challenges and Opportunities for a Cleaner Future

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Abstract: *India's energy demands have grown exponentially over the last few decades. This is only supposed to grow further with the increasing population and stressed emphasis over digitalization. To fulfil its increasing energy demands, it is pertinent for India to look for other viable sources of energy departing from solely relying on the conventional sources. In this direction, it is quintessential for India to pursue nuclear energy as a sustainable and clean source of energy. It has the potential of fulfilling the growing demands while ensuring the accomplishment of India's global climate commitments. This paper attempts to examine the dual narrative of challenges and opportunities shaping India's nuclear energy trajectory.*
There have been many significant advancements in the nuclear energy sector enhancing safety, scalability, and efficiency. It has enormous potential to help India meet its expanding energy needs, lowering its dependency on fossil fuels. Nevertheless, significant hurdles still persist, such as waste management and safety, financial and infrastructural constraints, and the most essential among them all, the need to align the domestic legal framework with the international obligations under various treaties and conventions, such as the Convention on Supplementary Compensation for Nuclear Damage, among others.
This work explores the viability of nuclear energy as a clean source of energy in India while examining the challenges and concerns. It further examines the ways in which regulatory frameworks, technological innovations, and sustainable development objectives interact to influence India's nuclear energy future..

Keywords: energy demands

I. INTRODUCTION

A shift to sustainable energy sources is required due to India's increasing energy demands, which are being fuelled by the country's fast industrialisation and urbanisation.[1]India, the world's third-largest energy consumer, relies extensively on fossil fuels, which exacerbates climate change and pollution in the environment.[2]The nation must diversify its energy mix with low-carbon alternatives in order to fulfil its obligations under the Paris Agreement and reach net-zero emissions by 2070.[3]

Given its capacity to produce dependable, high-output, low-carbon electricity, nuclear energy stands out among other clean energy sources. Nuclear power offers a steady energy supply in contrast to intermittent solar and wind power, making it an essential part of India's long-term energy security.[4]

With an emphasis on thorium, a resource in which India possesses substantial stocks, India's nuclear energy program has developed under the three-stage nuclear power strategy (discussed in the following section).[5]Approximately 3% of

[1]*Energy in India today – India Energy Outlook 2021 – analysis*. IEA. Retrieved January 18, 2025, from https://www.iea.org/reports/india-energy-outlook-2021/energy-in-india-today

[2]*Power Sector at a Glance ALL INDIA | Government of India | Ministry of Power*. (2022) Retrieved January 18, 2025, from https://powermin.gov.in/en/content/power-sector-glance-all-india

[3]*Spotlight| National Portal of India*. (2021). Retrieved January 19, 2025, fromhttps://www.india.gov.in/spotlight/indias-long-term-low-carbon-development-strategy

[4]Nuclear Power in India—World Nuclear Association. (2024). Retrieved January 19, 2025, from https://world-nuclear.org/information-library/country-profiles/countries-g-n/india

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India's total electricity generation currently comes from nuclear power, although there are ambitious plans to raise this percentage over the next several decades.[6]

India's Sustainable Development Goals (SDGs) are in line with the use of nuclear energy, especially SDGs 7 (Affordable and Clean Energy) and 13 (Climate Action).[7]India can improve energy security, lessen its reliance on coal, and support global efforts to combat climate change by increasing its nuclear capacity.[8]

This article aims to critically evaluate the viability of nuclear energy as a clean energy source in India. It explores the current status of nuclear energy in India and its role in the broader energy transition. It further looks into the opportunities for nuclear expansion, including technological advancements and environmental benefits. The article also undertakes to examine challenges in scaling nuclear power, such as legal, financial, and infrastructural constraints.

India's Nuclear Energy Landscape

Historical Context

India's nuclear energy program began in the years following independence, propelled by Dr. Homi Bhabha's vision, which established the framework for the nation's nuclear policy. The government was given sole authority for nuclear research and development by the Atomic Energy Act of 1948 and the Atomic Energy Act of 1962.[9]

The emphasis on the three-stage nuclear power approach, which seeks to harness the nation's enormous thorium supplies for long-term energy sustainability, makes India's nuclear program distinctive.[10] Among the three phases are:

- Stage 1 – Use of natural uranium in Pressurized Heavy Water Reactors (PHWRs).
- Stage 2 – Development of Fast Breeder Reactors (FBRs) to convert uranium-238 into plutonium-239.
- Stage 3 – Advanced Heavy Water Reactors, deployment ofThorium-based reactors, leveraging India's abundant thorium reserves.

Despite international bans on nuclear technology exports after India's nuclear tests in 1974 (Pokhran-I) and 1998 (Pokhran-II), the 2008 Indo-U.S. Civil Nuclear Agreement was an important turning point.[11] It allowed India to continue its autonomous nuclear weapons program while participating in the international nuclear trade.[12]

Current Status of Nuclear Energy in India

With a total installed capacity of roughly 7,480 MW, India currently has 22 nuclear reactors spread among 7 nuclear power stations.[13]The largest operational plant is the KudankulamNuclear Power Plant (Tamil Nadu), which was established in partnership with Russia and has plans to expand further.[14]

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[5]*Bhabha atomic research centre (Barc): About us*. (2020). Retrieved January 20, 2025, from https://barc.gov.in/about/?tab=3

[6]*36th Annual Report 2022-23* (36). (2023). Nuclear Power Corporation of India Limited. https://www.npcil.nic.in/WriteReadData/userfiles/file/NPCIL_Annual_Report_2022_23_English_29082023.pdf

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[8]Clarke, L., Wei, Y.-M., De La Vega Navarro, A., Garg, A., Hahmann, A. N., Khennas, S., Lima de Azevedo, I. M., Löschel, A., Singh, A. K., Steg, L., Strbac, G., & Wada, K. (2022). Energy systems. In P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 613–746). Cambridge University Press.

[9]*Department of atomic energy | India*. (2023). Retrieved January 21, 2025, from https://dae.gov.in/

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[11]*50 years of Pokhran I: Revisiting India's Peaceful Nuclear Explosion*. (2024). Orfonline.Org. Retrieved January 21, 2025, from https://www.orfonline.org/expert-speak/50-years-of-pokhran-i-revisiting-india-s-peaceful-nuclear-explosion

[12]World Nuclear Association, 2023.

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As part of its clean energy transition, the Indian government aims to expand nuclear capacity to 22,480 MW by 2031.[15]There are numerous new initiatives underway, such as:

- Kakrapar Atomic Power Project (KAPP-3 and KAPP-4) – India's first indigenous 700 MW PHWRs.[16]
- Gorakhpur Nuclear Power Plant (Haryana) – Under construction, based on PHWR technology.[17]
- Jaitapur Nuclear Power Plant (Maharashtra) – Proposed 9,900 MW project in collaboration with France, expected to be the world's largest nuclear plant.[18]

Policy and Legal Framework Governing Nuclear Energy

A stringent regulatory structure that aims to guarantee safety, security, and environmental compliance oversees India's nuclear industry. The key legal instruments include:

- Atomic Energy Act, 1962 - Empowers the central government to regulate nuclear activities and oversee research, production, and development.[19]
- Civil Liability for Nuclear Damage Act, 2010 (CLND Act) - Establishes a liability regime for nuclear incidents, with operators bearing primary liability, in line with the international conventions.[20]
- Environmental Protection Laws - The Environmental Impact Assessment (EIA) Notification, 2006, mandates nuclear projects to undergo environmental scrutiny before approval.[21]
- International Safeguards - India adheres to International Atomic Energy Agency (IAEA) safety standards and has entered agreements such as the Convention of Nuclear Safety (1994) and the Convention on Supplementary Compensation for Nuclear Damage (CSC), 2010.[22]

Challenges in India's Nuclear Energy Expansion

India's nuclear energy industry faces numerous obstacles despite policy support:

- **Financial and Infrastructure Restrictions:** Nuclear projects have a large initial outlay, and delays and cost overruns can affect future expansions.
- **Public Opposition and Safety Concerns:** Protests against nuclear power plants, like Kudankulam, draw attention to public concerns about radiation hazards and safety.[23]

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[13]*37th Annual Report 2023-24*. (2024). Nuclear Power Corporation of India Limited.https://www.npcil.nic.in/WriteReadData/userfiles/file/Annual_Report_2023_2024_26082024_01.pdf

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- **Nuclear Waste Management:** Long-term environmental issues are raised by India's existing lack of a permanent geological repository for high-level nuclear waste.
- **Dependency on Foreign Technology:** Although India is developing indigenous reactors, it still relies significantly for uranium fuel and reactor components on foreign suppliers (such as the USA, France, and Russia).[24]

This gives a brief overview at a few of the varying challenges that India faces, a more detailed discussion is given in the following sections.

Future Prospects for India's Nuclear Energy Program

India's aspirations for nuclear energy are consistent with its objective of achieving Net Zero by 2070 and a clean energy transition.[25] In order to tackle current issues, policy initiatives are concentrating on:

- Accelerating Indigenous Nuclear Technologies - Deployment of Advanced Heavy Water Reactors (AHWRs) and Small Modular Reactors (SMRs) for decentralized energy production.
- Strengthening Nuclear Safety Regulations - Enhanced Nuclear Safety Regulatory Authority (NSRA) oversight for plant safety and waste disposal.
- Expanding International Cooperation - Partnerships with the USA, Russia, France, and Japan to enhance technological capabilities and secure uranium fuel supplies.

As India continues expanding its nuclear energy program, a balanced approach incorporating legal, environmental, and technological safeguards will be crucial in ensuring a sustainable and cleaner energy future.

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Opportunities in Nuclear Energy Development

For India's long-term energy security, economic expansion, and sustainable development, nuclear energy offers a huge opportunity.[26] Nuclear power appears as a feasible option as the nation seeks to fulfil its growing electrical consumption while making the shift to cleaner energy. The main prospects that nuclear energy development presents in India are outlined in the following sections.

Contribution to Energy Security and Reliability

India's increasing energy demands necessitate the requirement of having a diverse energy portfolio. In contrast to solar and wind energy, which are influenced by weather fluctuations, nuclear energy offers a steady, dependable, and uninterrupted power source. Nuclear power plants can provide electricity round the clock with a capacity factor of more than 80%, which lessens reliance on imported fossil fuels and improves energy security.

Moreover, India has substantial thorium reserves, estimated at 846,477 tonnes,[27] which, if properly exploited through the three-stage nuclear program, could maintain its long-term energy independence.

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[23] *A decade on, Kudankulam nuclear plant protesters say still face ordeal*. (2022, June 6). Hindustan Times. https://www.hindustantimes.com/india-news/a-decade-on-kudankulam-nuclear-plant-protesters-say-still-face-ordeal-101654455406226.html

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Climate Change Mitigation and Decarbonization

Nuclear power is a low-carbon energy source that has the potential to support the renewable energy initiatives as India strives to achieve net-zero carbon emissions by 2070.Nuclear energy emits negligible greenhouse gases in contrast to coal-based thermal power. According to the Intergovernmental Panel on Climate Change (IPCC, 2022), nuclear power produces less than 15 gCO_2 per kWh, comparable to wind and hydroelectric power but significantly lower than coal-fired plants (~820 gCO_2 per kWh).[28] By increasing the nuclear power production, India will be able to lower its carbon footprint, meet the goals of the Paris Agreement, and contribute to the fight against climate change worldwide.

Economic and Industrial Development

Investing in nuclear energy infrastructure yields substantial financial gains, such as:

- **Job Creation**: According to the Ministry of Power, thousands of direct and indirect jobs in the supply chain, operations, and construction sectors will be generated by the massive nuclear projects such as the Jaitapur Nuclear Power Plant (9,900 MW).[29]
- **Support for Domestic Manufacturing**: The make in India campaign contributes in lessening reliance on imported technology by promoting domestic production of nuclear components.
- **Technology Transfer and Innovation**: The research and industrial capabilities in India are benefitted by partnerships with international leaders like France (EDF), Russia (Rosatom), and the United States (Westinghouse), which enable the transfer of cutting-edge nuclear technologies.[30]

Advancement of Indigenous Nuclear Technology

To solidify its position as a global leader in nuclear energy, significant strides are being made by India in the development of indigenous nuclear technologies. Among the significant developments are:

- Pressurized Heavy Water Reactors (PHWRs) - Achieving a significant milestone in self-reliance, India has successfully developed 700 MW PHWRs at Kakrapar Atomic Power Station (KAPP-3 and KAPP-4).
- Fast Breeder Reactors (FBRs) - To reduce the dependency on uranium, the upcoming prototype Fast Breeder Reactor at Kalpakkam will use thorium and plutonium fuel cycles.
- Small Modular Reactors (SMRs) - India is investigating the deployment of SMRs, which provide flexibility in distributed energy generation and need less capital expenditure.

These technological advancements put India in a position to become a potential global exporter of nuclear technology in the future.

Strengthening Energy Infrastructure in Rural India

One of the most significant challenges India has faced is providing access to energy in rural and remote areas. Nuclear power, particularly Small Modular Reactors (SMRs) and thorium-based reactors, is a scalable source of stable electricity for underserved regions.

Potential benefits include:

- Reduced reliance on diesel generators, which are expensive and polluting.
- Rural electrification, support to industries, healthcare, and education.
- Improving energy equity, bridging the urban-rural electricity divide.
- Decentralized nuclear energy can help improve access to energy and quality of life for millions of Indians.

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International Cooperation and Diplomacy Strengthened

India's nuclear energy expansion is developing strategic international cooperation, thereby enhancing diplomatic relations as well as technological development. The most significant agreements are as follows:

- Indo-U.S. Civil Nuclear Agreement (2008) – Facilitated India's access to global nuclear technology and fuel markets.
- India's Membership in the International Atomic Energy Agency (IAEA) – Strengthened nuclear safety protocols and regulatory compliance.
- Collaborations with France, Russia, and Japan—Facilitated technology exchange and funding for projects like the Jaitapur and Kudankulam.

These collaborations not only aid India's nuclear ambitions but also boost its geopolitical status as a responsible nuclear power.

Nuclear Hydrogen Production Potential

Hydrogen production by utilizing nuclear reactors: This is another emerging area of opportunity. Clean hydrogen will be produced from electrolysis or thermochemical cycles using High temperature gas-cooled reactors (HTGRs) and advanced PHWRs for India's National Hydrogen Mission.[31]

Key applications:

- Hydrogen-based steel production reduces industrial emissions.
- Fuel for transportation replacing fossil fuels in heavy industries.
- Grid storage solutions, enhancing renewable energy integration.

This integration of nuclear energy with the hydrogen economy could accelerate India's clean energy transition.

Long-Term Sustainability Through Thorium Utilization

India has the world's largest thorium reserves, which can be a sustainable source of nuclear fuel in the long term. Thorium is:

- Abundant and widely available in India's monazite sands.
- More efficient, generating less nuclear waste.
- Proliferation-resistant, reducing security risks.

India intends to achieve thorium-based energy self-sufficiency through its three-stage nuclear program, thereby ensuring long-term sustainability and energy independence.

Nuclear energy holds tremendous potential for India, offering both energy security and economic growth in addition to playing a vital role in the battle against climate change and fostering technological advancement. This will require much more robust regulation, greater public awareness, and strategic investments when the country aims to move to net-zero emissions.

Challenges in Scaling Nuclear Energy

Although nuclear energy promises to be clean and sustainable power, its scaling in India faces significant challenges. These challenges are regulatory, financial, technological, environmental, and socio-political in nature, which need to be addressed to ensure the long-term viability of nuclear energy in India's energy transition.

High Costs and Financial Constraints

High upfront capital cost. The cost to build large nuclear facilities runs into billions of dollars, and finance is one of the significant challenges. For example, the Jaitapur Nuclear Power Plant, planned to be the largest in the world, will cost $30 billion.[32]

[31] Government of India. (2022). *National Hydrogen Mission: Green energy roadmap*. Retrieved from https://www.india.gov.in

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Some key financial challenges:

- Long gestation periods – Nuclear projects generally take 10–15 years from planning to operation, delaying financial returns.
- High decommissioning costs – The shutdown of old reactors calls for massive finances and infrastructure.
- Limited private sector participation – Atomic Energy Act, 1962, bars foreign and private investments in nuclear power, thus causing financial barriers.[33]
- Possible solutions comprise public-private partnerships (PPPs), sovereign green bonds, and foreign investment incentives to ease the financial burden of the government.

Regulatory and Legal Hurdles

The Indian nuclear sector follows strict regulatory and legal frameworks aimed at safety and security. In this regard, bureaucratic delays and complex approval procedures, along with policy uncertainties, hinder the speedy execution of nuclear projects.

Some of the key regulatory issues are:

- Civil Liability for Nuclear Damage Act, 2010 (CLND Act) – Imposes liability on suppliers, discouraging foreign investment in nuclear technology.[34]
- Lengthy environmental clearance processes – Nuclear projects require rigorous environmental and safety assessments, delaying approvals.
- Land acquisition issues – Acquiring land for newNuclear power projects(NPPs) often faces legal and political opposition, leading to project delays.

To overcome these regulatory hurdles, India requires policy reforms, streamlined approval processes, and clear liability frameworks to attract foreign investment and speed up nuclear expansion.

Public Perception and Opposition to Nuclear Energy

Nuclear energy is met with strong public opposition, largely based on safety fears and myths. The two high-profile accidents in Chernobyl (1986) and Fukushima (2011) have only increased the public's fears over the risks posed by nuclear power.[35]

The following are the key public concerns:

- Radiation risks and safety – Fears over possible nuclear accidents and radioactive contamination.
- Waste disposal concerns – Long-term storage and handling of nuclear wastes.
- Displacement of local communities – Public objections from indigenous and rural communities who might be displaced by NPP constructions.

Developing confidence among the public requires open communication, involvement of the community, and robust safety procedures for the successful development of nuclear power.

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Nuclear Waste Management and Disposal

Nuclear waste disposal is one of the critical challenges for the expansion of nuclear energy. Though nuclear power produces very little waste compared to coal, high-level radioactive waste (HLW) needs secure long-term storage facilities.

Main issues are as follows:

- Permanent disposal sites – India is currently using interim storage facilities rather than deep geological repositories.
- Radioactive contamination risks – Improper disposal can pose serious environmental and health risks.
- High treatment cost of waste – Advanced technologies for waste management involve highly expensive capital.
- Advanced reprocessing technologies, deep geological storage solutions, and international best practices are needed to safely and sustainably dispose of nuclear waste in India.

Uranium availabilities highly limited, and associated with fuel supply risks:

India does not have significant indigenous uranium reserves and needs to import nuclear fuel from other countries.[36] Even with thorium, commercial utilization is still under development. Numerous challenges in nuclear fuel supply are prevalent, such as dependence on imports from other countries, such as Kazakhstan, Canada, and Russia, geopolitical risk influencing nuclear fuel availability. Additionally, thorium-based reactors have been slow, limiting self-sufficiency. India must expand domestic uranium mining, accelerate thorium reactor development, and diversify its international fuel supply partnerships to overcome fuel supply constraints.

Environmental and Ecological Concerns

While nuclear power is a low-carbon energy source, it has some environmental risks. The construction and operation of NPPs can affect local ecosystems, water resources, and biodiversity.

Some of the key environmental concerns are:

- Water-intensive cooling systems – Nuclear reactors consume vast amounts of water to cool, putting potential pressure on local water resources.
- Thermal pollution – Warm water released from the reactors can confuse aquatic life.
- The possibility of radioactive leaks – Even though this is a rare phenomenon, it may have significant environmental impacts.

Making use of new reactor designs, closed-loop cooling, and high-level environmental monitoring will certainly help reduce the ecological impact of nuclear power.

Geopolitical and Strategic Risks

Nuclear energy development is closely linked to international geopolitics and security concerns. India's expansion of nuclear power is influenced by global non-proliferation treaties, strategic alliances, and regional security dynamics.

Key geopolitical challenges include:

- Restrictions from the Nuclear Suppliers Group (NSG) – India is not a signatory to the Nuclear Non-Proliferation Treaty (NPT), limiting its access to certain nuclear technologies.[37]

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- Geopolitical tensions with neighbouring countries – Challenges from China and Pakistan have brought security concerns on nuclear facilities
- Cyber-attacks – Nuclear Power infrastructure faces mounting threats of cyber attacks

India needs to expand international partnerships, nuclear security steps, and bilateral diplomacy to ensure it tackles all these geopolitical adversities.

Technical and Infrastructure Challenges

Induction of the nuclear power era demands a sufficient technical workforce along with sophisticated research capabilities and state-of-the-art infrastructure development. India has an issue with:

- Limited skilled workforce: There are trained nuclear engineers and scientists, a shortage in them.
- Old grid infrastructure: There is the existing power grid which needs up-gradation in the integration of increased nuclear energy.
- Slow penetration of next generation of reactors: Small modular reactors (SMRs), advanced nuclear technologies and Fusion Reactors are at very early stages of development

These barriers need investments in education for nuclear and R&D besides smart grid technologies.

The Path Forward: A Balanced Approach

The expansion of nuclear energy in India is of paramount importance toward achieving energy security, reducing carbon emissions, and supporting economic growth. However, realizing its potential requires a holistic and balanced strategic approach to manage regulatory, financial, technological, environmental, and social challenges in the process of nuclear energy deployment. A meaningful path forward toward a sustainable, resilient nuclear energy sector would rely on policy reform, technological innovation, international cooperation, and social engagement.

Strengthening Policy and Regulatory Frameworks

Nuclear energy will scale only if there are reforms in policy and regulation that simplify project clearances, bring investments to the industry, and reassure safety in nuclear operations. Such areas for reform are:

Reforms in the Civil Liability for Nuclear Damage Act, 2010

The CLND Act places liability on nuclear suppliers, thus discouraging private and foreign investment in nuclear projects. A balanced liability framework that is aligned with international norms, such as the Convention on Supplementary Compensation for Nuclear Damage (CSC), could attract more global partners.

Fast-tracking Environmental and Land Acquisition Approvals

Long EIAs and land acquisition processes delay nuclear projects. Introducing a time-bound clearance mechanism, backed by independent environmental watchdogs, can facilitate responsible and efficient decision-making.

Public-Private Partnerships in Nuclear Energy

Given the state dominance in India's nuclear sector, legal reforms opening private sector involvement would help push the nuclear frontier. Foreign direct investment (FDI) into nuclear energy would increase the viability of financial returns and technical efficiency.

Strengthening Fuel Security and Sustainable Waste Management

Nuclear fuel supply and radioactive waste disposal continue to be issues that have significant implications for sustainable nuclear energy development.

Diversifying Uranium Supply Chains

Since India does not have a significant domestic uranium reserve, securing long-term international uranium supply agreements is critical. Strengthening strategic ties with Kazakhstan, Canada, Russia, and Australia will reduce dependence on a single supplier.

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Fast-Tracking Thorium Reactor Development
Thorium-based reactors can ensure long-term fuel sustainability. India should fast-track projects like the Prototype Fast Breeder Reactor (PFBR) at Kalpakkam, which aims to use thorium efficiently.

Permanent Nuclear Waste Disposal Facilities:
It is time for India, which is still storing nuclear waste in temporary facilities, to invest in deep geological repositories (DGRs), like Finland's Onkalo DGR, for long-term waste management purposes.

International Cooperation
Nuclear technology is global, and India needs international cooperation for nuclear development.

International Frameworks:
India needs to expand participation globally in all these frameworks of the international nuclear framework.India needs to boost its cooperation with the International Atomic Energy Agency (IAEA), Nuclear Suppliers Group (NSG) and Convention on Nuclear Safety (CNS) in quest for more developed nuclear technologies and best practices (IAEA, 2023).

Supporting Strategic Collaborations with Nuclear Pioneers
Cooperation with countries including France, Russia, and the U.S. through the agreement such as the Indo-US Civil Nuclear Agreement in 2008 will enable technology transfer and expertise sharing besides collaborative research activities.

Engaging Public Audience and Overcoming Perceptions
Public acceptance towards nuclear power mainly hinges on an erroneous safety opinion or hearsay; public apathy toward such concerns should thus be resolved using information.

Enhancing Public Education Activities
Governments and industries should take the initiative of conducting public enlightenment programs on the safety of nuclear energy, radiation dangers, and clean energy benefits. Lessons have been learned from France and Canada, where nuclear energy has seen a higher trust level in public due to aggressive communication strategies employed.

Community Participation in Nuclear Programmes
Engaging local communities in decision-making processes and offering economic incentives (e.g., job creation, infrastructure development, and local investment near nuclear plants) can mitigate public resistance.

Ensuring Transparent Risk Communication
Governments and nuclear operators must provide timely, transparent, and scientifically accurate information about nuclear projects, safety protocols, and emergency preparedness.

Integrating Nuclear Energy with Renewable Energy Sources
Instead of nuclear and renewables as competing energy sources, a hybrid energy model that integrates nuclear with solar, wind, and hydroelectric power can optimize India's energy mix.

Nuclear-Renewable Hybrid Power Grids
Hybrid grids combining nuclear baseload power with solar and wind intermittency management can enhance grid stability and reliability.

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Energy Storage Solutions

Nuclear energy, combined with advanced battery storage technologies and hydrogen production, can provide a continuous source of power with reduced dependence on the grid.

Building India's Nuclear Energy Workforce

A skilled workforce is critical to ensure the safe and efficient growth of nuclear energy.

Expanding Nuclear Engineering and Research Programs

Improving nuclear engineering curricula in top institutions such as IITs, IISc, and BARC training schools can develop a strong pipeline of talent.

Facilitating International Training and Knowledge Exchange

This collaboration would expose Indian scientists and engineers to state-of-the-art nuclear technologies through associations with global nuclear institutions such as MIT, CEA (France), and Rosatom (Russia).

II. CONCLUSION

It becomes imperative for India to look towards nuclear energy as a part of its energy mix, as it holds significant potential towards the accomplishment of its various goals, be it the global commitments of the country or its growing domestic energy demands. Although India's nuclear energy ambitions hold significant potential for addressing energy security, carbon neutrality, and sustainable development goals, it is still essential that a balanced and strategic approach is adopted to navigate the challenges and maximize the opportunities.

There is a need to take various factors into consideration and then make reforms that are not confined only to a particular field but across various sectors that affect India's nuclear energy ambitions. By implementing progressive policy reforms, advancing next-generation reactor technologies, strengthening public trust, and fostering global partnerships, India can establish a robust and sustainable nuclear energy sector. This will not only accelerate the country’s transition toward clean energy but also position India as a global leader in nuclear innovation and sustainable development.