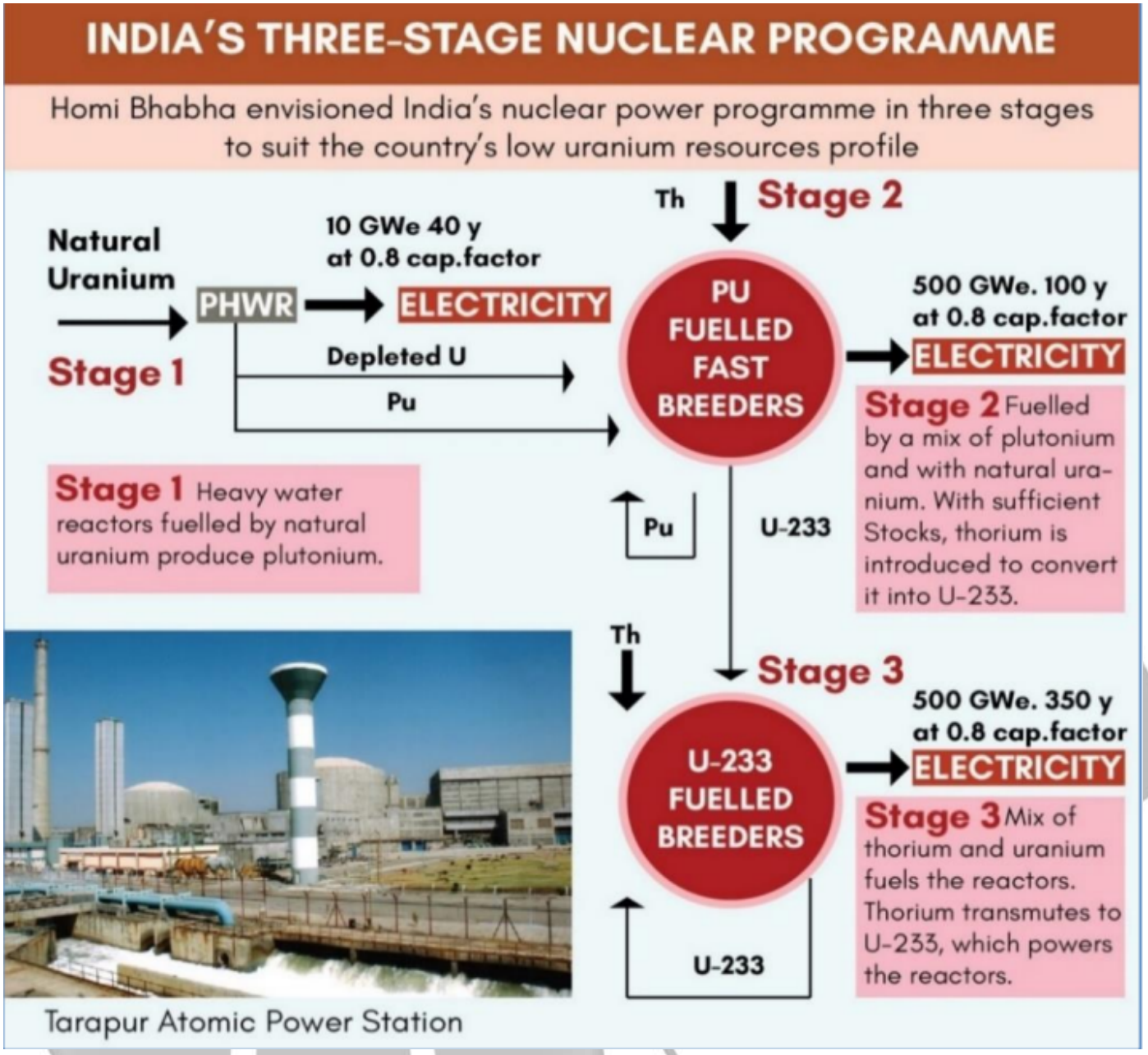
India’s Nuclear Energy Roadmap

This editorial is based on “India’s long pursuit of nuclear power” which was published in Hindustan Times on 15/04/2025. The article brings into picture the gap between India’s nuclear energy ambitions and actual progress, highlighting the need for private participation and innovation to achieve the 100,000 MW target by 2047.

For Prelims: India's nuclear journey, Bharat Small Reactors, Small Modular Reactors, Prototype Fast Breeder Reactor, International Atomic Energy Agency,2005 US-India Civil Nuclear Agreement.

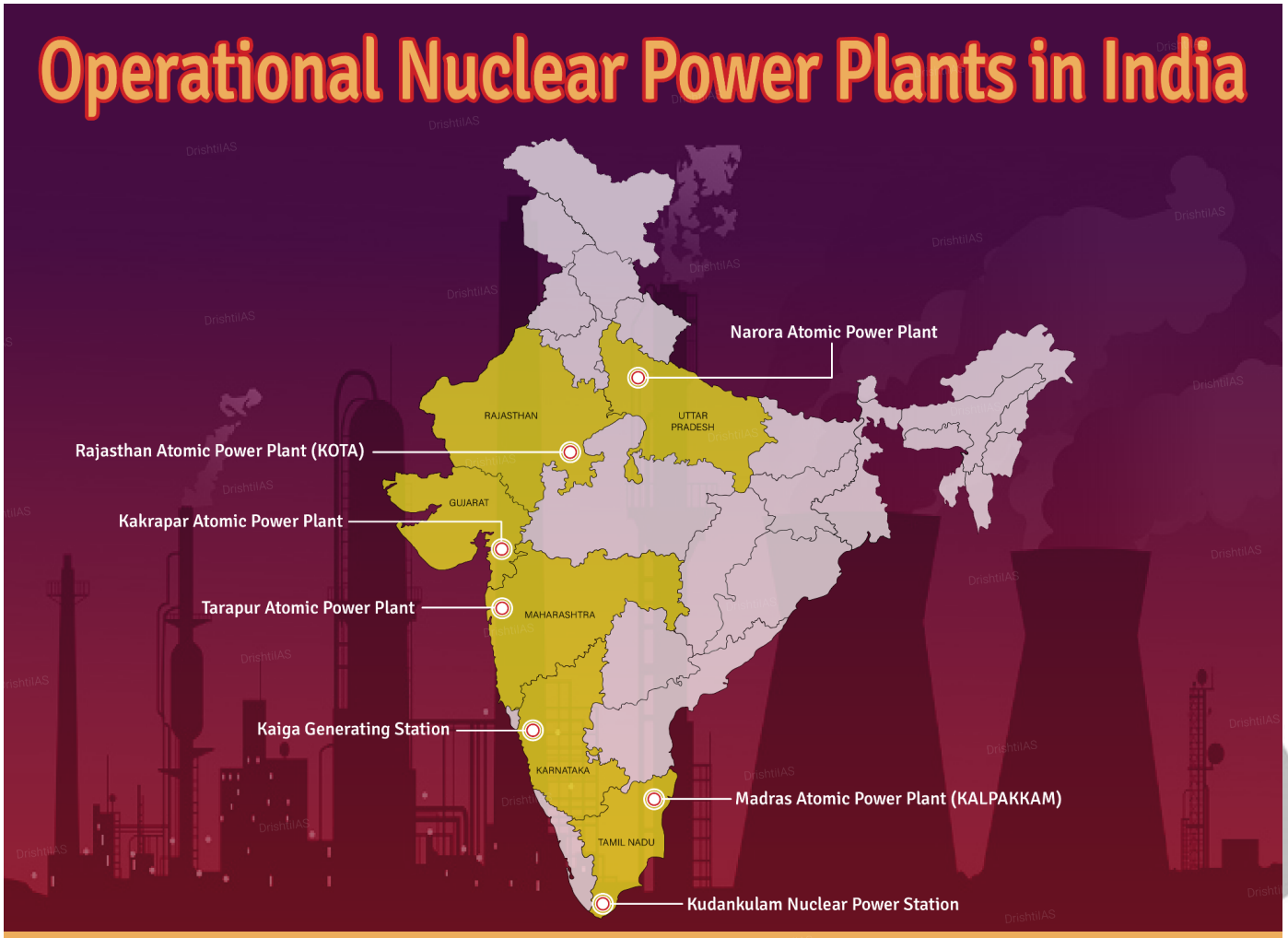
For Mains: Role of Nuclear Energy in Advancing India’s Energy Transition and Driving Economic Growth, Key Issues Associated with India's Nuclear Energy Sector.

India's nuclear journey reflects both ambition and challenge, with the **recent FY26 Union Budget** targeting **100,000 MW of nuclear capacity by 2047**—crucial for both industrial growth and net-zero emissions by 2070. Despite **Homi Bhabha's visionary three-stage plan from 1954,** actual achievements have consistently fallen short of declared targets, with current capacity a**t only 8,180 MW.** India needs to intensify efforts in this regard through **greater private sector participation, technological innovation, and focused implementation** to meet its growing electricity demands and achieve energy security.



What is the Role of Nuclear Energy in Advancing India's Energy Transition and Driving Economic Growth?

- **Reducing Fossil Fuel Dependency and Achieving Net-Zero Goals:** Nuclear energy plays a pivotal role in India's strategy to reduce dependency on fossil fuels and meet its **net-zero emissions target by 2070.**
  - With the ambitious target of **100,000 MW** of nuclear capacity by **2047**, nuclear power is poised to be a cornerstone in the country's clean energy transition.
  - For instance, India's nuclear power capacity is set to grow from **8,180 MW** to **22,480 MW** by **2031-32**.
- **Catalyst for Energy Security and Stable Supply:** Nuclear energy is integral to ensuring **energy security** by providing a stable, uninterrupted power supply.
  - Unlike renewable sources like **wind and solar,** which are intermittent, nuclear plants can operate **24/7**, ensuring a consistent energy output.
  - As India's electricity demand grows at **6-8%** annually, nuclear power helps stabilize the grid. The government plans to add **18 reactors** by **2031-32**, underscoring nuclear energy's critical role in maintaining a **stable power supply** amid rising demand.



- **Economic Growth Through Industrial Decarbonization:** Nuclear energy contributes significantly to **economic growth** by enabling decarbonization in energy-intensive industries like **steel, aluminium, and cement.**
  - By providing reliable **captive power** through technologies like **Bharat Small Reactors (BSRs)**, nuclear energy supports industrial sectors in meeting carbon reduction targets.
  - The **private sector participation** in BSR projects further bolsters this, with the **government allocating ₹20,000 crore for Small Modular Reactors (SMRs)** to diversify and modernize energy infrastructure by **2033**.
- **Enhancing Technological Innovation and R&D:** Nuclear energy drives **technological innovation** and research, particularly through advancements in **Fast Breeder Reactors (FBRs)**.
  - These technologies not only improve nuclear efficiency but also align with India's **long-term energy strategy** to reduce reliance on uranium.
  - The **Prototype Fast Breeder Reactor (PFBR)**, which reached **core loading** in **2024**, exemplifies India's progress toward developing **thorium-based nuclear power**.
- **Strategic International Partnerships and Energy Diplomacy:** Nuclear energy enhances India's **energy diplomacy** by fostering international collaborations.
  - The **2005 US-India Civil Nuclear Agreement** opened access to **global uranium**

markets, helping India secure uranium supplies crucial for its growing nuclear fleet.
    - **India and France** have agreed to collaborate on developing next-generation nuclear reactors, including advanced modular reactors and small modular reactors
- **Job Creation and Skill Development:** Nuclear energy plays a significant role in **job creation** and **skill development**, which are crucial for India's **economic growth**.
    - The expansion of nuclear power plants generates employment opportunities in **construction, operations, maintenance**, and technology development.
    - Nuclear power creates about **25% more employment per unit of electricity** than wind power, while workers in the nuclear industry earn one third more than other renewable sectors. **(International Atomic Energy Agency)**
        - This aligns with India's broader goal of enhancing its **industrial workforce** to meet future energy demands.
- **Supporting Decentralized Energy Generation in Remote Areas:** Nuclear energy provides a viable solution for **decentralized power generation**, especially in **remote and off-grid areas**.
    - Small Modular Reactors (SMRs) are ideal for such locations due to their **modular design**, which allows for factory-based manufacturing and shorter construction timelines.
    - The **Bharat Small Reactors (BSRs)**, designed to be deployed near industrial clusters, will not only serve these areas but also promote **sustainable local energy economies**.

What is the Current Status of Nuclear Energy Around the Globe?

- **About**: Nuclear energy, developed for power generation since the 1950s, currently contributes **around 9% of global electricity** and is the **second-largest source of low-carbon power**, supplying about a **quarter of the world's low-carbon electricity**. It is central to achieving clean energy goals and sustainable development.
- **Key Stats:**
    - **440 operational reactors** globally, producing **2602 TWh** in 2023
    - **14 countries** produce over **25% of their electricity from nuclear (France ~70%).**
    - **Top producers**: **USA** (779.2 TWh), **China** (406.5 TWh), **France** (323.8 TWh).
    - **Reactor construction in 2025**: **Lufeng 1** (China), **Leningrad 2-4** (Russia).
    - **Shutdowns**: **Doel 1 (Belgium).**
    - **Emerging nuclear nations: Bangladesh, Turkey** (first plants under construction).

What are the Key Issues Associated with India's Nuclear Power Sector?

- **Slow Pace of Project Implementation:** While India aims to ramp up its nuclear capacity significantly, projects have experienced significant delays.
    - The **Prototype Fast Breeder Reactor (PFBR)**, which began construction in **2004**, only achieved **core loading** in **2024**, and **commercial operations** are still far off.
    - This delay may hinder the timely realization of **India's nuclear goals**, such as the target of **100,000 MW** by **2047**, highlighting inefficiencies in project management.
- **Uranium Supply Constraints:** Despite advancements in nuclear technology, **uranium supply constraints** remain a critical challenge.
    - India's uranium production is limited, contributing to only **1-2% of global production.**.
    - The **2005 US-India Civil Nuclear Agreement** has alleviated some pressure by securing access to international uranium markets, but India still faces dependency on **external sources** for fuel, which can lead to geopolitical risks.
        - Also, **reactors utilizing imported uranium must comply with IAEA safeguards** to guarantee that the material is used exclusively for peaceful purposes, which places an additional compliance burden on India.
- **Technological Bottlenecks in Thorium Utilization:** India's ambitious **three-stage nuclear program** hinges on **thorium-based reactors**, but progress in the **second and third stages** remains stunted.
    - The **Fast Breeder Reactors (FBRs)**, essential for transitioning to thorium, have faced

consistent **technological bottlenecks**.
    - Meanwhile, India's **accelerator-driven subcritical system (ADSS)**, proposed in **2003**, has not yet materialized, delaying the shift to thorium.
- **Financial Constraints and Investment Challenges:** The **high capital costs** associated with nuclear power, combined with **financial constraints**, are hindering the sector's growth.
    - Although the **Union Budget 2025-26** allocated **₹20,000 crore** for **Small Modular Reactors (SMRs)**, the nuclear sector still faces challenges in attracting sufficient investment.
    - According to the **CEA (Central Electricity Authority)**, the capital cost of a PHW nuclear power plant in India is about **INR 117 million.**
        - And funding is often insufficient to overcome cost overruns and delays in large-scale nuclear projects.
- **Safety Concerns and Public Perception:** Despite robust safety protocols, the **public perception of nuclear power** remains a significant barrier.
    - Incidents like the **Fukushima disaster** have heightened **global concerns** about nuclear safety, contributing to resistance in some regions.
    - While **radiation levels** in India's plants remain **well below global safety thresholds**, the public remains wary.
    - For example, **Kudankulam's radiation levels** have dropped from **0.081 micro-sieverts in 2014** to **0.002 micro-sieverts**, but this has not entirely alleviated public apprehension over nuclear safety**, complicating land acquisition and community support.**
- **Environmental and Waste Management Issues:** Nuclear waste management continues to be a **challenging issue** for India's nuclear power sector.
    - While India has established systems for handling nuclear waste, including **on-site storage** followed by **long-term storage**, the lack of **centralized waste repositories** remains a concern.
    - India's nuclear plants store waste for **five to seven years** before transferring it to storage facilities, but the long-term management of **spent fuel** is still unresolved.

What Measures can India Adopt to Enhance the Effectiveness and Productivity of the Nuclear Energy Sector?

- **Fast-Tracking Project Approvals and Implementation:** India must **accelerate the approval process** for nuclear projects and streamline **regulatory clearances**.
    - By establishing a **single-window clearance system**, India can reduce delays and improve **project turnaround times**, ensuring that the **100,000 MW target** by **2047** is met without further setbacks.
    - Leveraging **public-private partnerships (PPP)** will inject **capital** and **innovation** into India's nuclear sector.
    - Encouraging **private sector investment** through **amendments to the Atomic Energy Act** will create a conducive environment for **faster reactor deployment**.
- **Enhancing Indigenous Technology and R&D:** Investing heavily in **indigenous nuclear technology** will reduce **reliance on foreign suppliers** and ensure **energy security**.
    - India's progress in **Small Modular Reactors (SMRs)** and **Fast Breeder Reactors (FBRs)** needs to be complemented with **focused R&D** efforts.
    - This will help overcome **technological bottlenecks** and ensure **self-reliance** in nuclear power.
- **Strengthening Uranium Exploration and Supply Chains:** To address the **uranium supply shortage**, India should ramp up **domestic uranium exploration** and expedite **mining projects**.
    - The **recent discovery in Jaduguda Mines** offers an opportunity to boost reserves for **nuclear reactors**.
    - By deepening ties with countries like the **US**, **Russia**, and **France**, India can secure **long-term supply contracts** and benefit from **shared research** on next-generation nuclear technologies.
        - These partnerships will enable faster adoption of **Small Modular Reactors (SMRs)** and accelerate capacity building in the nuclear sector.
- **Focus on Skilled Workforce and Capacity Building:** Investing in **human capital** is crucial for

enhancing the productivity of India's nuclear sector.
    - By expanding **nuclear education** and **training programs**, India can develop a **skilled workforce** capable of operating and maintaining advanced nuclear reactors.
    - Collaboration with global institutes and establishing **nuclear universities** will equip future generations with the expertise needed to manage the evolving demands of the **nuclear energy landscape**.
- **Optimizing Nuclear Waste Management Systems:** India should establish a **centralized nuclear waste management facility** to ensure **sustainable handling** of spent fuel.
    - While on-site storage and **long-term waste disposal** are being practiced, a comprehensive solution for **waste reuse and recycling** is crucial for sustainability.
    - Investments in **advanced reprocessing technologies** will reduce environmental risks and improve **public acceptance** of nuclear energy.

Conclusion:

Nuclear energy is pivotal to India's clean energy transition, energy security, and industrial decarbonization goals. To achieve the 100,000 MW target by 2047 and align with the **Paris Agreement and SDG 7 (Affordable and Clean Energy),** India must overcome project delays and uranium constraints. **Strategic international partnerships and public trust** will be key to unlocking nuclear energy's full potential in India's growth story.

Drishti Mains Question:

Despite being a reliable source of clean energy, nuclear power in India has remained underutilized. Examine the key challenges in the expansion of nuclear energy in India.

UPSC Civil Services Examination, Previous Year Questions (PYQs)

Prelims

Q. In India, why are some nuclear reactors kept under "IAEA safeguards" while others are not? (2020)

(a) Some use uranium and others use thorium

(b) Some use imported uranium and others use domestic supplies

(c) Some are operated by foreign enterprises and others are operated by domestic enterprises

(d) Some are State-owned and others are privately owned

Ans: (b)

Mains

Q. With growing energy needs should India keep on expanding its nuclear energy programme? Discuss the facts and fears associated with nuclear energy. (2018)