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INDIA'S
NUCLEAR LANDSCAPE
2025

AN OVERVIEW OF CURRENT & UPCOMING NUCLEAR ENERGY INFRASTRUCTURE

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What's INSIDE

Introduction

India is progressively growing its nuclear power program for civilian utilization in order to satisfy the need for reliable and clean electricity. 22 nuclear reactors with a combined capacity of **8,180 MW** are in operation in the nation as of 2024, while several more are being built to meet the goal of **22,480 MW by 2031**. Using its plentiful thorium supplies, India emphasizes thorium-based reactors for long-term sustainability after completing its three-stage nuclear program. In partnership with France, the United States, and Russia, the Nuclear Power Corporation of India Limited (NPCIL) is leading the nuclear development. Through the 2008 Indo-U.S. nuclear accord and agreements with **the Nuclear Suppliers Group (NSG)**, India has gained access to worldwide nuclear fuel and technology, while not being a member to the Nuclear Non-Proliferation Treaty (NPT). The government is also advancing **small modular reactors (SMRs)** and indigenous **advanced heavy water reactors (AHWRs)** to strengthen energy security. However, high costs, safety concerns, and long project timelines remain key challenges in this sector’s growth.

Current Status & Capacity

- As of **January 30, 2025**, India’s nuclear capacity is **8180 MW**.
- Contribution to energy - The share of nuclear power in the total electricity generation in the country was about **2.8% in the year 2022-23**.
- India has 22 operating reactors. Among these eighteen reactors are **Pressurized Heavy Water Reactors (PHWRs)** and four are **Light Water Reactors (LWRs)**.

Figure 1: Schematic view of India’s currently operating nuclear reactors

India’s currently operating nuclear reactors:

S No	Plant Name	Date of commercial operation	Location	Gross Power (MWe)	Type
1	Tarapur Atomic Power Plant-1 (TAPS-1)	Oct 1969	BOISAR, MAHARASTRA	160	BWR
2	Tarapur Atomic Power Plant-2 (TAPS-2)	Oct 1969	BOISAR, MAHARASTRA	160	BWR
3	Rajasthan Atomic Power Plant-1 (RAPS-1)	Dec 1973	KOTA, RAJASTHAN	100	PHWR
4	Rajasthan Atomic Power Plant-2 (RAPS-2)	Apr 1981	KOTA, RAJASTHAN	200	PHWR
5	Madras Atomic Power Plant-1 (MAPS-1)	Jan 1984	KALPAKKAM, TAMILNADU	220	PHWR
6	Madras Atomic Power Plant-2 (MAPS-2)	Mar 1986	KALPAKKAM, TAMILNADU	220	PHWR
7	Narora Atomic Power Plant-1 (NAPS-1)	Jan 1991	NARORA, UTTAR PRADESH	220	PHWR
8	Narora Atomic Power Plant-2 (NAPS-2)	July 1992	NARORA, UTTAR PRADESH	220	PHWR
9	Kakrapar Atomic Power Plant-1 (KAPS-1)	May 1993	TAPI, GUJARAT	220	PHWR
10	Kakrapar Atomic Power Plant-2 (KAPS-2)	Sep 1995	TAPI, GUJARAT	220	PHWR
11	Kaiga Generating Station-1 (KGS-1)	Nov 2000	KAIGA, KARNATAKA	220	PHWR
12	Kaiga Generating Station-2 (KGS-2)	Mar 2000	KAIGA, KARNATAKA	220	PHWR
13	Rajasthan Atomic Power Plant-3 (RAPS-3)	Jun 2000	KOTA, RAJASTHAN	220	PHWR
14	Rajasthan Atomic Power Plant-4 (RAPS-4)	Dec 2000	KOTA, RAJASTHAN	220	PHWR
15	Kaiga Generating Station-3 (KGS-3)	May 2007	KAIGA, KARNATAKA	220	PHWR
16	Kaiga Generating Station-4 (KGS-4)	Jan 2011	KAIGA, KARNATAKA	220	PHWR
17	Tarapur Atomic Power Plant-3 (TAPS-3)	Aug 2006	BOISAR, MAHARASTRA	540	PHWR
18	Tarapur Atomic Power Plant-4 (TAPS-4)	Sept 2005	BOISAR, MAHARASTRA	540	PHWR
19	Rajasthan Atomic Power Plant-5 (RAPS-5)	Feb 2010	KOTA, RAJASTHAN	220	PHWR
20	Rajasthan Atomic Power Plant-6 (RAPS-6)	Mar 2010	KOTA, RAJASTHAN	220	PHWR
21	Kudankulam Nuclear Power Station-1 (KKNPS-1)	Dec 2014	KUDANKULAM, TAMILNADU	1000	PWR
22	Kudankulam Nuclear Power Station-2 (KKNPS-2)	Mar 2017	KUDANKULAM, TAMILNADU	1000	PWR

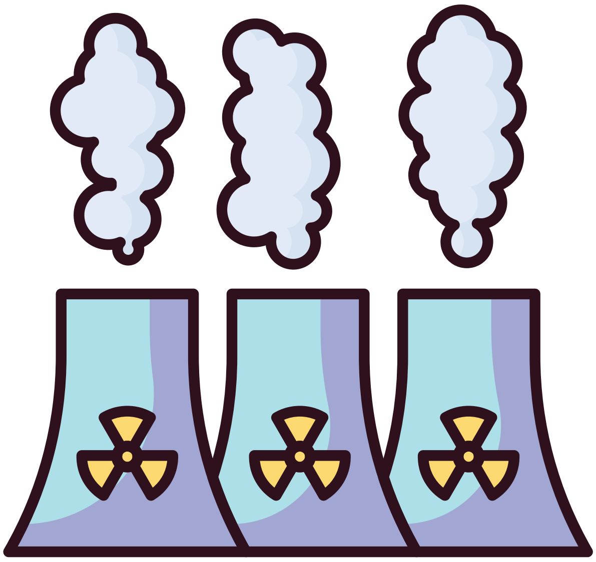


Figure 2: Mass flows in nuclear fuel production (Source: Energies)

Process involved in Nuclear Fuel Production:

The Indian nuclear program was designed with a unique sequential three-stage approach, aimed at optimizing the use of the country's modest uranium and abundant thorium resources. This program operates on a closed fuel cycle, where the spent fuel from one stage is reprocessed to create fuel for the subsequent stage. This closed cycle significantly enhances the energy potential of the fuel while also reducing the amount of waste produced.

Stages of the Indian Nuclear Program

Stage One: Pressurized Heavy Water Reactors (PHWRs)
The first stage utilizes natural uranium as fuel in Pressurized Heavy Water Reactors. Natural uranium consists of only 0.7% Uranium-235, which undergoes fission to release energy (approximately 200 MeV per atom). The remaining 99.3% is Uranium-238, which is not fissile but can be converted into Plutonium-239 within the reactor through a process called transmutation. This stage generates energy and produces a small quantity of Plutonium-239 as a by-product of the fission process.

Stage Two: Fast Breeder Reactors (FBRs)
The second stage involves Fast Breeder Reactors, which are fueled by a mixed oxide of Uranium-238 and Plutonium-239, recovered from the reprocessing of spent fuel from the first stage. In FBRs, Plutonium-239 undergoes fission to produce energy while simultaneously breeding more Plutonium-239 from Uranium-238. This characteristic of producing more fuel than it consumes is why it is termed a "breeder" reactor. Over time, this allows for the accumulation of Plutonium inventory by continuously feeding Uranium-238 into the system.

Stage Three: Thorium Utilization
India possesses the world's third-largest reserves of Thorium-232, which is not fissile and must be converted into a fissile material, Uranium-233, through transmutation in a Fast Breeder Reactor. In the third stage, once a sufficient inventory of Plutonium-239 is established, Thorium-232 will be introduced as a blanket material in the FBRs to facilitate its conversion into Uranium-233. This transition is crucial for the long-term sustainability of India's nuclear energy program, as it aims to leverage the vast thorium reserves available in the country.

Types of Reactors used

Pressurized Water Reactor

- The Pressurized Water Reactor (PWR) is the most widely used type of nuclear reactor, with approximately 300 operational reactors for power generation and several hundred more utilized for naval propulsion. Originally designed for submarine power systems, PWRs use regular water as both a coolant and a moderator. This design features a primary cooling circuit that flows through the reactor core under extremely high pressure, preventing the water from boiling. Heat from this circuit is transferred to a secondary circuit, where steam is produced to drive a turbine for power generation. In Russia, these reactors are referred to as VVER (Water-Water Energy Reactors), as they are both water-cooled and water-moderated. A PWR has fuel assemblies of 200-300 rods each, arranged vertically in the core, and a large reactor would have about 150-250 fuel assemblies with 80-100 tonnes of uranium.

Boiling Water Reactors

- This reactor type shares many characteristics with the Pressurized Water Reactor (PWR) but differs in having a single cooling circuit. The water in this circuit is maintained at a lower pressure, around 75 times atmospheric pressure, allowing it to boil directly in the reactor core at approximately 285°C. The reactor is designed to function with 12-15% of the water in the upper section of the core existing as steam, which reduces the moderating effect and slightly lowers efficiency in that region. Boiling Water Reactors (BWRs) have the advantage of being more adaptable to load-following operations compared to PWRs.

Pressurized Heavy Water Reactors

- Pressurized heavy water reactors (PHWRs) typically use natural uranium oxide fuel, which contains 0.7% U-235. To compensate for this, they require a highly efficient moderator—heavy water (D_2O). While PHWRs extract more energy per kilogram of mined uranium compared to other reactor types, they also generate a significantly larger volume of spent fuel per unit of energy produced. Similar to pressurized water reactors (PWRs), the primary coolant transfers heat to a secondary circuit, where steam is produced to drive turbines. Their pressure tube design allows for continuous refueling without shutting down the reactor by isolating individual tubes from the cooling system. Additionally, PHWRs are more cost-effective to construct than large pressure vessel designs, though the tubes tend to have lower durability.

Atomic Minerals Directorate for Exploration and Research (AMD)

The Atomic Minerals Directorate for Exploration and Research (AMD) is primarily responsible for identifying and assessing uranium resources within the country. To fulfill this mandate, AMD conducts investigations nationwide through its Regional Exploration & Research Centres located in New Delhi, Bengaluru, Jamshedpur, Shillong, Jaipur, Nagpur, and Hyderabad (which serves as the headquarters and South Central Region hub).

AMD employs cutting-edge technology for airborne geophysical surveys and carries out multidisciplinary field operations, including geological, geophysical, and geochemical surveys at both regional and detailed levels. It also utilizes advanced hydrostatic rigs for drilling activities. The organization's laboratories are equipped with state-of-the-art facilities to support field investigations. Additionally, AMD has specialized groups dedicated to beach-sand and offshore studies, as well as rare metal and rare earth investigations.

The **Atomic Energy Regulatory Board** (AERB), the national authority responsible for enforcing nuclear and radiation safety regulations, oversees AMD's exploration and research activities.

Nuclear Fuel Cycle Facilities

Nuclear fuel cycle facilities encompass both the front-end and back-end processes, including exploration, mining, milling, fuel fabrication, spent fuel reprocessing, and other related operations.

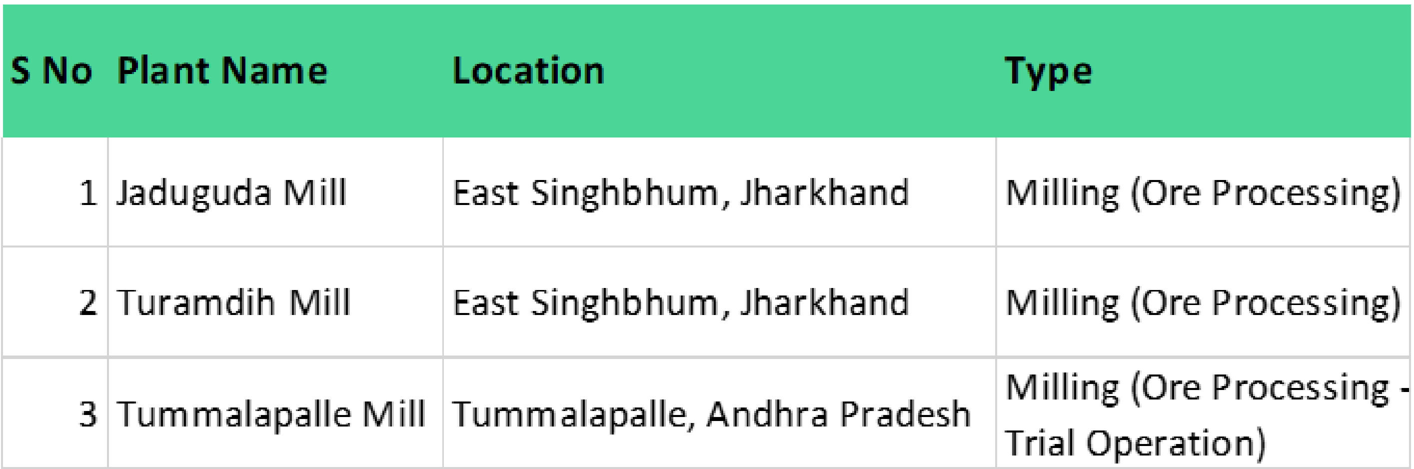
Organizations involved in the exploration and processing of natural resources

- **Uranium Corporation of India Ltd. (UCIL):**

Uranium Corporation of India Limited (UCIL) operates underground uranium mines in Jharkhand at Jaduguda, Bhatin, Narwapahar, Turamdih, Bagjata, and Mohuldih, as well as in Andhra Pradesh at Tummalapalle. Additionally, it runs an open-cast uranium mine at Banduhurang in Jharkhand. The Atomic Energy Regulatory Board (AERB) oversees these mining operations under the Atomic Energy (Radiation Protection) Rules, 2004.

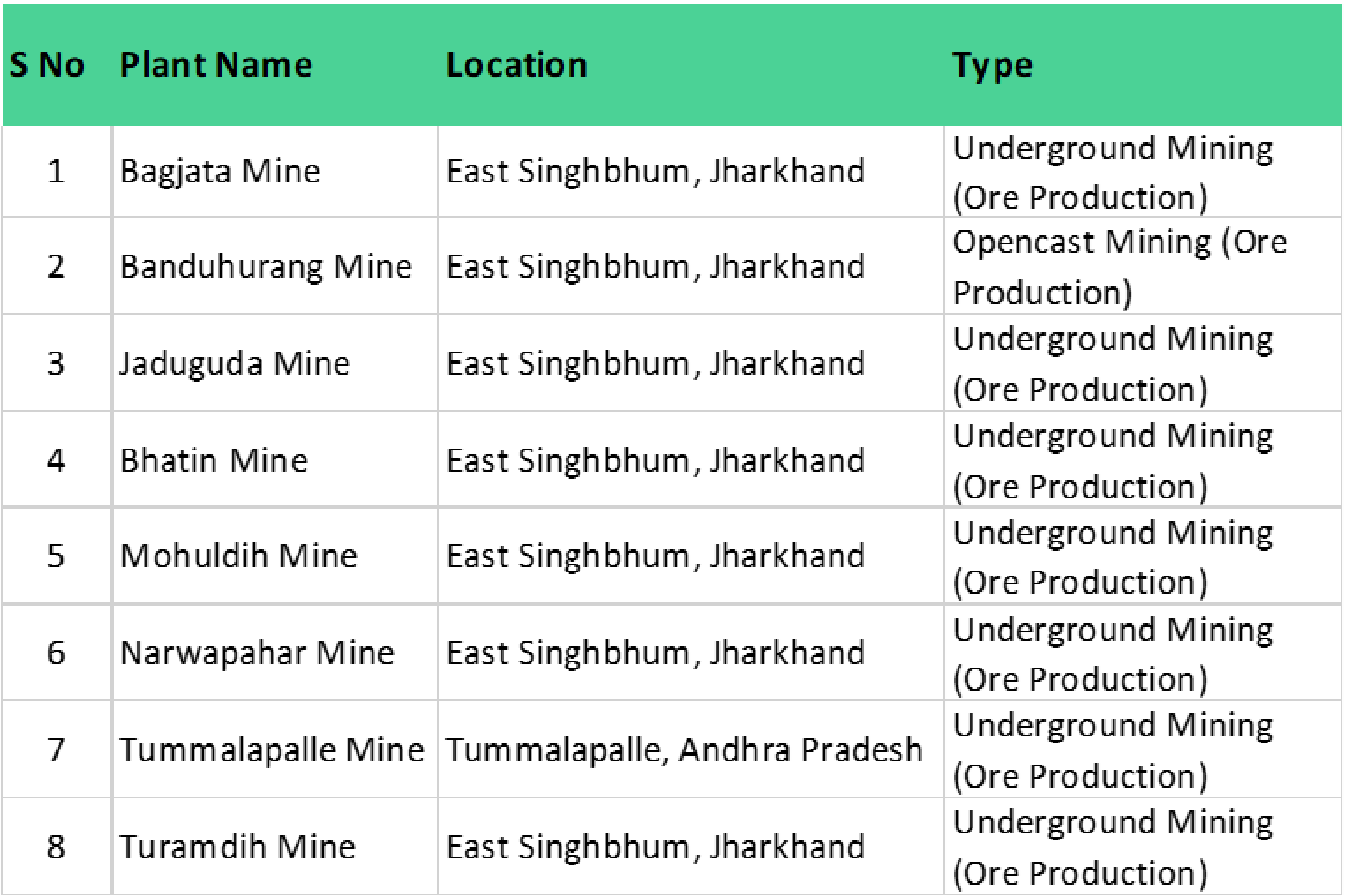
UCIL also manages three ore processing plants located at Jaduguda, Turamdih, and Tummalapalle, where uranium ore undergoes chemical processing to extract uranium. In addition to enforcing the Atomic Energy (Radiation Protection) Rules, 2004, AERB regulates industrial safety at these facilities under the Factories Act, 1948, and the Atomic Energy (Factories) Rules, 1996.

UCIL Mills in India:



S No	Plant Name	Location	Type
1	Jaduguda Mill	East Singhbhum, Jharkhand	Milling (Ore Processing)
2	Turamdih Mill	East Singhbhum, Jharkhand	Milling (Ore Processing)
3	Tummalapalle Mill	Tummalapalle, Andhra Pradesh	Milling (Ore Processing - Trial Operation)

UCIL mines in India:



S No	Plant Name	Location	Type
1	Bagjata Mine	East Singhbhum, Jharkhand	Underground Mining (Ore Production)
2	Banduhurang Mine	East Singhbhum, Jharkhand	Opencast Mining (Ore Production)
3	Jaduguda Mine	East Singhbhum, Jharkhand	Underground Mining (Ore Production)
4	Bhatin Mine	East Singhbhum, Jharkhand	Underground Mining (Ore Production)
5	Mohuldih Mine	East Singhbhum, Jharkhand	Underground Mining (Ore Production)
6	Narwapahar Mine	East Singhbhum, Jharkhand	Underground Mining (Ore Production)
7	Tummalapalle Mine	Tummalapalle, Andhra Pradesh	Underground Mining (Ore Production)
8	Turamdih Mine	East Singhbhum, Jharkhand	Underground Mining (Ore Production)

- **Indian Rare Earths Limited (IREL):**

Indian Rare Earths Limited (IREL) operates three Mineral Separation Plants (MSPs) at Chavara, Manavalakurichi, and Chatrapur (Orissa Sands Complex – OSCOM), where heavy minerals such as Ilmenite, Rutile, Garnet, Zircon, Sillimanite, and Monazite are extracted from mined beach sands. These MSPs are regulated by the Atomic Energy Regulatory Board (AERB) under the Atomic Energy (Radiation Protection) Rules, 2004.

Additionally, IREL has two chemical processing plants located at OSCOM and Udyogamandal. At OSCOM, monazite undergoes chemical processing to extract uranium, thorium, and rare earth elements. The Udyogamandal facility focuses on the value addition of rare earths and processing secondary uranium sources. Beyond the Atomic Energy (Radiation Protection) Rules, 2004, AERB also enforces industrial safety regulations at these plants under the Factories Act, 1948, and the Atomic Energy (Factories) Rules, 1996.

IREL Mining Facilities:

S No	Plant Name	Location	Type
1	M/s Indian Rare Earths Ltd., Manavalakurichi, Tamilnadu	Kanyakumari District, Tamilnadu	Beach Sand Mineral Separation Plant
2	M/s Indian Rare Earths Ltd., OSCOM, Chatrapur, Odisha	Ganjam District, Odisha	Beach Sand Mineral Separation Plant
3	M/s Indian Rare Earths Ltd., Chavara, Kerala	Kollam District, Kerala	Beach Sand Mineral Separation Plant

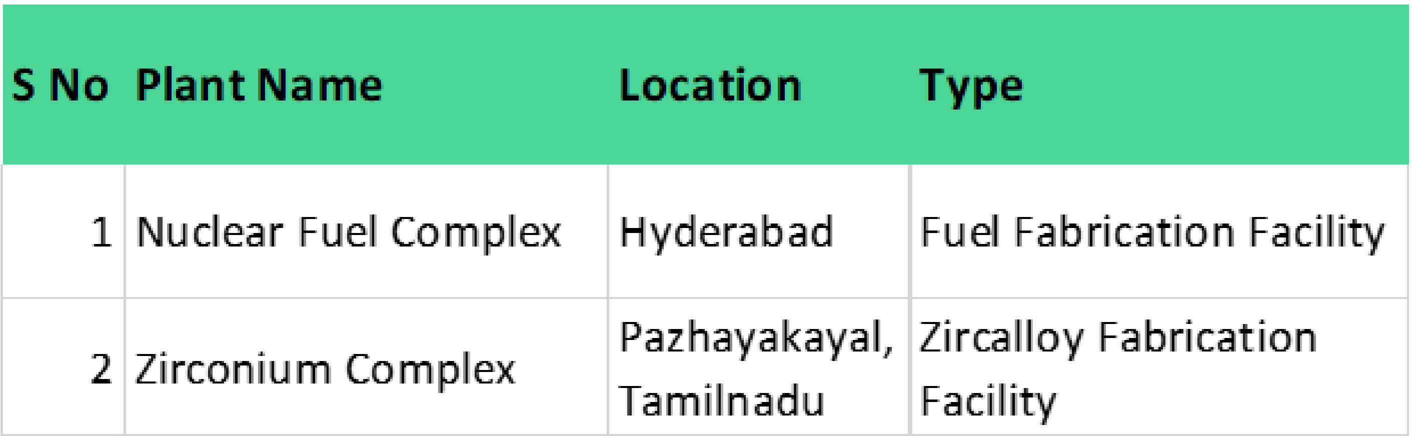
IREL Mineral Production Facilities:

S No	Plant Name	Location	Type
1	M/s Indian Rare Earths Ltd., Udyogmandal (HPRE)	Ernakulam District, Kerala	Rare Earth Production Plant
2	M/s Indian Rare Earths Ltd., Udyogmandal (RED)	Ernakulam District, Kerala	Uranium Recovery Plant
3	M/s Indian Rare Earths Ltd., OSCOM, Odisha (MoPP)	Ganjam District, Odisha	Monazite Processing Plant

Nuclear Fuel Complexes

NFC’s specialty lies in the manufacturing of nuclear fuel bundles for Pressurized Heavy Water Reactors (PHWR), Boiling Water Reactors (BWR) and Fast breeder reactors, along with many reactor core components, various tubes and high purity special materials etc. There are currently two NFCs in the country - situated in Hyderabad and Pazhayakayal (Tamil Nadu), with a new facility under development in Kota in Rajasthan, adjacent to Heavy Water Plant, Rawatbhata Rawatbhata (HWP-Kota). These facilities process uranium ore concentrates (UOC) from uranium ore processing plants into uranium oxide pellets, which are then inserted into zircaloy tubes and assembled into fuel assemblies for nuclear reactors.

Nuclear Fuel Complexes in India



S No	Plant Name	Location	Type
1	Nuclear Fuel Complex	Hyderabad	Fuel Fabrication Facility
2	Zirconium Complex	Pazhayakayal, Tamilnadu	Zircalloy Fabrication Facility

Industrial Facilities

Heavy Water Board (HWB) and Electronics Corporation of India Ltd. (ECIL) are the two organizations that are responsible for the reactor grade heavy water production and all the electronics equipments for control and automation purposes.

- **Heavy Water Board (HWB):**

The Heavy Water Board (HWB), a unit under the Industries and Minerals Sector of the Department of Atomic Energy (DAE), is responsible for producing Heavy Water (Deuterium Oxide - D_2O). Additionally, it manufactures various organo-phosphorus solvents to meet the needs of DAE units.

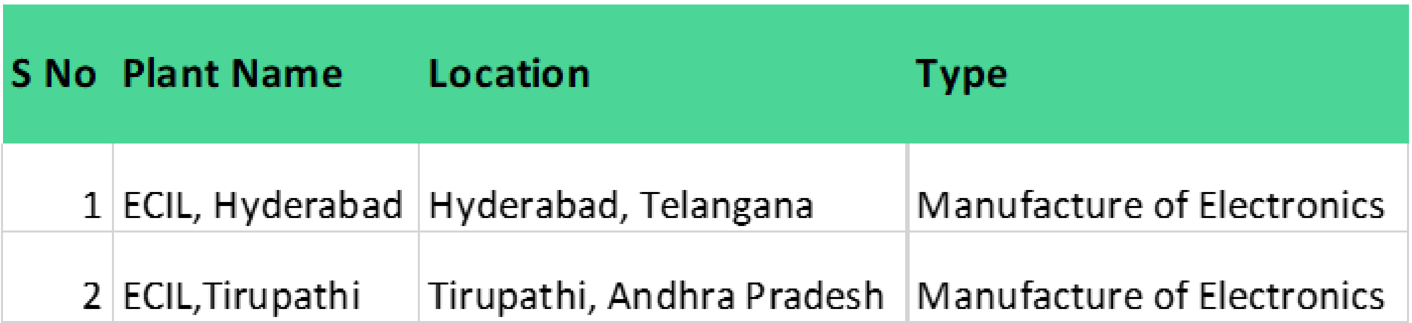
Heavy water production takes place at facilities in Manuguru (Telangana), Rawatbhata (Rajasthan), Thal (Maharashtra), and Hazira (Gujarat). Meanwhile, plants in Baroda (Gujarat), Tuticorin (Tamil Nadu), and Talcher (Odisha) focus on producing organo-phosphorus solvents and other chemicals for DAE applications. HWB is also engaged in the recovery of rare materials, such as uranium, at its Technology Demonstration Plant (TDP) in Mumbai.

- **Electronics Corporation of India Ltd. (ECIL):**

Electronics Corporation of India Limited (ECIL) manufactures nucleonic gauges, radiation detectors & instruments along with other electronic instruments and control & automation products. ECIL has two manufacturing units located at Hyderabad and Tirupathi.

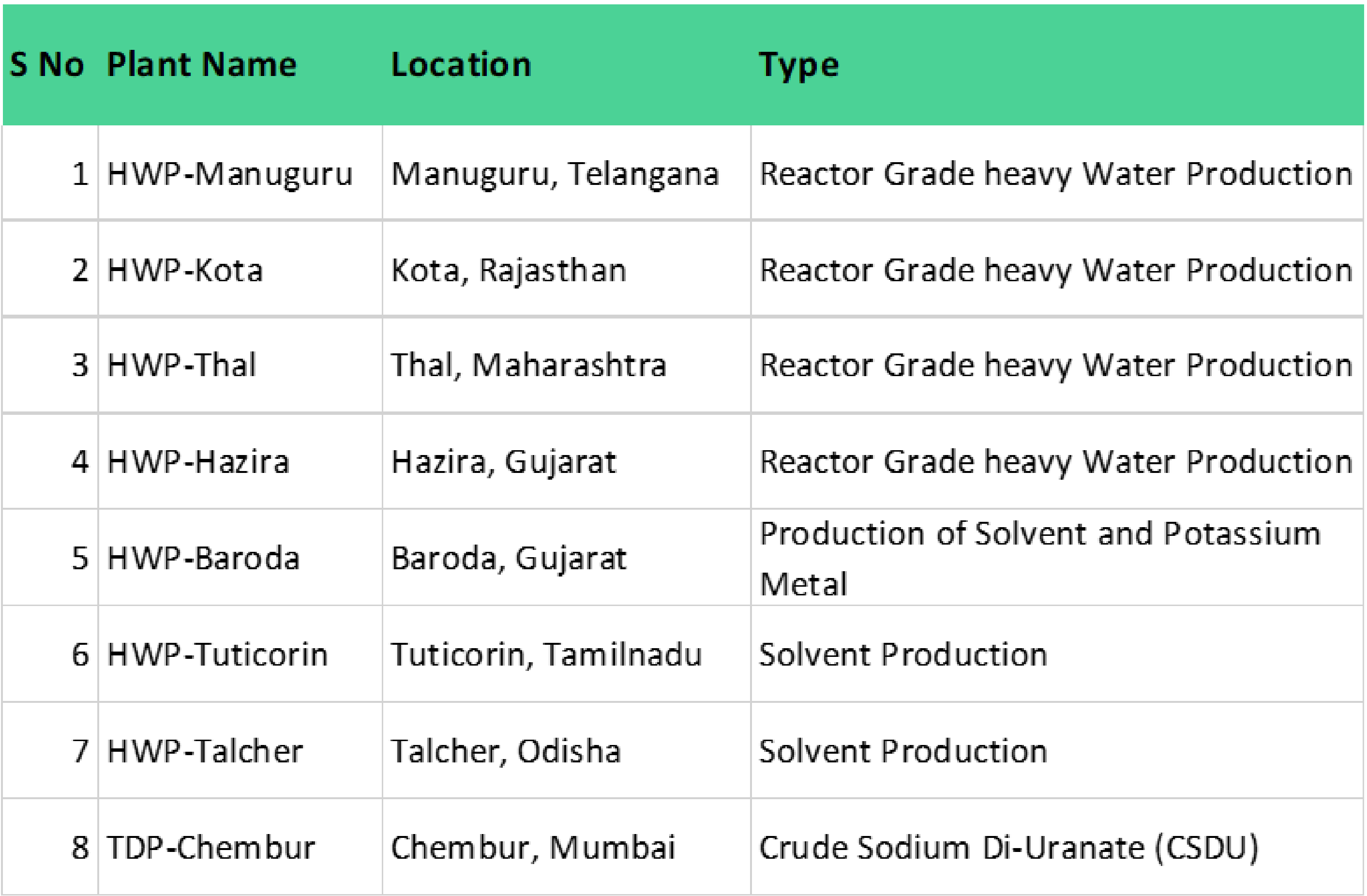
ECIL is primarily engaged in the design, development, and production of a wide range of electronics products, with a focus on sectors like defense, nuclear power, aerospace, telecommunications, and IT. The company has made significant contributions to the Indian nuclear and space programs by supplying crucial systems for the country's atomic energy plants and satellite projects. ECIL also offers services in areas such as automation, security, and information technology, and is known for its high-quality manufacturing capabilities and technological innovations.

ECIL Facilities in India:



S No	Plant Name	Location	Type
1	ECIL, Hyderabad	Hyderabad, Telangana	Manufacture of Electronics
2	ECIL,Tirupathi	Tirupathi, Andhra Pradesh	Manufacture of Electronics

HWB Facilities in India:



S No	Plant Name	Location	Type
1	HWP-Manuguru	Manuguru, Telangana	Reactor Grade heavy Water Production
2	HWP-Kota	Kota, Rajasthan	Reactor Grade heavy Water Production
3	HWP-Thal	Thal, Maharashtra	Reactor Grade heavy Water Production
4	HWP-Hazira	Hazira, Gujarat	Reactor Grade heavy Water Production
5	HWP-Baroda	Baroda, Gujarat	Production of Solvent and Potassium Metal
6	HWP-Tuticorin	Tuticorin, Tamilnadu	Solvent Production
7	HWP-Talcher	Talcher, Odisha	Solvent Production
8	TDP-Chembur	Chembur, Mumbai	Crude Sodium Di-Uranate (CSDU)

Details of the facilities of UCIL, IREL and NFC along with the industrial facilities:

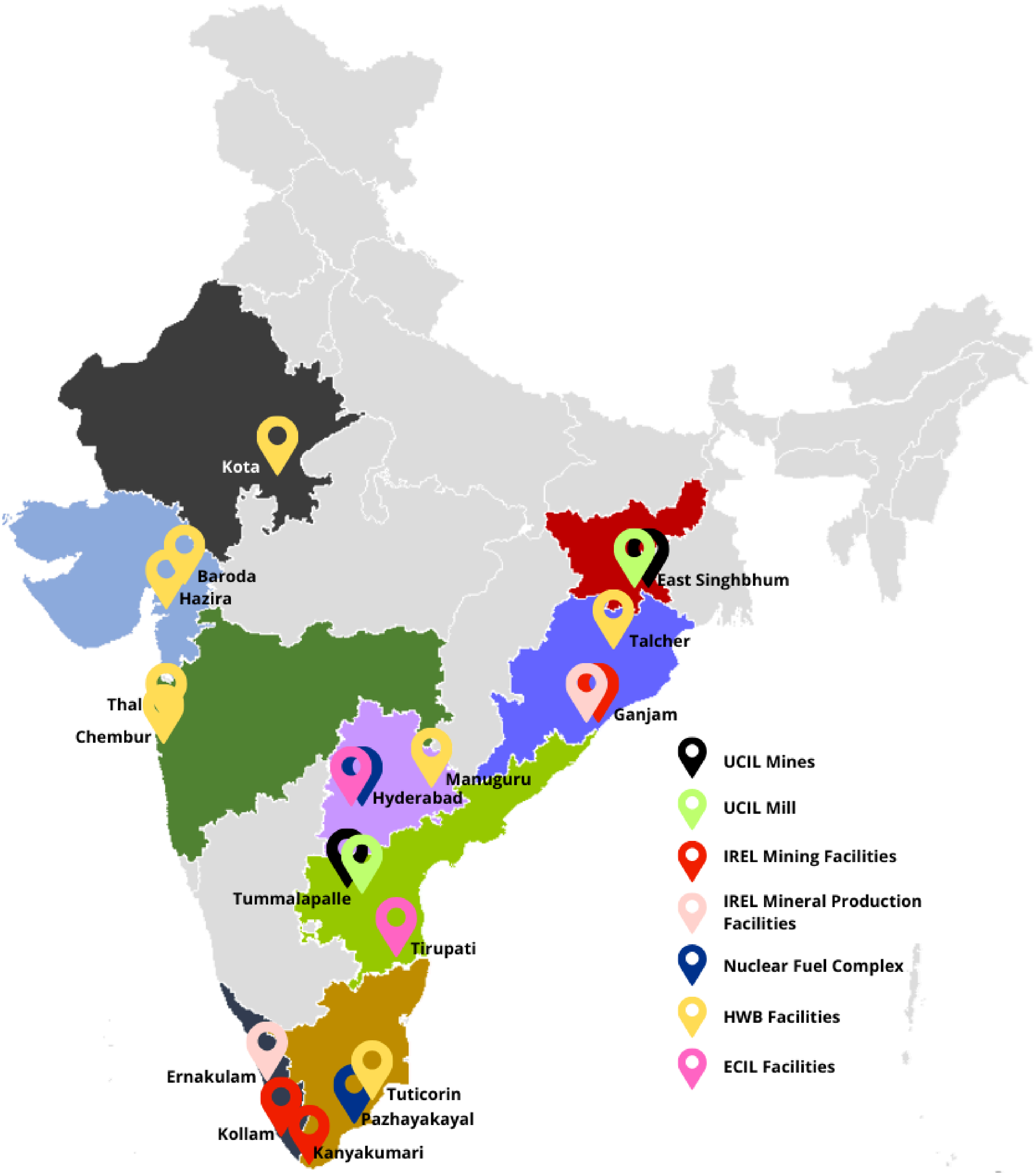


Figure 3: Schematic view of India's nuclear fuel fabrication facilities and industrial facilities

Radiation Facilities

Radiation facilities encompass the use of radiation sources and radiation-generating equipment across various applications. The major categories of radiation applications include industrial, medical, research, consumer products, and scanning facilities. In industrial settings, radiation is used in processes such as radiation processing facilities, industrial radiography, nucleonic gauges, and well-logging applications. Medical applications of radiation fall into two primary categories: diagnostic and therapeutic uses of ionizing radiation. In research, radiation is utilized in gamma irradiation chambers, research accelerators, and laboratories handling both sealed and unsealed radioactive sources.

Radiation Processing Facilities:

Radiation Processing Facilities are of two types:

- **Gamma based** i.e., Radioactive source based Gamma Radiation Processing Facility (GRAPF) - Gamma Radiation Processing Facilities (GRAPFs) are utilized for various applications requiring high-intensity irradiation, such as food preservation, sterilization of healthcare products, wood polymerization, and rubber vulcanization.
- **Accelerator based**, Industrial Accelerator Radiation Processing Facility (IARPF) - Photon and electron beam produced from the IARPF is used for radiation processing of food items, healthcare products and cross-linking of cables.

Future Plans and Expansion:

The government aims to achieve a nuclear power capacity of **100 GW by 2047**, making nuclear energy a key component of India's energy strategy. This initiative supports the broader vision of Viksit Bharat by enhancing energy security and reducing reliance on fossil fuels. To reach this target, strategic policy measures and infrastructure investments are being implemented, focusing on the advancement of indigenous nuclear technology and fostering public-private partnerships.

Government Initiatives for Enhancing India’s Nuclear Capacity:

India is actively expanding its nuclear power capacity to meet rising energy demands and environmental objectives. The government has outlined plans to increase nuclear power generation from the current **8,180 MW to 22,480 MW by 2031-32**. This growth includes the construction and commissioning of ten reactors with a combined capacity of 8,000 MW across Gujarat, Rajasthan, Tamil Nadu, Haryana, Karnataka, and Madhya Pradesh. Additionally, pre-project activities have begun for ten more reactors, scheduled for phased completion by 2031-32. Furthermore, the government has granted in-principle approval for a 6 x 1208 MW nuclear power plant in collaboration with the USA at Kovvada in Srikakulam district, Andhra Pradesh.

A major milestone was reached on September 19, 2024, when Unit-7 of the **Rajasthan Atomic Power Project (RAPP-7)**, one of India's largest and third fully indigenous nuclear reactors, achieved criticality, initiating a controlled fission chain reaction. This achievement highlights India's growing expertise in developing and operating homegrown nuclear technology, reinforcing its commitment to a self-reliant nuclear energy future.

Recent Developments in Nuclear Energy in India:

- A major uranium deposit has been discovered within and around the existing lease area of Jaduguda Mines, India's oldest uranium mine. This discovery is expected to extend the mine's operational lifespan by over 50 years.

- The first two units of the indigenous 700 MWe Pressurized Heavy Water Reactor (PHWR) at Kakrapar, Gujarat (KAPS-3 & 4), commenced commercial operations in the financial year 2023-24.

- As part of India's commitment to a closed fuel cycle, the country's first **Prototype Fast Breeder Reactor (PFBR 500 MWe)** reached several key milestones in 2024. These include the filling and purification of primary sodium in the main vessel, commissioning of all four sodium pumps (two primary and two secondary), and the initiation of core loading with the first reactor control rod on March 4, 2024.

- A supplementary Joint Venture agreement has been signed between **NPCIL and NTPC** to develop nuclear power projects in India. The JV, named **ASHVINI**, will operate under the Atomic Energy Act 1962 (amended in 2015) and oversee the construction, ownership, and operation of nuclear plants, including the upcoming **4x700 MWe PHWR at Mahi-Banswara**, **Rajasthan**.

Nuclear Power Reactors under Construction

S No	State	Location	Project	Capacity	Sanctioned Cost (₹ crore)
1	Gujarat	Kakrapar	KAPP 3&4	2 x 700	11459*
2	Rajasthan	Rawatbhata	RAPP 7&8	2 X 700	12320
3	Tami Nadu	Kudankulam	KKNPP 3&4	2 X 1000	39849
		Kalpakkam	PFBR	500	5677
4	Haryana	Gorakhpur	GHAVP 1&2	2 x 700	20594

**Under Revision*

Nuclear Power Reactors accorded administrative approval and financial sanction

S No	State	Location	Project	Capacity (MW)	Sanctioned Cost (₹ crore)
1	Haryana	Gorakhpur	GHAVP 3&4	2 x 700	105000
2	Rajasthan	Mahi-Banswara	Mahi Banswara 1&2	2 X 700	
			Mahi Banswara 3&4	2 X 700	
3	Karnataka	Kaiga	Kaiga 5&6	2 X 700	
4	Madhya Pradesh	Chutka	Chutka 1&2	2 X 700	
5	Tamil Nadu	Kudankulam	KKNPP 5&6	2 X 1000	49621

Sites accorded 'In-Principle' approval

S No	State	Site	Capacity	In Cooperation with
1	Maharashtra	Jaitapur	6 X 1650	France
2	Andhra Pradesh	Kovvada	6 X 1208	United States of America
3	Gujarat	Chhaya Mithi Virdi	6 X 1000*	
4	West Bengal	Haripur	6 X 1000*	Russian Federation
5	Madhya Pradesh	Bhimpur	4 X 700	Indigenous PHWR

**Nominal Capacity*

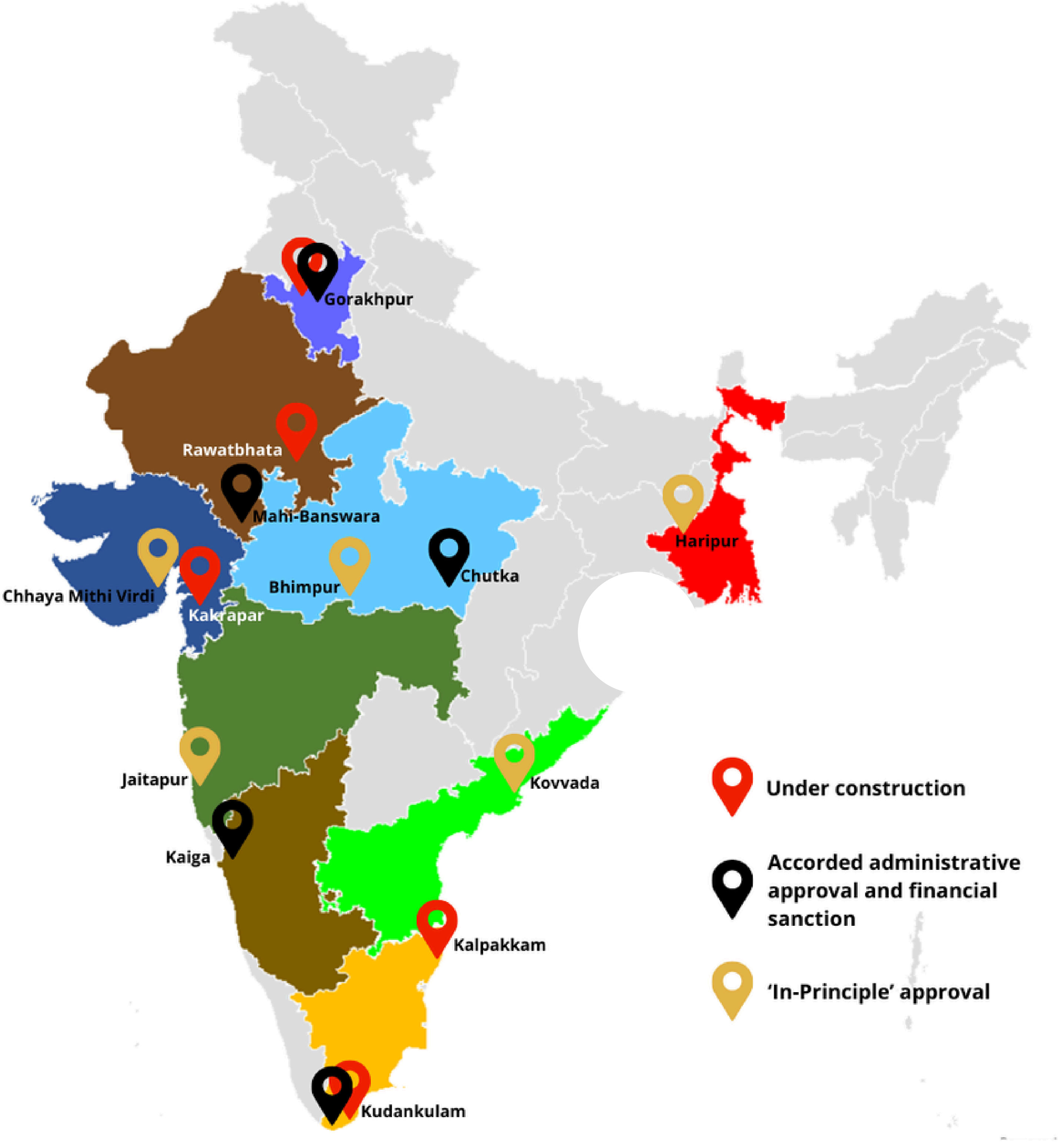


Figure 4: Schematic view of India's upcoming nuclear facilities

Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), a PSU under Department of Atomic Energy, is currently constructing a 500 MWe Prototype Fast Breeder Reactor at Kalpakkam, Tamil Nadu. Further, it is proposed to construct a series of twin reactors as given below:

S No	Proposed Fast Breeder Reactor	Capacity (MWe)	Start of construction	Commercial operation	Location of plant
1	FBR-1	600	2021	2029	Kalpakkam, Tamil Nadu
2	FBR-2	600	2021	2031	
3	FBR-3	600	2025	2033	Site yet to be selected
4	FBR-4	600	2025	2035	

India’s Nuclear Energy Mission

According to the **International Atomic Energy Agency (IAEA)**, Small Modular Reactors (SMRs) are advanced nuclear reactors with a power output ranging from under 30 MWe to over 300 MWe. They encompass both small and medium-sized modular reactors, depending on the specific national context. Designed with standardized structures, systems, and components (SSCs), SMRs are manufactured in factories and transported to the project site for installation, reducing construction time. This approach enables cost efficiency through serial production and allows for the addition of power modules as energy demand grows.

A major highlight of the **Union Budget 2025-26** is the introduction of the Nuclear Energy Mission, dedicated to the research and development (R&D) of Small Modular Reactors (SMRs). The government has earmarked **₹20,000 crore** for this initiative, with the goal of developing and commissioning **at least five indigenously designed SMRs by 2033**.

The government will enter into partnerships with the private sector with the motive of:
- Setting up Bharat Small Reactors.
- Research & development of Bharat Small Modular Reactor.
- Research & development of newer technologies for nuclear energy.

Bharat Small Reactors:

The government is accelerating the expansion of nuclear energy by developing Bharat Small Reactors (BSRs) and fostering private-sector collaborations. BSRs are **220 MW Pressurized Heavy Water Reactors (PHWRs)** with a strong track record of safety and performance. These reactors are being optimized to require less land, making them suitable for industrial deployment in sectors like steel, aluminum, and metals, where they can function as captive power plants to support decarbonization efforts.

Under this initiative, private entities will provide land, cooling water, and capital, while the **Nuclear Power Corporation of India Limited (NPCIL)** will oversee design, quality assurance, and operation and maintenance within the existing legal framework. This strategy aligns with India’s goal of achieving 500 GW of non-fossil fuel-based energy by 2030 and meeting 50% of its energy needs from renewables, as pledged at the COP26 Summit in Glasgow in 2021.

Beyond BSRs, the **Bhabha Atomic Research Centre (BARC)** is developing Small Modular Reactors (SMRs) to repurpose decommissioned coal-based power plants and provide electricity to remote areas. Additionally, the Department of Atomic Energy (DAE) plans to introduce advanced nuclear reactor designs, including high-temperature gas-cooled reactors for hydrogen production and molten salt reactors to leverage India's abundant thorium reserves.

Bharat Small Modular Reactors:

India is actively exploring Small Modular Reactors (SMRs) as a key component of its energy transition strategy to achieve net-zero emissions while maintaining energy security. These advanced nuclear reactors, with a capacity ranging from under **30 MWe to over 300 MWe**, offer a scalable, flexible, and cost-efficient alternative to traditional large reactors. With rising energy demands and the need for dependable, low-carbon power, SMRs have the potential to complement renewable energy sources and enhance grid stability. Their modular design enables factory-based manufacturing, reducing construction time and costs, making them suitable for both grid-connected and remote applications.

India's expertise in Pressurized Heavy Water Reactors (PHWRs) provides a strong foundation for developing indigenous SMR designs. Integrating SMRs into the energy mix will help address land constraints, reduce reliance on fossil fuels, and strengthen India's ability to meet its climate commitments under the Paris Agreement (2015), which the country ratified in October 2016.

Research & Development Facilities

Bhabha Atomic Research Centre (BARC)

India's top nuclear research facility is the Bhabha Atomic Research Centre (BARC), which is situated in Trombay, Mumbai. BARC, which was founded in 1954 and bears the name of the famous scientist Dr. Homi J. Bhabha, is a leader in nuclear research and technology in India. The center focuses on a variety of scientific activities, such as innovative materials, radiation medicine, reactor development, and nuclear power generation. BARC has made substantial contributions to the nation's nuclear energy and defense programs and is also a major player in the development of nuclear fuel cycles. It is renowned for its groundbreaking contributions to the military and civilian uses of nuclear technology.

Reactor technologies, fuel reprocessing and waste management, isotope applications, radiation technologies and their applications to agriculture, health, and the environment, accelerator and laser technology, electronics, instrumentation, reactor control, and materials science are among the areas in which BARC has active research and development groups. Several fundamental scientific disciplines have placed a strong emphasis on basic and applied research, which has enabled synergy between basic research and technology development.

Raja Ramanna Centre for Advanced Technology (RRCAT)

The Raja Ramanna Centre for Advanced Technology, a subsidiary of the Department of Atomic Energy (DAE), Government of India, focuses on research and development in cutting-edge non-nuclear fields such as lasers, particle accelerators, and related technologies. Established by the DAE to complement the work done at the Bhabha Atomic Research Centre (BARC) in Mumbai, the center aims to advance scientific and technological progress in the areas of lasers and accelerators.

The Centre has independently designed, developed, and commissioned two synchrotron radiation sources, Indus-1 and Indus-2, which operate as national facilities. In addition, the Centre is engaged in several significant accelerator-related projects, including the development of a high-energy proton accelerator for a fission neutron source, electron accelerators for food irradiation and industrial uses, free electron lasers (FEL) in the terahertz and infrared (IR) spectral ranges, as well as superconducting and magnetic materials necessary for the accelerator. The Centre is also advancing technologies such as superconducting radio-frequency cavities, cryomodules, high-power radio-frequency generators, cryogenics, magnets, ultrahigh vacuum systems, precision fabrication, and control instrumentation to support various R&D programs.

Variable Energy Cyclotron Centre (VECC)

The Centre was initially tasked with conducting research in experimental nuclear physics, radiation damage studies, and isotope production for research and nuclear medicine. Over time, it evolved into a national facility with fully equipped design and development capabilities in mechanical engineering, power electronics, RF engineering, and computation. To support experimental nuclear physicists, a robust theoretical group also developed. In recognition of the important achievement of extracting the first alpha particle beam, VECC celebrates June 16th as its Foundation Day. In May 1990, the Centre became an independent R&D unit of the Department of Atomic Energy (DAE).

Currently, VECC operates three cyclotrons: the K130 Cyclotron, in operation since 1977; the K500 Superconducting Cyclotron, which provides heavy-ion beams for basic science research; and the 30 MeV Medical Cyclotron, which produces radiopharmaceuticals for cancer diagnostics, serving as a valuable societal service. The Centre now operates across three campuses: the main campus at Bidhannagar, the New Town campus for upcoming projects, and the Chakgaria campus, which houses the Medical Cyclotron Facility.

Indira Gandhi Centre for Atomic Research (IGCAR)

The Indira Gandhi Centre for Atomic Research (IGCAR), located in Kalpakkam, Tamil Nadu, was established in 1971 as the second-largest facility of the Department of Atomic Energy, after Bhabha Atomic Research Centre. Its primary goal is to advance sodium-cooled Fast Breeder Reactor (FBR) technology, a key component of India's second-stage Atomic Energy Programme, aimed at utilizing thorium reserves and addressing the country's growing energy demands. IGCAR has made significant progress, including the development of the Fast Breeder Test Reactor (FBTR) and the ongoing construction of the 500 MWe Prototype Fast Breeder Reactor (PFBR). The Centre also conducts extensive research in reactor engineering, materials science, fuel reprocessing, and advanced engineering disciplines. It collaborates with various national and international institutions and contributes to sectors such as defense and space. IGCAR also houses state-of-the-art facilities, including a large library, a central workshop, and a well-equipped computer division to support its research activities.

With a dedicated staff of over 2,800 scientists, engineers, and support personnel, the Centre boasts a significant annual budget of around 754.47 crore rupees. IGCAR’s collaboration with educational and research institutions further strengthens its role in driving technological advancements and solutions for critical challenges across multiple sectors.

Transport of Radioactive material:

With the growing use of radiation sources across various sectors, including medicine, industry, agriculture, research, and training, the transportation of radioactive materials has significantly increased. This involves the movement of such materials from manufacturing sites to usage locations, between different usage sites, and finally to facilities responsible for safe disposal. In India, over a lakh packages containing radioactive materials are transported annually, with activity levels ranging from a few kilo Becquerels to Peta Becquerels.

The Atomic Energy Regulatory Board (AERB) serves as the national authority responsible for enforcing regulations on the safe handling and transportation of radioactive materials. The transport of these materials in India is governed by the AERB Code on **Safe Transport of Radioactive Material (AERB/NRF-TS/SC-1 (Rev.1), 2016)**, which aligns with the International Atomic Energy Agency (IAEA) regulations outlined in the ‘Safe Transport of Radioactive Material’ SSR-6, 2012 Edition.

- The Atomic Energy Regulatory Board (AERB) has issued a regulatory guide titled **Security of Radioactive Material during Transport (AERB/NRF-TS/SG-10), 2008**. This guide defines security measures based on the potential radiological risks associated with the malicious use of radioactive materials. Its primary objective is to assist authorized users, consignors, carriers, and other relevant stakeholders in implementing and maintaining security protocols to safeguard radioactive materials during transport. These measures aim to prevent theft, sabotage, or any other malicious actions that could lead to serious radiological consequences.

- The AERB Code on **Safe Transport of Radioactive Material (AERB/NRF-TS/SC-1 (Rev.1) 2016)** outlines the classification, design, and testing standards for radioactive materials, as well as for the packaging, packages, and associated activity limits. It also specifies requirements for transport controls, approval processes, and administrative procedures to ensure the safe transportation of radioactive materials.

Radioactive waste management:

The regulatory body oversees waste management for both radioactive and chemical wastes produced by nuclear power plants and other nuclear fuel cycle facilities. It also supervises waste management in the industrial and research facilities of the **Department of Atomic Energy (DAE)**. Additionally, medical facilities that generate radioactive waste from diagnostic and/or therapeutic uses must comply with the safety standards set by the Atomic Energy Regulatory Board (AERB).

Nuclear power plants in operation produce solid, liquid, and gaseous waste. In line with waste management principles, no waste in any form is released into the environment unless it has been cleared, exempted, or excluded from regulations. The highest priority is given to minimizing waste and reducing its volume through careful selection of processes and technologies used in radioactive waste management facilities. The technologies used for managing nuclear waste are as follows:

- **Solid Waste:** Solid waste produced by nuclear power plants is conditioned appropriately before being disposed of in **Near Surface Disposal Facilities (NSDF)** located within the plant's exclusion zone. These facilities are designed to securely contain the radionuclides until they decay to a level of negligible activity.

- **Liquid Waste:** Low-level liquid waste from nuclear power plants is treated and then released into the environment, ensuring it meets regulatory limits. The treatment process typically includes chemical treatment, evaporation, ion exchange, and filtration.

- **Gaseous Waste:** Gaseous waste is treated at its source of generation. After treatment, the gaseous waste is released into the environment through a 100-meter-high stack, following filtration and dilution, with continuous monitoring of radionuclide levels to ensure compliance with regulatory standards.

Global Energy mix and Primary Energy sources

The world's energy mix is changing dramatically as nations strive to increase the proportion of renewable energy sources and lower their carbon footprints. Nearly 80% of the world's energy still comes from fossil fuels, with natural gas, coal, and oil being the main suppliers, according to latest data. But renewable energy is growing, accounting for around 29% of the world's electrical production, with solar and wind power accounting for the majority. **About 10% of the world's electricity comes from nuclear power**, making it a significant low-carbon energy source. Reliance on fossil fuels is steadily declining, while the share of nuclear and renewable energy is predicted to keep increasing as international efforts to tackle climate change strengthen.

Recent developments indicate a renewed interest in nuclear energy. In September 2024, major financial institutions, including Goldman Sachs, Morgan Stanley, and Bank of America, announced support for an initiative to triple global nuclear energy capacity by 2050. This initiative aligns with emissions targets set at the COP28 climate conference and aims to revitalize the nuclear sector. Additionally, tech companies are increasingly investing in nuclear energy to meet their substantial power demands. Amazon Web Services (AWS) has pledged over $500 million towards U.S. nuclear energy to support its AI-driven expansion and net-zero goals.

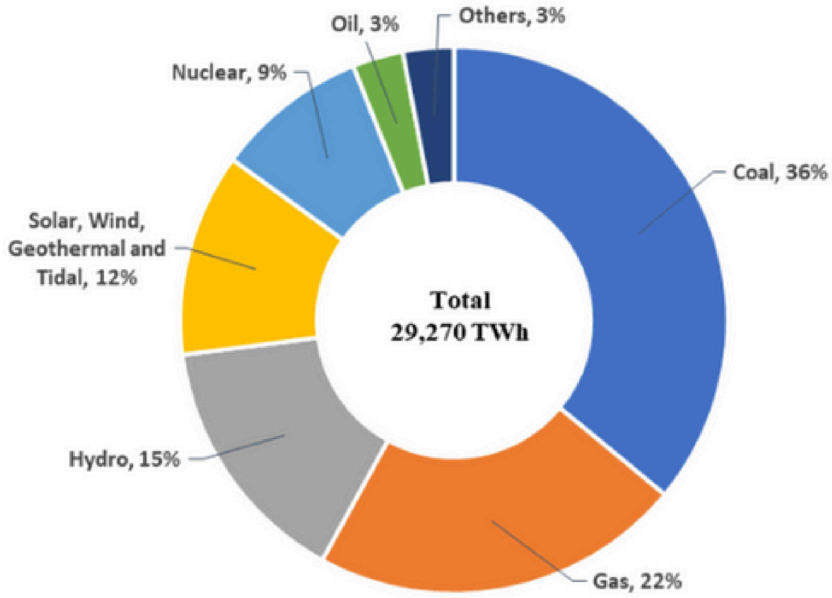
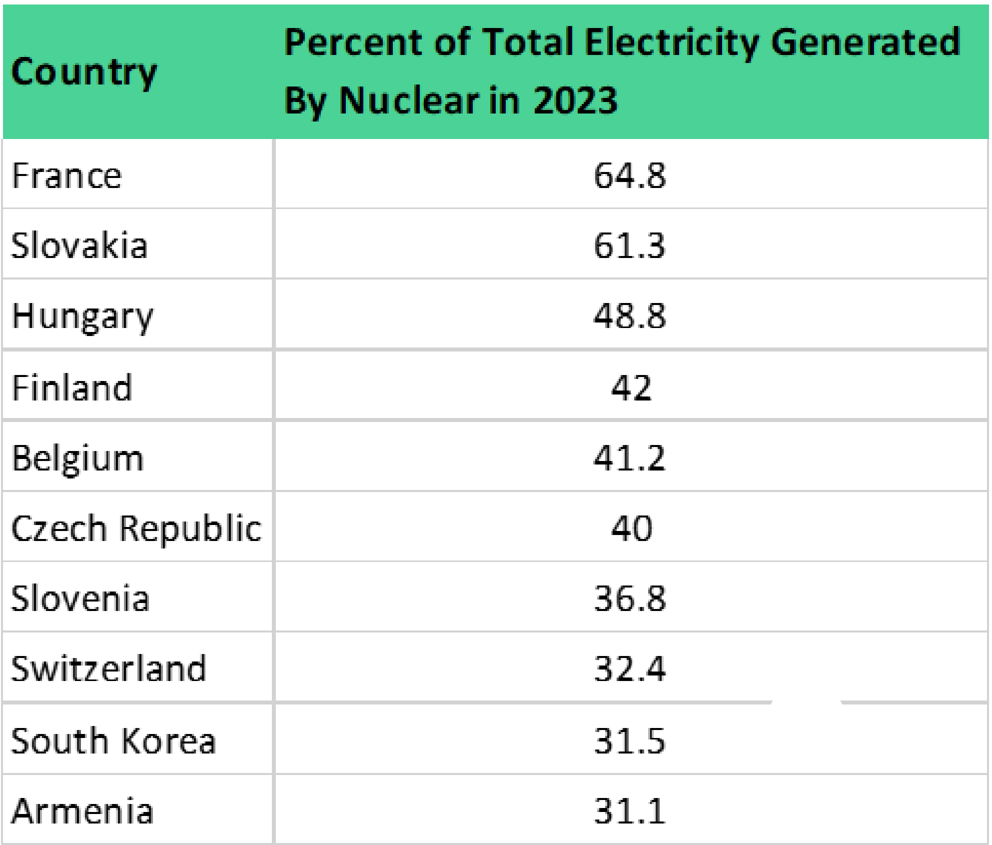


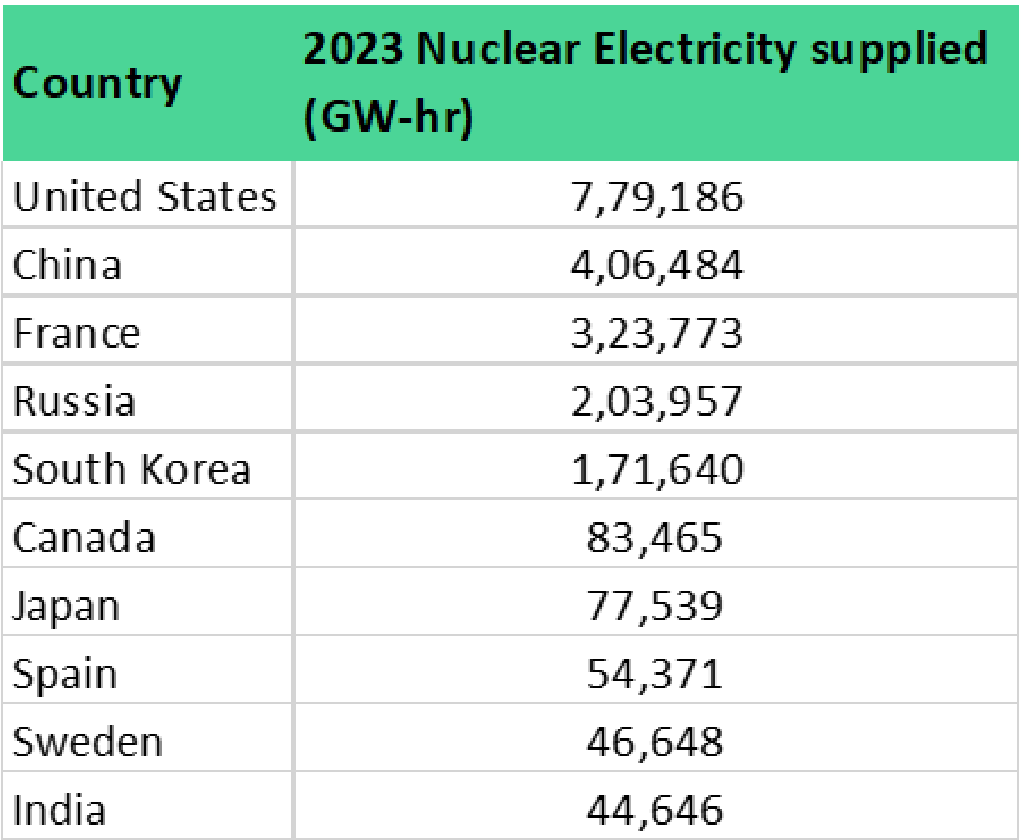
Figure 5: World electricity production by source 2022 (source: International Energy Agency)

Top 10 Nuclear Generating Countries - by Share of Nuclear Energy



Country	Percent of Total Electricity Generated By Nuclear in 2023
France	64.8
Slovakia	61.3
Hungary	48.8
Finland	42
Belgium	41.2
Czech Republic	40
Slovenia	36.8
Switzerland	32.4
South Korea	31.5
Armenia	31.1

Top 10 Nuclear Generating Countries - by Generation



Country	2023 Nuclear Electricity supplied (GW-hr)
United States	7,79,186
China	4,06,484
France	3,23,773
Russia	2,03,957
South Korea	1,71,640
Canada	83,465
Japan	77,539
Spain	54,371
Sweden	46,648
India	44,646

Source: International Atomic Energy Agency; U.S. Energy Information Administration

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