India's Role in ITER: Advancing Science Diplomacy and Atomic Energy Leadership

Punit Kumar
Department of Physics, University of Lucknow, India
E-mail: kumar_punit@lkouniv.ac.in

Introduction

India's participation in the International Thermonuclear Experimental Reactor (ITER) project underscores its commitment to advancing nuclear fusion technology and fostering global scientific collaboration. ITER is a landmark international effort to replicate the Sun's fusion process, aiming to produce limitless, clean energy. As a key partner, India contributes critical components, including cryostat manufacturing, diagnostics, and superconducting magnets, showcasing its engineering expertise. The involvement of the Institute for Plasma Research (IPR), Gandhinagar, and Indian industries strengthens the nation's technological capabilities and scientific diplomacy. The success of ITER could revolutionise the energy sector, providing a carbon-free alternative to fossil fuels. By investing in fusion technology, India positions itself at the forefront of future energy innovation, reinforcing its commitment to clean energy and international cooperation.



Flags of participating nations at the ITER site (Source: ITER)

ITER, located in Cadarache, France, is a scientific collaboration involving India, the European Union, the United States, Russia, China, Japan, and South Korea. This project seeks to demonstrate the feasibility of nuclear fusion as a sustainable, large-scale, and carbon-free energy source. Unlike conventional nuclear fission, which splits atoms and generates long-lived radioactive waste, fusion merges atomic nuclei, releasing immense energy with minimal radioactive byproducts, making it a cleaner alternative for future energy production.

ITER aims to generate 500 megawatts (MW) of power from an initial input of 50 MW, proving that fusion can be a net energy-positive process. Achieving this milestone would mark a significant breakthrough in energy science, bringing the world closer to harnessing fusion as a viable power source. If successful, ITER will lay the foundation for the development of commercial fusion reactors, which could revolutionise the global energy landscape by providing a nearly inexhaustible and environmentally friendly alternative to fossil fuels.



Indian Prime Minister and French President at the ITER site (Source: ITER)

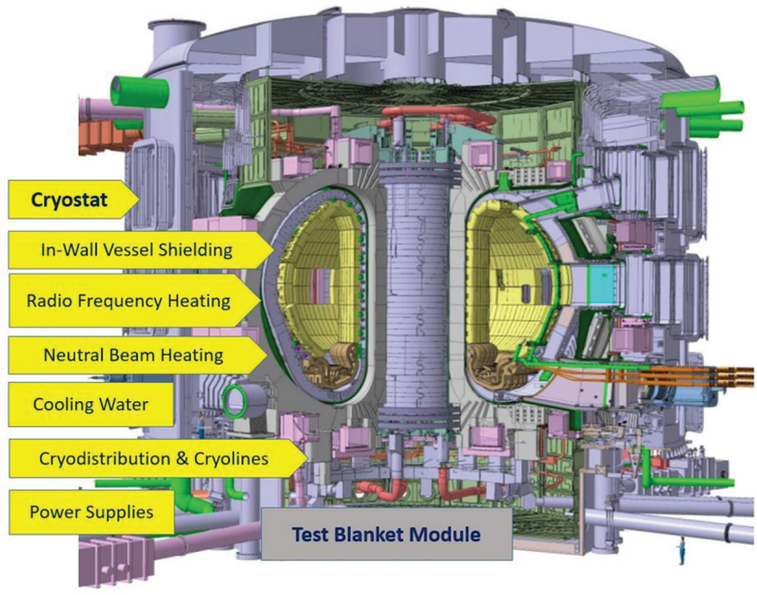
In a landmark moment for both diplomacy and science, Indian Prime Minister Narendra Modi and French President Emmanuel Macron visited the ITER facility on 12 February 2025. This historic occasion marked the first ever visit by both leaders to the world's largest and most ambitious nuclear fusion initiative, an endeavour that holds the potential to transform the global pursuit of clean and sustainable energy.

India's Technological Contributions to ITER

India officially joined ITER in 2005, committing 9.1% of the total project cost through both financial and in-kind contributions. The IPR serves as the India's nodal agency.

Among India's most significant contributions is designing and fabricating the world's largest cryostat, a massive 3,800-ton stainless steel structure. This crucial component provides structural integrity and thermal insulation to the ITER, ensuring the extreme conditions required for nuclear fusion. Additionally, India has supplied essential cooling and cryogenic systems, including cryolines and a cryodistribution system. These help maintain the superconducting magnets at ultra-low temperatures, ensuring the stability of the powerful magnetic fields needed to confine the plasma.

India also plays a key role in providing high-power electrical systems, such as radio-frequency heating sources and steady-state power supplies, essential for sustaining the fusion reaction. Further, Indian scientists have developed sophisticated diagnostic tools to monitor plasma conditions within

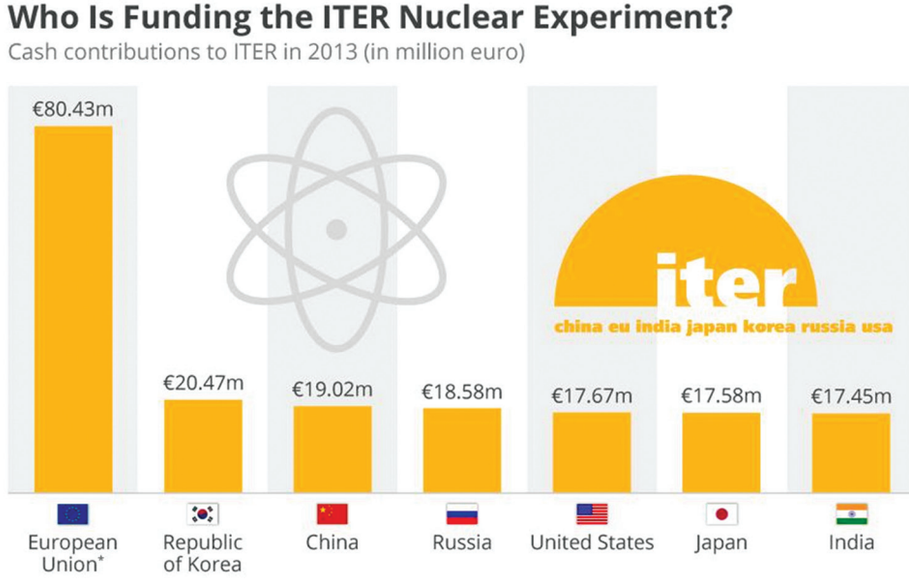


ITER – Indian Contribution (Source: ITER India)

the machine, contributing to precise measurements and control of the fusion process. Alongside this, India is actively researching advanced plasma-facing materials capable of withstanding the extreme environments within the reactor. These technological contributions reinforce India's expertise in fusion research and strengthen its position as a crucial player in international scientific collaborations aimed at achieving sustainable energy solutions.

India's Science Diplomacy through ITER

India's participation in the ITER project strengthens its scientific diplomacy by deepening global research partnerships and advancing its clean energy goals. By engaging in this prestigious mega-science initiative, India not only reinforces its research and technological capabilities but also enhances its role in global scientific policymaking. More significantly, India's active involvement in ITER exemplifies its approach



Economic footprint of the ITER project (Source: ITER)

to atomic energy diplomacy, wherein the country leverages nuclear science and technology as a tool for global engagement, energy security, and geopolitical influence.

International Collaboration

One of the primary benefits of India's participation in ITER is the opportunity to collaborate with leading scientific and technological institutions worldwide. This partnership allows Indian researchers, engineers, and industries to engage with cutting-edge nuclear fusion research, positioning India at the forefront of next-generation energy technologies. The collaboration fosters the exchange of expertise between Indian scientists and their international counterparts, accelerating India's learning curve in advanced fusion technology. The knowledge gained through ITER not only enhances India's standing in global science and technology but also has far-reaching implications for its domestic nuclear energy programs. India's participation enables it to acquire crucial insights into the complexities of fusion technology, which could be instrumental in developing its indigenous fusion reactors.

Additionally, ITER serves as a valuable platform for Indian industries to integrate into the global supply chain of precision-engineered nuclear components, paving the way for international collaborations that extend beyond the realm of fusion energy. The successful involvement of Indian firms in designing, manufacturing, and assembling ITER's sophisticated systems highlights the nation's expanding capabilities in advanced nuclear engineering. These achievements enhance India's credibility as a technological collaborator in major scientific ventures. Notably, Larsen & Toubro (L&T) has played a key role in fabricating the world's largest cryostat, an essential structure that sustains the reactor's extremely low temperatures. In addition, leading Indian IT firms such as Tata Consultancy Services (TCS) and HCL Technologies have significantly contributed to developing cutting-edge control systems that help ensure ITER's operational stability and efficiency.

Atomic Energy Diplomacy

ITER provides India a strategic platform to participate in shaping global energy policies and technological frameworks. Since its nuclear program's inception, India has faced geopolitical challenges, including nuclear technology denial regimes that restricted access to advanced nuclear materials and expertise. Despite these constraints, India pursued a self-reliant nuclear energy program, achieving remarkable success in both fission and fusion research. ITER provides India with a unique opportunity to engage with the global nuclear community on equal footing, reinforcing its position as a responsible nuclear power committed to the peaceful applications of atomic energy.

Participation in ITER also enhances India's influence in global scientific policymaking. As one of the seven major partners in this multi-billion-dollar project, India has a seat at the table in shaping the future of nuclear fusion research and energy policies. This strategic positioning allows India to advocate for global energy policies that align with its long-term interests, particularly in sustainable energy development, climate change mitigation, and equitable access to advanced nuclear technologies.

India's engagement in ITER strengthens diplomatic ties with key global powers, reinforcing its broader foreign policy objectives. The project serves as a bridge for scientific cooperation between India and countries such as the United States, Russia, and the European Union, fostering trust and collaboration beyond nuclear energy. Given the growing importance of science and technology in global diplomacy, India's involvement in ITER underscores its commitment to using scientific advancements to strengthen international relations.

Domestic Front

India's contributions to ITER are shaping its domestic nuclear landscape. The cooperation also provides valuable training opportunities for Indian scientists and engineers, ensuring the country builds a skilled workforce capable of handling future fusion projects. By engaging in cutting-edge research, Indian universities and research institutions are now more equipped to contribute to the global knowledge pool on fusion energy.

Additionally, India's work on ITER complements its long-term vision of developing its own experimental fusion reactor, which aims to be a stepping stone toward an indigenous demonstration fusion power plant. The experience gained through ITER will significantly accelerate India's progress toward self-sufficiency in fusion energy research.

Secure Tomorrow

Given its rapidly growing population and increasing energy demands, energy security is a critical aspect of India's long-term development strategy. While India has made significant strides in renewable energy, including solar and wind power, these sources alone may not meet its future energy needs. Nuclear fusion presents a promising alternative, offering a nearly limitless, carbon-free energy source with minimal environmental impact.

By investing in ITER, India is preparing for a future where fusion energy could become a commercial reality. If ITER successfully demonstrates that nuclear fusion can be a net energy-positive process, it will pave the way for the development of commercial fusion power plants. Such a breakthrough would drastically reduce dependence on fossil fuels, helping India achieve its climate commitments while ensuring a stable and sustainable energy supply.

Fusion energy aligns with India's goal of reducing greenhouse gas emissions and combating climate change. Unlike conventional nuclear fission, fusion does not produce long-lived radioactive waste, making it a safer and cleaner energy alternative. By actively participating in ITER, India is positioning itself as a leader in green energy solutions, reinforcing its commitment to a sustainable and environmentally responsible future.

Conclusion

India's involvement in ITER serves as a model for how scientific collaboration can be leveraged as a tool for diplomacy, technological advancement, and energy security. Through its contributions to this groundbreaking project, India has demonstrated its ability to lead in high-end nuclear research while fostering international partnerships. At the same time, India's participation in ITER is a reflection of its broader strategy of atomic energy diplomacy, where scientific cooperation is used to enhance global influence, build strategic alliances, and drive technological progress. As the world moves closer to unlocking the potential of nuclear fusion, India's role in ITER will continue to shape the future of energy, innovation, and international cooperation. By investing in fusion technology today, India is securing its energy future and reinforcing its position as a responsible and forward-thinking global power. The lessons learned from ITER will not only benefit India's nuclear research programs but will also contribute to the collective global effort to develop a cleaner, more sustainable energy source for future generations.

Resources

1. ITER Official Website – https://www.iter.org/
2. ITER-India Website - https://www.iterindia.in/
3. Wikipedia - https://en.wikipedia.org/wiki/ITER

4. Rebut PH (1995) ITER: the first experimental fusion reactor. Fusion Engineering and Design, 30(1-2): 85–118. https://doi.org/10.1016/0920-3796(94)00403-T
5. Aberg A (2021) The ways and means of ITER: reciprocity and compromise in fusion science diplomacy. History and Technology, 37(1): 106–124. https://doi.org/10.1080/07341512.2021.1891851
6. Geng S (2022) An Overview of the ITER project. Journal of Physics: Conference Series, 2386: 012012. https://doi.org/10.1088/1742-6596/2386/1/012012
7. How India is emerging as a key stakeholder in the future energy economy. India News Network, 13.02.2025.