Nuclear Energy in India

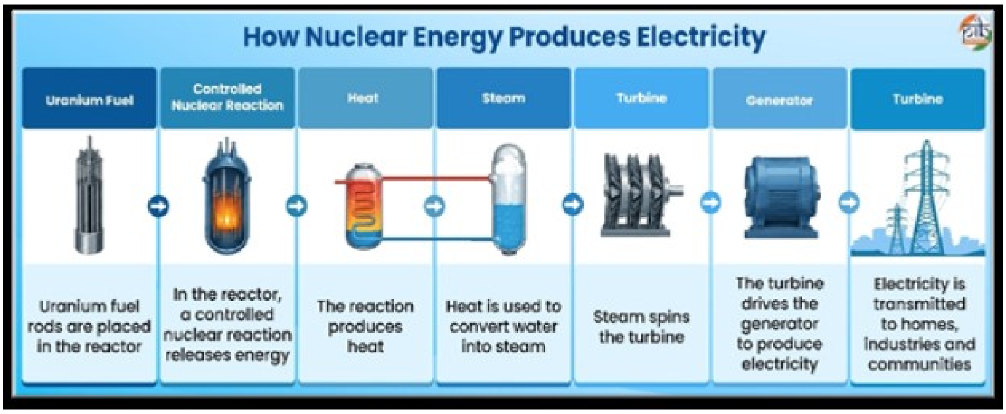
Mains: *GS III – Energy*

Why in News?

India's energy transition faces a unique challenge and nuclear energy has emerged as an important pillar of India's long-term energy strategy.

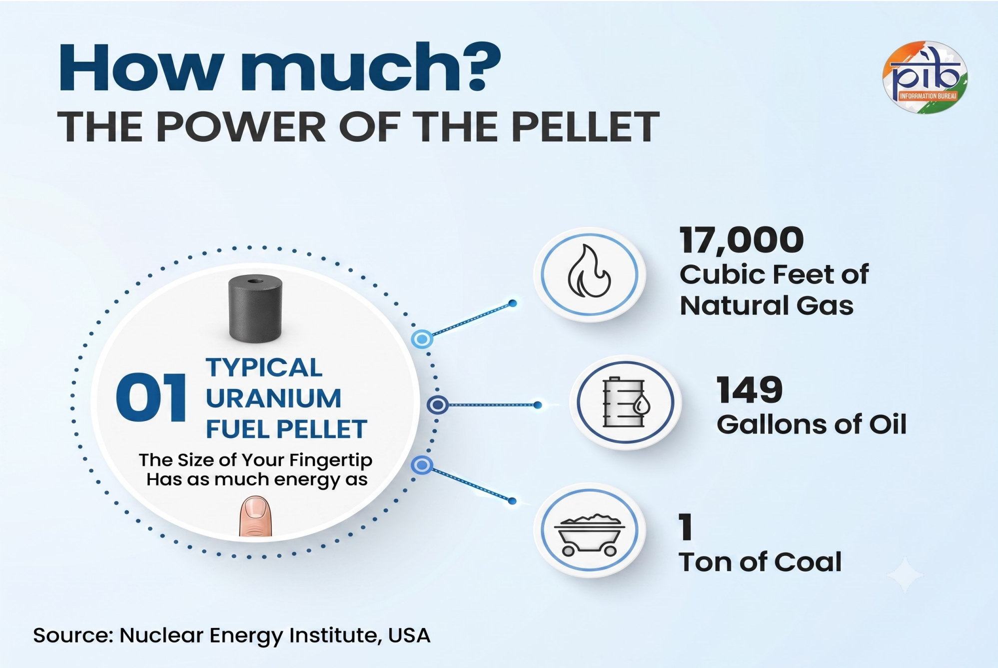
How nuclear power is produced?

- **Process** – Nuclear power plants generate electricity by harnessing heat released through a carefully controlled process called nuclear fission.
- The heat converts water into steam, which drives a turbine connected to a generator.
- The generated electricity powers homes, industries, and essential services. The entire process operates within multiple engineered safety barriers and a robust regulatory framework.



- **Nuclear Fuel –** Nuclear fuel is the material placed inside a nuclear reactor to generate electricity.
- Its atoms split through nuclear fission and release large amounts of heat.
- The heat converts water into steam and the steam drives turbines to generate electricity.
- Nuclear reactor fuels can be **fissile,** which directly sustain the chain reaction or **fertile**, which are first converted into fissile fuels inside the reactor.
- The most common nuclear fuels are **Natural Uranium**, **Uranium-235 (U-235)**, **Low-Enriched Uranium (LEU)**, **Plutonium-239 (Pu-239)**, and **Mixed Oxide (MOX) fuel**.
- Most countries, including the United States, France, China, Japan, South Korea, Canada, and Russia, use **Low-Enriched Uranium (LEU)** in Light Water Reactors.
- India mainly uses **Natural Uranium** in **Pressurised Heavy Water Reactors**

(PHWRs), which do not require uranium enrichment.
- India also uses **MOX fuel** in its **Prototype Fast Breeder Reactor (PFBR)**.
- India's uranium reserves are of low grade and therefore need to be supplemented through imports.
- India, however, has abundant reserves of thorium (Th-232).



- This is a fertile rather than fissile radioactive material, found mainly in the coastal sands of **Kerala, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal and Jharkhand**.
- Inside a reactor, Th-232 absorbs a neutron and transforms into **Uranium-233**, which is fissile.
- India's long-term nuclear strategy is centred on utilising its abundant **thorium reserves**, through its three-stage nuclear power programme.

Why nuclear energy matters for India?

- **Increasing Energy Demand** – India's electricity demand is expected to rise substantially with industrialisation, urbanisation, electrification and the expansion of digital infrastructure.
- **Sustaining Essential Services** – Reliable baseload electricity is essential for hospitals, industries, railways, defence establishments, communication networks and other critical services.
- **Low Carbon Footprint** – Nuclear power is highly carbon-efficient. Every gigawatt of nuclear capacity avoids about 5.4 million tonnes of carbon dioxide equivalent emissions per year.
- **Net-Zero Target** – It helps India cut greenhouse gas emissions and support its long-term climate commitments leading up to 2070.
- **Fossil Fuel Reduction** – Nuclear power lowers India's heavy reliance on imported coal and oil.
- **The Thorium Path** – India follows a unique three-stage nuclear program designed to eventually use its massive domestic **thorium** (a radioactive metallic element used as a

nuclear fuel) reserves for long-term energy independence.

What are the advantages of nuclear power?

- **Low-carbon generation** – Nuclear power produces electricity with very low operational greenhouse-gas emissions.
- **Reliable baseload power** – Nuclear reactors can operate continuously and are not dependent on weather conditions.
- **Energy security** – Nuclear energy can reduce dependence on imported coal, oil and gas.
- **Land efficiency** – Nuclear plants generate large quantities of electricity from relatively compact sites.
- **Industrial development** – Nuclear expansion stimulates domestic manufacturing, engineering, research and high-skilled employment.
- **Grid stability** – Nuclear generation can complement variable renewable energy such as solar and wind.
- Thus, nuclear power should not be viewed as a competitor to renewable energy but as a complementary component of India's diversified clean-energy mix.

What is the present status of nuclear power in India?

- **Installed capacity** – India currently operates **24 nuclear power reactors** with an **installed capacity of 8.78 GW.**
- **Under construction** – Nine reactor units with a combined capacity of 7.5 GW are under construction.
- The Government has also approved 10 indigenous Pressurised Heavy Water Reactors (PHWRs) in fleet mode and initiated pre-project activities for two 500 MW Fast Breeder Reactors.
- **Initiatives** – The country's policy direction has gained further momentum through initiatives such as the **Nuclear Energy Mission** announced in the Union Budget 2025–26 and the **SHANTI Act, 2025.**
- These measures seek to accelerate nuclear capacity addition, encourage indigenous technology and manufacturing, promote innovation and facilitate wider participation in the nuclear sector.
- India has set an ambitious objective of achieving **100 GW** of nuclear **power capacity by 2047**, making nuclear energy an important component of its long-term development strategy.

*More importantly, India's nuclear programme is closely linked with the larger objectives of **Aatmanirbhar Bharat, energy security, technological self-reliance and Viksit Bharat.***

What is India’s three-stage nuclear power programme?

- **Significance** – India's nuclear programme was designed around the country's distinctive resource endowment.
- While its uranium resources are relatively limited, India possesses substantial thorium

reserves.

- The three-stage programme seeks to progressively convert these resources into a sustainable source of nuclear energy.
- **Stage I: Pressurised Heavy Water Reactors** – The first stage uses natural uranium in Pressurised Heavy Water Reactors (PHWRs).
- Heavy water acts as the moderator and coolant, allowing natural uranium to be used without enrichment.
- The reactor produces electricity while the spent fuel contains plutonium. Through reprocessing, this plutonium is recovered for use in the second stage.
- **Stage II: Fast Breeder Reactors** – The second stage involves Fast Breeder Reactors (FBRs).
- These reactors use plutonium-based fuel and are designed to generate electricity while producing additional fissile material.
- The Prototype Fast Breeder Reactor (PFBR) at Kalpakkam, developed with major indigenous technological inputs, **attained first criticality in April 2026**.
- This represents a major milestone in India's progression towards the second stage of its nuclear programme.
- The PFBR was developed under the leadership of the Indira Gandhi Centre for Atomic Research (IGCAR), with extensive participation from Indian industry.
- Nearly 90 per cent of the reactor's equipment and systems were domestically manufactured, demonstrating India's growing capabilities in advanced nuclear technology.
- **Stage III: Thorium-Based Reactors** – The third stage envisages the utilisation of India's abundant thorium-232 resources.
- Thorium is fertile rather than fissile.
- When thorium-232 absorbs a neutron, it can ultimately be converted into uranium-233, a fissile material capable of sustaining a nuclear chain reaction.
- The successful development of the first two stages is therefore critical for establishing the technological foundation for large-scale utilisation of thorium.

Small Modular Reactors – A New Opportunity
• India is also exploring Small Modular Reactors (SMRs) as an emerging nuclear technology. • SMRs generally have a capacity of up to **300 MWe** and are designed to enable modular manufacturing, potentially reducing construction time and improving standardisation. • Under the Nuclear Energy Mission announced in the Union Budget 2025–26, ₹20,000 crore has been allocated for research, design, development and deployment of indigenous SMRs. • India is developing technologies including the 220 MWe Bharat Small Modular Reactor (BSMR-200), the 55 MWe SMR-55, and a High-Temperature Gas-Cooled Reactor aimed at applications such as hydrogen production. • SMRs could have applications beyond conventional grid electricity, including remote-area power supply, replacement of retiring coal plants, industrial process heat and hydrogen production.

What are the challenges ahead?

- **High capital** – Nuclear projects involve high upfront capital costs and long

construction periods.
- Delays can increase project costs significantly.
- **Need for R&D and Manpower** – India needs continued investment in advanced research, skilled manpower and domestic manufacturing capabilities.
- **Waste management** – Radioactive waste management and nuclear safety require sustained public confidence.
- **Availability of Fuel** – Rapid expansion must ensure adequate availability of nuclear fuel and resilient supply chains.
- **Integration of Energy** – Nuclear energy must be integrated with renewable energy, storage technologies and modern transmission infrastructure rather than being pursued in isolation.

What could be done?

- India should adopt a balanced strategy based on nuclear-renewable complementarity.
- Faster deployment of indigenous PHWRs, successful commercialisation of breeder technology, continued research on thorium-based systems and development of SMRs can strengthen the country's nuclear ecosystem.
- Greater investment in R&D, human resources and domestic manufacturing should accompany regulatory reforms.
- At the same time, safety must remain the overriding principle, with robust institutions, transparent risk communication and strong emergency-response mechanisms.

What lies ahead?

- With nuclear capacity targeted to reach **100 GW by 2047**, India has an opportunity to create a resilient low-carbon energy system in which nuclear power provides dependable baseload electricity while renewables drive large-scale clean-energy expansion.
- A combination of indigenous technology, responsible regulation, scientific innovation, environmental stewardship and public trust can enable nuclear energy to become a major pillar of India's journey towards a sustainable, secure and self-reliant Viksit Bharat.

Reference

PIB| India’s Nuclear Energy