

Energy Sector in India

Installed Capacity in India

- India is the third largest producer of electricity in the world.
- The total installed generation capacity of India as of May 31, 2023, is 417.67 GW. Out of which, total fossil fuel capacity is 237.27 GW, total non-fossil fuel capacity (Including hydro) is 173.62 GW, and nuclear capacity is 6.78 GW.
- India's electricity sector is dominated by fossil fuels, in particular coal, which supplies about 49.1 % of the country's total production of energy by commercial sources.

Installed Generation Capacity (as of May 31, 2023)

Category	Installed Generation Capacity (GW)	% Share in Total
Fossil Fuels		
Coal	205.24	49.1%
Gas	24.82	6.0%
Lignite	6.62	1.6%
Diesel	0.59	0.1%
<i>Total Fossil Fuel</i>	<i>237.27</i>	<i>56.8%</i>
Non-Fossil Fuels		
Hydro	46.85	11.2%
Wind	42.87	10.3%
Solar	67.08	16.1%
Others (BM, Waste to Energy, Small Hydro)	15.75	4.3%
<i>Total Non-Fossil (including Hydro)</i>	<i>173.62</i>	<i>41.4%</i>
Nuclear	6.78	1.6%

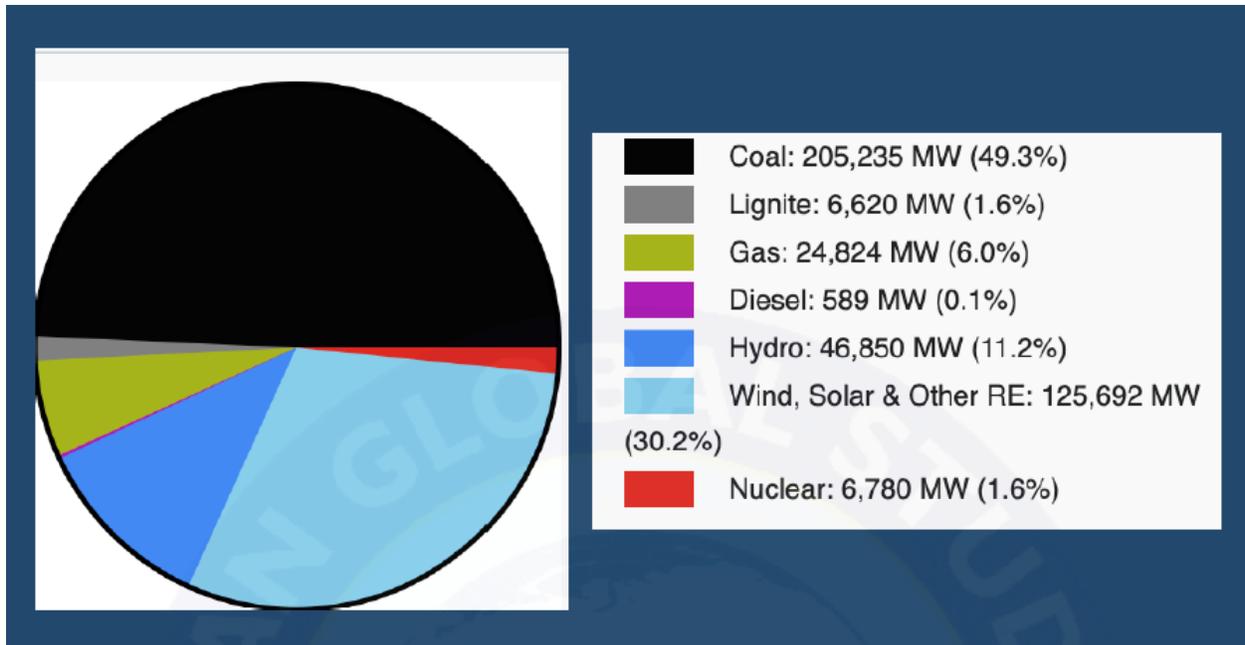
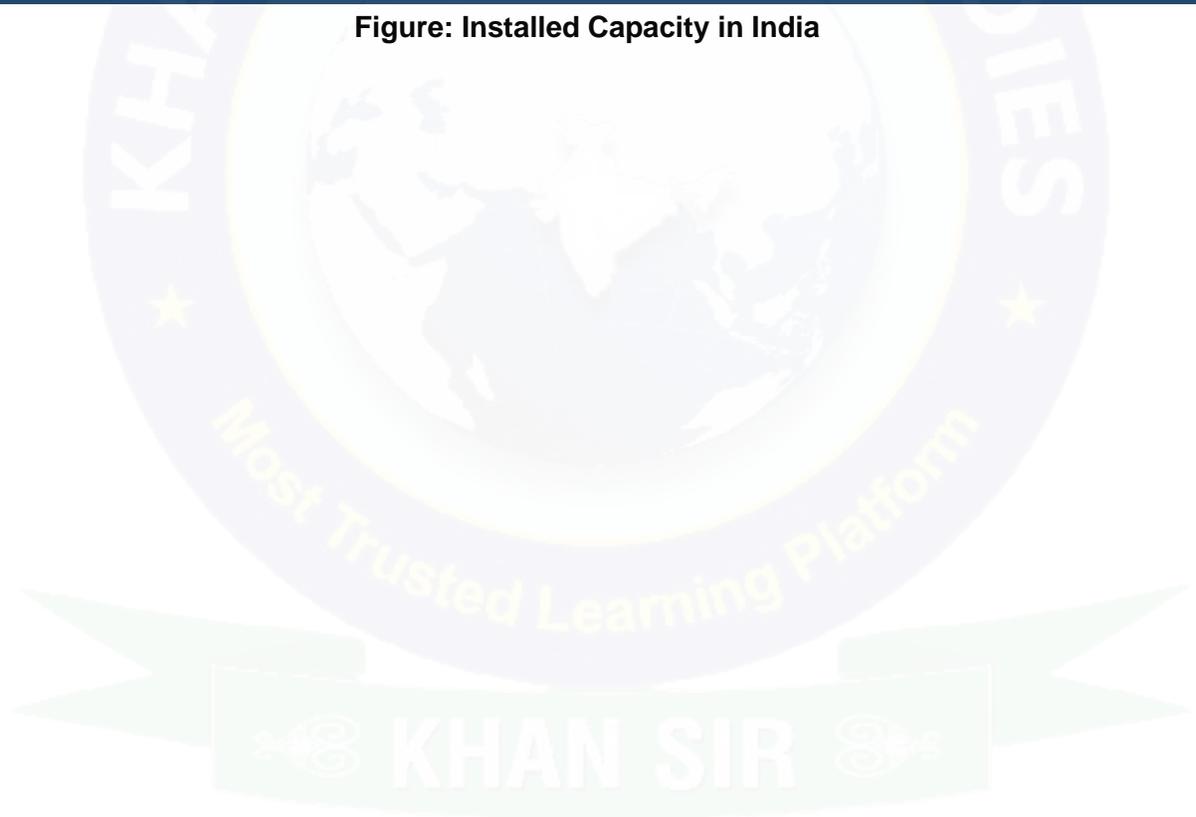


Figure: Installed Capacity in India



Coal Based Power in India

India's Coal Reserves

- According to India's Ministry of Coal, the country's total cumulative coal reserves were estimated at 361.41 billion tonnes (as of April 01, 2022).
- The majority of extracted coal is used for electricity production. The remaining coal is used for cement, steel and other industries.
- The coal reserves are primarily concentrated in five states: Odisha (88,104.60 million tonnes), Jharkhand (86,660.10 million tonnes), Chhattisgarh (74,191.76 million tonnes), West Bengal (33,871.25 million tonnes), and Madhya Pradesh (30,916.73 million tonnes).
- At current consumption rates, these reserves are projected to last approximately 111 years.
- This substantial reserve base positions India as the 4th largest country globally (after the USA, Australia, and China) in terms of coal reserves.

Problems of Using Hydrocarbons

Air Pollution

- Indian cities frequently appear among the most polluted in the world. The burning of coal in thermal power plants contributes significantly to air pollution levels in cities like Delhi, where air quality often falls into the "hazardous" category.

Greenhouse Gas Emissions

- Hydrocarbons, especially methane, contribute to the greenhouse effect. Methane oxidized into carbon dioxide (CO₂), increasing its concentration in the atmosphere and contributing to global warming.
- As per a report by the Ministry of Environment, Forest and Climate Change, India's carbon dioxide emissions from thermal power plants were over 1,000 million tonnes in 2019.

Water Scarcity

- Thermal power plants consume large amounts of water. Approximately 90% of India's thermal power generation relies on freshwater for cooling.
- Power plants consume about 20% as much water as India's entire population uses for domestic purposes.
- Approximately 278 million people in India are already facing the harsh reality of inadequate access to clean water. And the presence of 40% of India's thermal power plants in areas facing high water stress is putting more pressure in those areas.

Health Impacts

- Burning fossil fuels, especially from coal, releases pollutants into the air, which can aggravate respiratory conditions and lead to various health issues.
- Indian Council of Medical Research (ICMR) has reported that air pollution causes about 3 million deaths in India annually.

Energy Security Concerns

- India imports over 80% of its crude oil requirements. In 2020, India faced supply chain disruptions due to geopolitical tensions in the Middle East, underlining the vulnerability associated with heavy reliance on imported fossil fuels for energy.

Mitigation Measures

Clean Coal Technology

- Clean coal technology (CCT) refers to a set of technologies designed to enhance the efficiency and environmental acceptability of coal throughout its life cycle.
- CCT aims to reduce harmful emissions and improve fuel efficiency during coal combustion or conversion. These include:
 - **Emission Control:** Technologies like flue-gas desulfurization capture pollutants such as sulfur dioxide (SO₂) and particulate matter.
 - **Carbon Capture:** Carbon Capture and Storage (CCS) isolates carbon dioxide (CO₂) from emissions and stores it underground to mitigate climate impact.
 - **Coal Gasification:** Converts coal into syngas, a cleaner-burning fuel, allowing for more environmentally friendly industrial applications.

Significance

- Enables responsible coal usage while aligning with global sustainability goals, critical for countries with abundant coal reserves like India.

Coal Gasification

- Coal gasification is an industrial process that converts coal into syngas (short for synthesis gas)—a mixture of hydrogen, carbon monoxide, and methane—through controlled reactions with oxygen and steam.
- It offers a cleaner and more efficient way to utilize abundant coal reserves, mitigating harmful emissions like sulfur dioxide and particulates.
- Syngas serves as a raw material for essential industrial products such as methanol, DME (Dimethoxyethane), ammonia, and ammonium nitrate.
- Four coal gasification plants are planned by Coal India Ltd in 2023-24 to produce these valuable chemicals, advancing India's move toward sustainable energy.

Renewable Source of Energy

- Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed.
- They are natural and self-replenishing, and usually have a low- or zero-carbon footprint.
- Examples of renewable energy sources (also known as unconventional energy sources) include solar energy, wind energy, energy from biomass, and hydel energy, including tidal energy.

Why Renewable Energy?

- Low carbon footprint and low greenhouse gas emissions.
- Continuously available.
- Greater energy security
- Improved energy access
- Enhanced employment opportunities as it supports employment in the renewable energy sector.

Renewable Energy in India

- India stands 4th globally in Renewable Energy Installed Capacity (including Large Hydro), 4th in Wind Power capacity and 4th in Solar Power capacity (as per REN21 Renewables 2022 Global Status Report).
- India set an ambitious target to install 175 gigawatts (GW) of renewable energy capacity by the year 2022. This comprehensive goal included:
 - 100 GW from solar power
 - 60 GW from wind power
 - 10 GW from bio-power
 - 5 GW from small hydro power
- The Ministry of New and Renewable Energy (MNRE) is the nodal Ministry for all matters relating to new and renewable energy in India.

Recent Development

- India has set an enhanced target at the COP26 of 500 GW of non-fossil fuel-based energy by 2030. This is the world's largest expansion plan in renewable energy.
- After India's 2070 Net Zero announcement in 2022, India updated its Nationally Determined Contributions (NDC) to commit to 50% installed capacity from non-fossil fuels by 2030.
- Central Electricity Authority (CEA) projects that India will exceed its renewable energy target, achieving 57.4% of installed power capacity from green sources by 2026-27, against the committed 50% by 2030.
- However, due to the variable nature of renewable sources like solar and wind, only 35.04% of total electricity generated is expected to come from renewable sources by 2026-27, and 43.96% by 2031-32.
- By 2031-32, the total capacity is estimated to be 900,422 MW, with renewable energy making up 68% of this mix.

Solar Energy in India

How do Solar Panels Work?

- Each Solar cell has a thin semiconductor wafer which is made up of two layers of silicon. Silicon semiconductors can act as both conductors as well as insulators.
- One silicon layer is positively charged known as the N-type and the other silicon layer is negatively charged known as the P-type.
- N-type gives away electrons easily while on the other side P-side semiconductor receives the extra electrons in the electric field. This positive and negative layer hence compliments the formation of an electric field on the solar panel.
- Energy from the sun comes on the earth in the form of little packets called photons. When the sunlight strikes these photovoltaic cells already forming an electric field, the photons of sunlight startle the electrons inside these cells activating them to start flowing.
- These loose electrons that start flowing on the electric field further create the electric current.
- The electrical energy which we get from the solar energy through the photovoltaic cells is normally known as the Direct current (DC) electricity.
- To convert DC into alternating current (AC) special solar inverters need to be installed. The inverter turns DC electricity to 120 volts AC that can be further put into immediate use for the home appliances and leftover electricity goes back to the grid.
- Net metering is a billing mechanism that credits solar energy system owners for the electricity they add to the grid.

Advantages and Disadvantages of Solar Energy

Advantages

- Cleanest form of energy because it produces no carbon dioxide emissions.
- Cheap, as solar power systems do not require much maintenance, just needs to be cleaned twice every year. Once installed, solar panels provide free energy from the sun.
- Solar energy can be stored in batteries, ensuring a steady and reliable supply even when the sun isn't shining.
- In far-flung regions, where grid access is impractical, solar provides a lifeline.
- Usage of solar power significantly reduces electricity bills.
- Decentralized renewable energy solutions like solar energy are supporting several traditional rural trades and livelihoods in India.
- Solar energy is used for various purposes. Anything can generate electricity or heat (solar thermal) by solar energy.

Disadvantages

- Solar production decreases during cloudy days and winters.
- The installation and initial material costs for solar panels can be expensive.
- Solar panels require significant space for installation.
- Some solar technologies rely on rare materials, which can be a limitation.
- Grid integration of solar energy is also difficult.

Solar Energy Potential of India

- India is among the Tropical countries which receive ample solar insolation throughout the year. About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day.
- India ranks fourth globally (after China, the USA and Japan) in terms of solar power generation. Total solar power capacity installed in the country as of December 2023 is 73.32 GW.
- The top seven states in terms of highest installed capacity include Rajasthan (17.83GW), Gujarat (10.13 GW), Karnataka (9.05 GW), Tamil Nadu (6.89 GW), Maharashtra (4.87 GW), Telangana (4.69 GW) and Andhra Pradesh (4.55 GW).
- The National Institute of Solar Energy estimates India's solar potential to be about 748 GW, assuming 3% of the wasteland is covered by Solar PV modules.
- National Institute of Solar Energy, an autonomous institution of MNRE (Ministry of New and Renewable Energy) is the apex institute for research and development in the field of Solar Energy.

Initiatives Taken to Promote Solar Energy in India

National Solar Mission (NSM)

- It was **launched in January 2010**.
- The initial target of NSM was to install 20 GW solar power by 2022. This was upscaled to **100 GW** in early 2015.
- The objective of the National Solar Mission is to establish India as a global leader in solar energy.
- The Mission adopts a **three-phase approach**, Phase 1 (up to 2012 -13), Phase 2 (2013 - 17) and Phase 3 (2017 - 22).
- The immediate aim of the Mission is to focus on setting up an enabling environment for solar technology penetration in the country both at a centralized and decentralized level.

Solar Parks

- A solar park is a large area of land equipped with common infrastructure such as transmission systems, roads, water supply, drainage, and communication networks, facilitating hassle-free setup for solar project developers.
- The scheme was Initiated by the Ministry of New & Renewable Energy on December 12, 2014.
- Original aim was to develop 25 Solar Parks (100 MW+) and Ultra Mega Solar Power Projects (500MW+) with a total installed capacity of 20,000 MW within 5 years starting from 2014-15.
- The scheme's capacity was increased to 40,000 MW on March 21, 2017.
- The parks are planned to be operational by 2023-24.

Solar energy Tariff

- Solar tariff is the rate/cost at which one purchases the electricity from the installer/owner of a solar system under a Power Purchase Agreement (PPA). The rate is agreed upon for a certain period of time as per the clause of the agreement.
- In India, the solar tariff has come down from around Rs 18/kWh in 2010 to Rs. 2.44/kWh in 2018.

- As of now, in 2024, the prevailing tariff stands at Rs. 2.85/kWh.
- Various factors that influence solar tariffs include economies of scale, land availability, power evacuation systems, solar resource and location, policy and regulatory environment, technology and innovation, and financial factors.
- Solar tariffs in India across different categories are:
 - **Industry Average:** The industry average for solar tariffs in India is approximately INR 6.3 per kilowatt-hour (kWh).
 - **Commercial Consumers:** Commercial consumers typically pay higher tariffs due to their higher energy consumption. On average, commercial tariffs are around INR 7.7 per kWh. In Maharashtra, commercial tariffs can peak at INR 11 per kWh.
 - **Rooftop Solar Power Tariffs:** For rooftop solar installations, the tariffs vary based on factors like system size, location, and subsidies. Without any subsidy, rooftop solar power tariffs typically range from INR 5 to 8 per kWh.
 - **New Projects:** Since 2019, most newly-auctioned solar projects in India have tariffs in the range of INR 2.50 to 2.87 per kWh.

International Solar Alliance

- The International Solar Alliance (ISA) is an intergovernmental organization that was launched in 2015 during the Paris Climate Conference.
- The ISA was conceived as a joint effort by India and France to mobilize efforts against climate change through deployment of solar energy solutions.
- It is an alliance of more than 121 sunshine countries, primarily situated between the Tropic of Cancer and the Tropic of Capricorn, where they bask in abundant sunshine for over 180 days per year.
- It aims to promote the use of solar energy globally and focuses on increasing the deployment of solar technologies for energy access, energy security, and sustainable development.
- ISA has evolved into a treaty-based international organization since December 2017.
- Currently, 116 countries are signatories to the ISA Framework Agreement. 94 countries have taken the necessary steps to ratify the agreement and become full-fledged members.
- The ISA's headquarters is situated in Gurugram, NCR, India.

Purpose and Approach

- The ISA is an action-oriented, member-driven platform aimed at increasing the deployment of solar energy technologies.
- It focuses on energy access, energy security, and energy transition in its member countries.
- Special emphasis is given to Least Developed Countries (LDCs) and Small Island Developing States (SIDS).

Strategic Goals

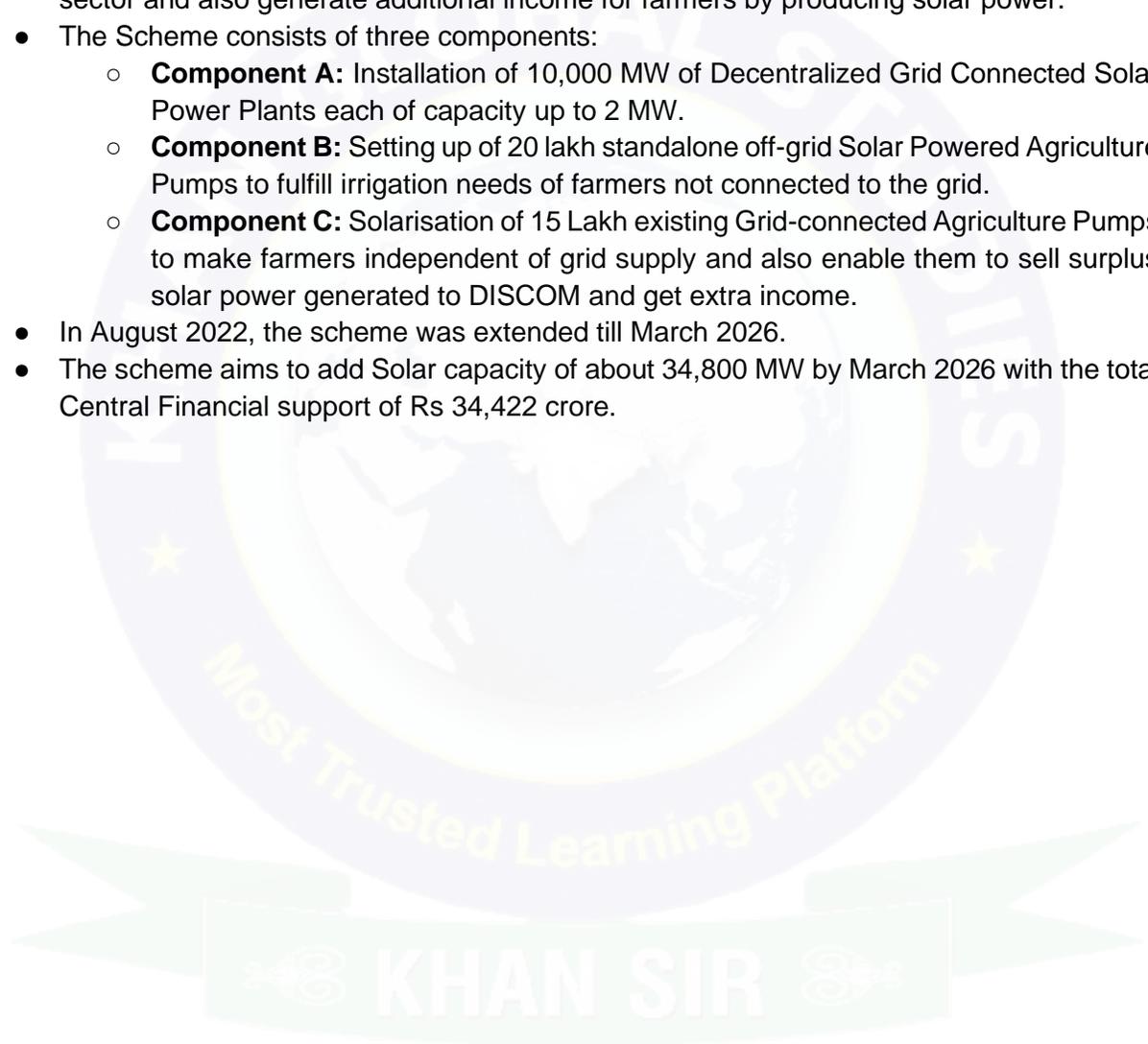
- The ISA is guided by its 'Towards 1000' strategy.
- The strategy aims to mobilize USD 1,000 billion in solar energy investments by 2030.
- It also targets delivering energy access to 1,000 million people and installing 1,000 GW of solar energy capacity.
- The strategy aims to mitigate 1,000 million tonnes of CO₂ emissions annually.

Programmatic Approach

- The ISA currently has 9 comprehensive programmes, each targeting a specific application of solar energy.
- Activities are focused on three priority areas:
 - Analytics & Advocacy
 - Capacity Building
 - Programmatic Support.

KUSUM Scheme

- Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahaabhiyan (PM-KUSUM) was launched by MNRE in 2019 to provide energy and water security, de-dieselise the farm sector and also generate additional income for farmers by producing solar power.
- The Scheme consists of three components:
 - **Component A:** Installation of 10,000 MW of Decentralized Grid Connected Solar Power Plants each of capacity up to 2 MW.
 - **Component B:** Setting up of 20 lakh standalone off-grid Solar Powered Agriculture Pumps to fulfill irrigation needs of farmers not connected to the grid.
 - **Component C:** Solarisation of 15 Lakh existing Grid-connected Agriculture Pumps to make farmers independent of grid supply and also enable them to sell surplus solar power generated to DISCOM and get extra income.
- In August 2022, the scheme was extended till March 2026.
- The scheme aims to add Solar capacity of about 34,800 MW by March 2026 with the total Central Financial support of Rs 34,422 crore.



Wind Energy in India

- Wind energy is a type of kinetic energy that is associated with natural wind or air flows in the earth's atmosphere.
- Wind turbines **utilize kinetic energy from the natural wind to generate electricity**. These wind turbines **convert the wind energy into mechanical power**, which is then converted to electric power to generate electricity.
- A wind farm is a **collection of wind turbines grouped together in a particular location** that is used collectively for the generation of electricity.
- There are two types of wind farms: **onshore wind farms** (power generated by wind turbines that are located on land and use the wind to generate electricity) and **offshore wind farms** (power generated by wind power when wind over open water, usually in the ocean, is used to generate power).

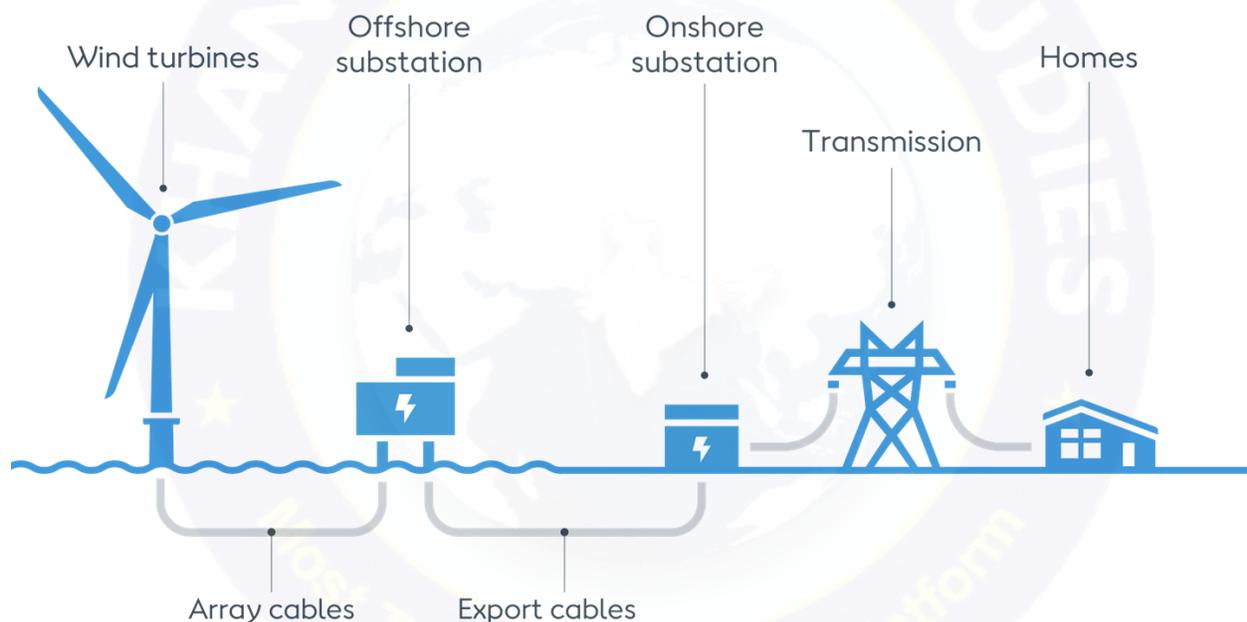


Figure. Wind Energy

Wind Energy Generation in India

- India ranks 4th globally after China, the United States and Germany, in terms of installed wind energy capacity, with 42.02 GW (onshore wind).
- As of April 2023, **Gujarat is the leading state in India** in terms of installed wind power capacity. The region has a wind energy capacity of over 10 gigawatts, which is almost one-fourth of the total wind capacity installed in the country.
- The Ministry of New & Renewable Energy (MNRE) is the Nodal Ministry, and the **National Institute of Wind Energy (NIWE) is the Nodal Agency** for the development of Offshore Wind Energy in India.

List of Largest Wind Power Plants in India

Sr. No.	Wind Power Plant	Installed Capacity (MW)
1.	Muppandal Wind Power Plant, Tamil Nadu	1500
2.	Jaisalmer Wind Park, Rajasthan	1064
3.	Brahmanvel wind farms, Maharashtra	528
4.	Kayathar, Tamil Nadu	300
5.	Dhalgaon wind farms, Maharashtra	278

Government Schemes, Policies and Initiatives

National Offshore Wind Energy Policy, 2015

- The Government of India notified National Offshore Wind Energy Policy, 2015 on 6 October 2015 for the development of offshore wind power in the country.
- The policy provides for **offshore wind power development up to a seaward distance of 200 nautical miles** from the baseline, i.e., up to the country's Exclusive Economic Zone (EEZ).
- Objectives of the National Offshore Wind Energy Policy are:
 - Encouraging investment in energy infrastructure.
 - Promoting spatial planning and management of maritime renewable energy resources in India's EEZ through suitable incentives.
 - Attaining energy security.
 - Reducing carbon emissions.
 - Boosting the indigenisation of offshore wind energy technologies.
 - Creating skilled manpower and employment in the offshore wind energy sector.
 - Developing coastal infrastructure and supply chain to support heavy construction & fabrication work and the operation & maintenance activities.

National Wind-Solar Hybrid Policy, 2018

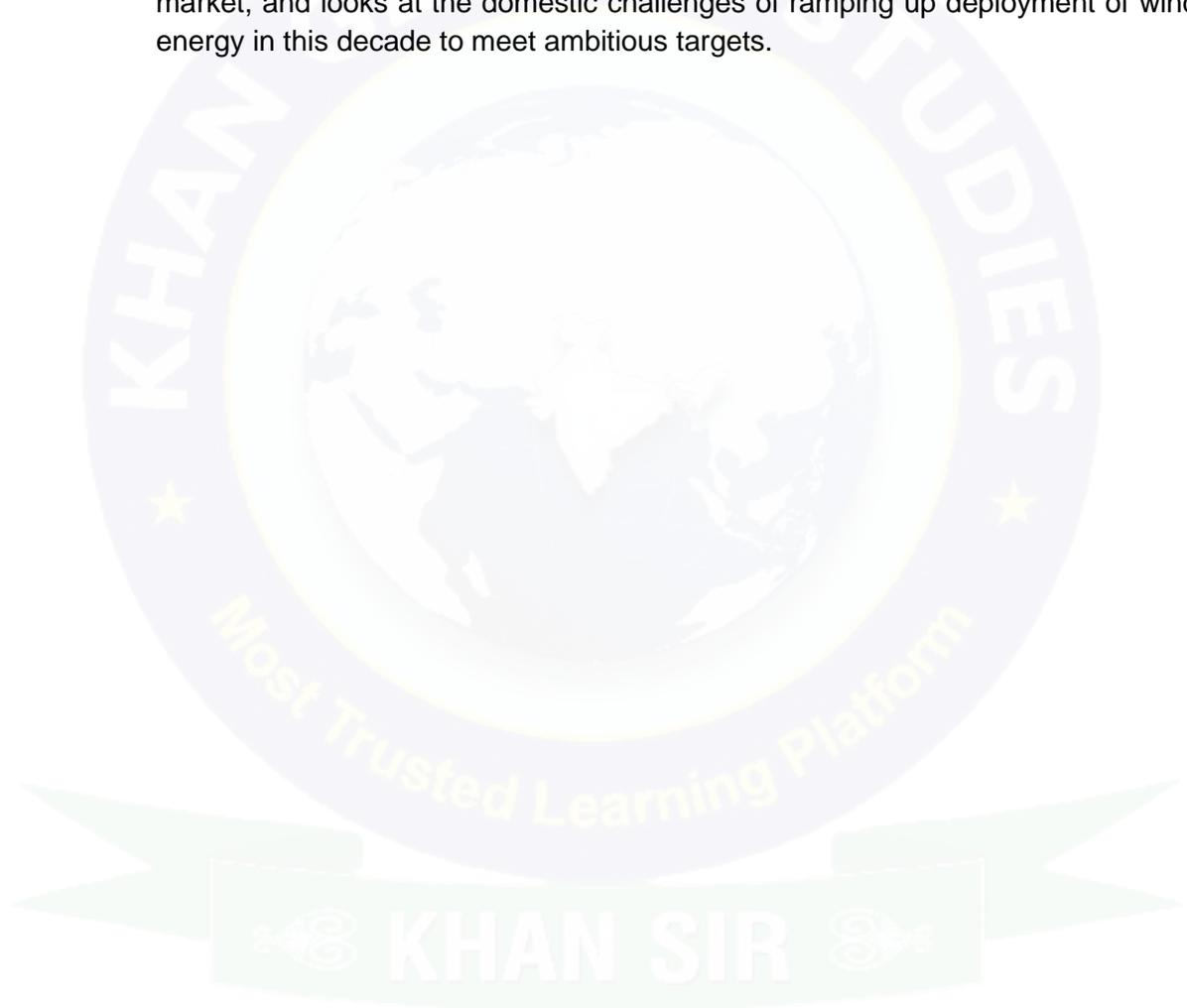
- The Ministry of New and Renewable Energy has issued the National Wind-Solar Hybrid Policy on 14 May 2018.
- The main objective of the Policy is to **provide a framework for promotion of large grid connected wind-solar PV hybrid systems** for optimal and efficient utilization of transmission infrastructure and land, reducing the variability in renewable power generation and achieving better grid stability.
- Policy also aims to encourage new technologies, methods and wayouts involving combined operation of wind and solar PV plants.
- The Government will encourage development of wind-solar hybrid systems through different schemes and programmes. All fiscal and financial incentives available to wind and solar power projects will also be made available to hybrid projects.

Recent Developments

- **Draft National Repowering Policy for Wind Power Projects, 2022** has been issued for stakeholders consultation. The objectives of the Repowering Policy are optimum utilization

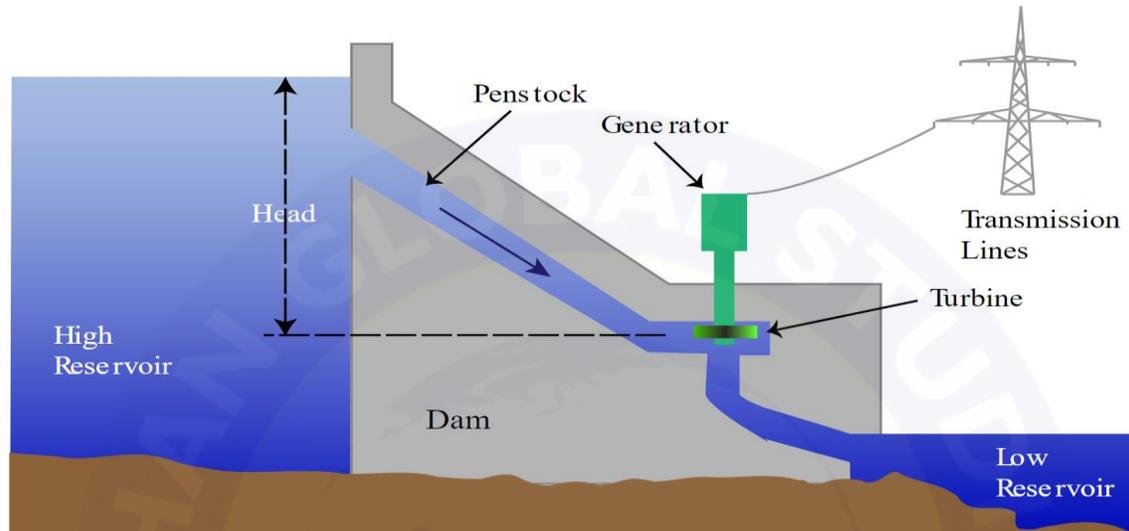
of Wind energy resources by maximizing energy (kWh) yield per sq.km of the project area and utilizing the latest state-of the art onshore Wind turbine technologies.

- The Ministry of New and Renewable Energy released a **revised strategy for the establishment of offshore wind energy projects** on August 17, 2023. This strategy has been revised after considering the feedback shared by several offshore developers. This provides a roadmap for **achieving 30 GW of offshore wind energy targets by 2030**.
- According to the report **From local wind power to global export hub: 'India Wind Energy Market Outlook 2023-2027'** published by the Global Wind Energy Council (GWEC) and MEC Intelligence (MEC+), India will add 22 gigawatt (GW) of wind energy capacity in India over the next five years, at the current pace of growth.
 - The report emphasizes the huge supply chain opportunities for India in the export market, and looks at the domestic challenges of ramping up deployment of wind energy in this decade to meet ambitious targets.



Hydropower

- Hydropower, or hydroelectric power uses the **natural flow of moving water to generate electricity.**



Hydroelectric Energy Production

- Hydropower technologies generate power by **using the elevation difference**, created by a dam or diversion structure, of water flowing in on one side and out, far below, on the other.
- As a renewable energy resource, hydro power is one of the most commercially developed. By building a dam or barrier, a large reservoir can be used to create a controlled flow of water that will drive a turbine, generating electricity.
- This energy source can often be more reliable than solar or wind power and also allows electricity to be stored for use when demand reaches a peak.

Hydropower in India

- In India, hydro power plants with a **capacity of 25 MW or below are classified as small hydro**. Hydro Power was looked after by the Ministry of Power prior to 1989.
- In 1989, plant capacity up to 3MW and below was transferred to the Ministry of New and Renewable Energy (MNRE). Subsequently plant capacity up to 25 MW and below was entrusted with the MNRE in November 1999.
- The first hydroelectric power plant in India is **Sidrapong hydroelectric power station** commissioned in 1897 in Darjeeling, followed by the second in Karnataka in 1902.
- The hydropower potential of India is around **1,45,000 MW** and at 60% load factor, it can meet the demand of around 85,000 MW. The estimated potential for power generation from Small hydropower projects is about 20,000 MW.
- India's **largest hydroelectric power plant is the Koyna Hydroelectric Project**, located near Patan in the Satara district of Maharashtra. It has a capacity of 1,960MW.

Measures Taken to Promote Hydro Power in India

- The Government had taken several policy initiatives for hydropower development in the country viz., National Electricity Policy 2005, National Tariff Policy 2016, National

Rehabilitation & Resettlement Policy 2007 and Right to Fair Compensation & Transparency in Land Acquisition, Rehabilitation and Resettlement Act, 2013.

- The Government has also issued measures to promote Hydro Power Sector on 8th March, 2019 under which the following provisions have been made:
 - **Declaring Large Hydro Projects (>25 MW) as Renewable Energy source.**
 - **Tariff rationalization** measures for bringing down hydropower tariff.
 - Budgetary Support for Flood Moderation/ Storage Hydro Electric Projects (HEPs).
 - Budgetary Support to Cost of Enabling Infrastructure i.e., roads/bridges.
- Subsequently, the **Hydro Purchase Obligation (HPO)** trajectory, for the period 2021-22 to 2029-30 has also been notified by the Government on 29.01.2021.



Biomass Power

- Biomass is **renewable organic material** that comes from plants and animals. Biomass contains stored chemical energy from the sun that is produced by plants through photosynthesis.
- Biomass can be burned directly for heat or converted to liquid and gaseous fuels through various processes.
- Biomass is used for heating and electricity generation and as a transportation fuel. Biomass is an important fuel in many countries, especially for cooking and heating in developing countries.
- Biomass sources for energy include:
 - **Wood and wood processing waste**—firewood, wood pellets, and wood chips, lumber and furniture mill sawdust and waste, and black liquor from pulp and paper mills.
 - **Agricultural crops and waste materials**—corn, soybeans, sugar cane, switchgrass, woody plants, algae, and crop and food processing residues.
 - **Biogenic materials in municipal solid waste**—paper products; cotton and wool products; and food, and wood wastes.
 - **Animal manure and human sewage** for producing biogas (renewable natural gas).

Biomass Energy in India

- About 32% of the total primary energy use in the country is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs.
- According to the Ministry of New and Renewable Energy, India's total **biomass potential is estimated to be about 18,000 MW**, with the potential for generating 146,500 million units of electricity per year.
- Biomass market in India is anticipated to attain Rs 32,000 crore by Fiscal Year 2030-31 aided by Government schemes along with investments from global green energy companies.

Biogas

- Biogas is produced when biodegradable organic materials/wastes such as cattle-dung, biomass from farms, gardens, kitchens, industry, poultry droppings, night soil and municipals wastes are subjected to a scientific process, called **Anaerobic Digestion** in a Biogas Plants.
- Biogas is the **mixture of gases** (primarily methane (CH₄) and Carbon di-oxide (CO₂) and traces of Hydrogen Sulfide (H₂S), Moisture) and has a calorific value of about 5000 kcal per m³.
- The digested slurry produced from Biogas Plants as a by-product is a better source of nutrient enriched organic manure for use in Agriculture. It not only helps in improving the crop yield but also maintains soil health.
- The Ministry of New and Renewable Energy promoted installation of biogas plants by implementing 2 Central Sector Schemes under Off-Grid/distributed and decentralized Renewable Power, which include:

- **New National Biogas and Organic Manure Programme (NNBOMP)**, for Biogas Plant size ranging from 1 cu.m. to 25 cu.m. per day.
- **Biogas Power Generation (Off-grid) and Thermal energy application Programme (BPGTP)**, for setting up biogas plants in the size range of 30 m³ to 2500 m³ per day, for corresponding power generation capacity range of 3 kW to 250 kW from biogas or raw biogas for thermal energy /cooling applications.

Measures Taken to Promote Biomass Power in India

The Government has taken various steps to promote the establishment of new and efficient biomass energy plants across the country which, inter alia, include the following:

- The Ministry of New and Renewable Energy has notified the **National Bioenergy Programme** in November, 2022 with budgetary outlay of Rs. 1715 Crore for a **period 01.04.2021 to 31.03.2026** to be implemented in two phases. This Programme supports setting up of Bioenergy plants by providing Central financial assistance.
- The Ministry of Petroleum and Natural Gas has launched the **Sustainable Alternative Towards Affordable Transportation (SATAT) initiative** in October, 2018 which assures offtake of BioCNG/Compressed Biogas (CBG) after purification through Oil Marketing Companies (OMCs) for sale as automotive fuels.
- Under the **GOBARDHAN scheme** implemented by Department of Drinking Water and Sanitation, Ministry of Jal Shakti, a financial assistance upto Rs. 50.00 lakh per district is available for setting up of community biogas plants in villages, blocks / district.
- The Ministry of Power has notified the **SAMARTH Mission (National Mission on Use of Biomass in Thermal Power Plants)** for promoting the blending of biomass in the existing coal powered thermal power plants.
- The Central Pollution Control Board, Ministry of Environment, Forest and Climate Change has notified guidelines to provide financial support for setting up of Biomass Pellet plants in the NCT of Delhi, states of Punjab and Haryana and NCR districts of Rajasthan and Uttar Pradesh.

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Hydrogen Fuel

- Hydrogen (H₂) is an alternative fuel that can be produced from diverse domestic resources.
- It is a clean fuel that, when consumed in a fuel cell, produces only water.
- It can be used in cars, in houses, for portable power, and in many more applications.
- Hydrogen can be deployed as a fuel in two distinct ways: in fuel cells which produce electricity, and via combustion to generate heat.
- Different types of hydrogen production are labelled by colour. “Grey” hydrogen is made from fossil fuels using steam reformation. “Blue” hydrogen also uses fossil fuels but captures and stores the CO₂. “Green” hydrogen is produced using electrolysis of water with electricity generated by renewable energy.

Hydrogen fuel cell

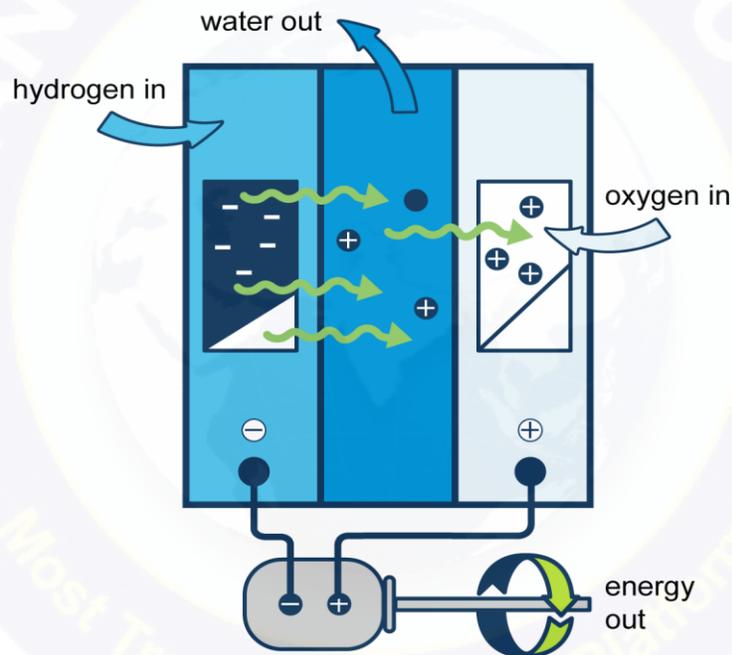


Figure. Hydrogen Fuel Cell

Production of Hydrogen Fuel

Hydrogen fuel can be produced through several methods. The most common methods are natural gas reforming (a thermal process), and electrolysis. Other methods include solar-driven and biological processes.

Thermal processes

- Thermal processes for hydrogen production typically involve steam reforming, a high-temperature process in which steam reacts with a hydrocarbon fuel to produce hydrogen.
- Many hydrocarbon fuels can be reformed to produce hydrogen, including natural gas, diesel, renewable liquid fuels, gasified coal, or gasified biomass.

Electrolytic processes

- Water can be separated into oxygen and hydrogen through a process called electrolysis.

- Electrolytic processes take place in an electrolyzer, which functions much like a fuel cell in reverse—instead of using the energy of a hydrogen molecule, like a fuel cell does, an electrolyzer creates hydrogen from water molecules.

Solar-driven processes

- Solar-driven processes use light as the agent for hydrogen production.
- There are a few solar-driven processes, including photobiological, photoelectrochemical, and solar thermochemical.
- Photobiological processes use the natural photosynthetic activity of bacteria and green algae to produce hydrogen.
- Photoelectrochemical processes use specialized semiconductors to separate water into hydrogen and oxygen.
- Solar thermochemical hydrogen production uses concentrated solar power to drive water splitting reactions often along with other species such as metal oxides.

Biological processes

- Biological processes use microbes such as bacteria and microalgae and can produce hydrogen through biological reactions.
- In microbial biomass conversion, the microbes break down organic matter like biomass or wastewater to produce hydrogen, while in photobiological processes the microbes use sunlight as the energy source.

Hydrogen as a Fuel in India

- As part of the National Hydrogen mission, the Ministry of Petroleum & Natural Gas (MoPNG) is undertaking several hydrogen initiatives and demonstration projects ultimately designed to achieve a greater use of hydrogen within India's energy sector.
- MoPNG is actively driving initiatives related to green hydrogen, including production and utilization in refineries, hydrogen blending in natural gas pipelines, localization of electrolyzer-based technologies, and promoting bio-pathways for green hydrogen production.
- India's hydrogen ambitions are driven by its need to achieve emissions reductions, seize opportunities for economic development and technology innovation and secure energy independence and security.

Green Hydrogen

What is Green Hydrogen?

- As per the Ministry of New and Renewable Energy, the term "Green Hydrogen" has been defined as **hydrogen produced using renewable energy sources**, including but not limited to electrolysis and biomass conversion.
- This definition extends to encompass electricity generated from renewable sources, which is stored in energy storage systems or incorporated into the grid in compliance with pertinent regulations.

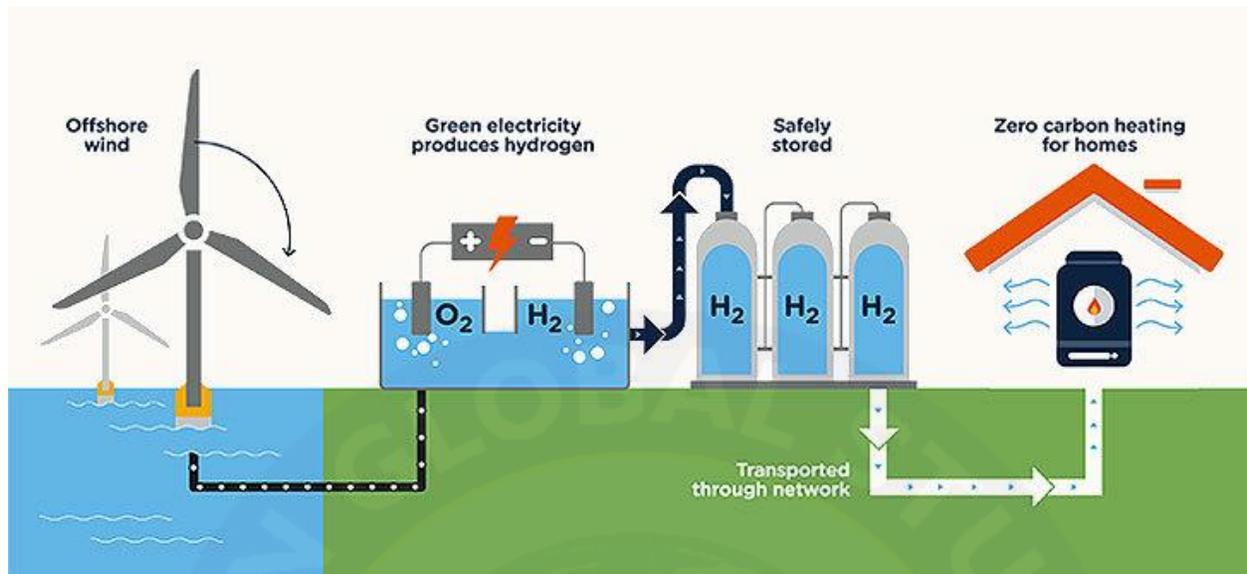


Figure. Green Hydrogen

How is Green Hydrogen Produced by Electrolysis?

- In this process, water is split into hydrogen (H_2) and oxygen (O_2) under the influence of electricity with zero carbon emissions.
- The water used in the electrolysis must contain salts and minerals to conduct the electricity.
- **Two electrodes** are immersed in the water and connected to a power source and a **direct current is applied**.
- The dissociation of hydrogen and oxygen occurs when the electrodes attract ions with an opposite charge to them.
- During the electrolysis, an oxidation-reduction reaction occurs due to the effect of the electricity.

Why is Grey Hydrogen a Problem?

- According to data from the International Energy Agency (IEA), some 94 million tonnes of hydrogen are consumed worldwide.
- The problem is that almost all of this hydrogen is produced from coal or natural gas, that is, it is obtained by the most polluting techniques for the planet.
- The production of this Grey hydrogen **emits 830 million tonnes of carbon dioxide per year**. This is the annual CO_2 emitted by the economies of Indonesia and the United Kingdom combined.
- Given this alarming data, green hydrogen can be an unrivaled tool to replace production models that contribute to climate change.

Benefits of Green Hydrogen

- **100 % sustainable**: Green hydrogen does not emit polluting gases either during combustion or during production. The only waste it generates is water.
- **Storable**: Green hydrogen can be compressed and stored in ad hoc tanks for a long time.

- **Versatile:** Green hydrogen can be transformed into electricity or synthetic gas and used for commercial, industrial or mobility purposes.
- **Renewable energy:** It uses natural resources that are not exhausted.
- **Transportable:** Because it is a very light element, compressed hydrogen tanks allow easier handling than lithium batteries because they are lighter, which facilitates transport as a result.
- **Household:** Green hydrogen can be stored in existing gas pipelines to power household appliances.

Limitations of Green Hydrogen

- **High cost:** Energy from renewable sources, which are key to generating green hydrogen through electrolysis, is more expensive to generate, which in turn makes hydrogen more expensive to obtain.
 - However, the fall in the price of renewable energies has opened a new window of opportunity for its cost to become increasingly competitive. Solar electricity is 10 times cheaper than it was a decade ago and wind energy costs less than half, making it possible for the electricity needed for the electrolysis process to be reduced in price.
- **High energy consumption:** Production of hydrogen in general and green hydrogen in particular requires more energy than other fuels.
- **Safety issues:** Hydrogen is a highly volatile and flammable element and extensive safety measures are therefore required to prevent leakage and explosions.
- **Investments:** Its implementation requires significant investments. It is said that USD 300 billion will be needed in the next few years globally for infrastructure and research.

Green Hydrogen in India

- India has set its sight on becoming **energy independent by 2047 and achieving Net Zero by 2070.**
- To achieve this target, increasing renewable energy use across all economic spheres is central to India's Energy Transition. Green Hydrogen is considered a promising alternative for enabling this transition.

National Green Hydrogen Mission

- The National Green Hydrogen Mission was approved by the Union Cabinet on January 4, 2022.
- It was launched on January 4, 2023 and had an outlay of Rs 19,744 crore, with the aim to make India a global hub for production, usage and export of green hydrogen.
- The mission aims to add to India's effort on becoming self-reliant through clean energy and become a model state in global clean energy transition.

Objectives

- Making India a leading producer and supplier of Green Hydrogen in the world.
- Creation of export opportunities for Green Hydrogen and its derivatives.
- Reduction in dependence on imported fossil fuels and feedstock.
- Development of indigenous manufacturing capabilities.
- Attracting investment and business opportunities for the industry.

- Creating opportunities for employment and economic development.
- Supporting R&D projects.

Mission Outcomes

The mission outcomes projected by 2030 are:

- **Development of green hydrogen production capacity of at least 5 MMT** (Million Metric Tonne) per annum with an associated renewable energy capacity addition of about 125 GW in the country.
- Over Rs. Eight lakh crore in total investments.
- Creation of **over Six lakh jobs**.
- Cumulative reduction in **fossil fuel imports over Rs. One lakh crore**.
- Abatement of nearly 50 MMT of annual greenhouse gas emissions.

Mission Sub-Components

- **SIGHT Programme:** Under the Strategic Interventions for Green Hydrogen Transition Programme (SIGHT), two distinct financial incentive mechanisms – targeting domestic manufacturing of electrolysers and production of Green Hydrogen – will be provided under the Mission.
- **Pilot projects:** The Mission will also support pilot projects in emerging end-use sectors and production pathways. Regions capable of supporting large scale production and/or utilization of Hydrogen will be identified and developed as Green Hydrogen Hubs.
- **R&D Projects:** Public-Private Partnership framework for R&D (Strategic Hydrogen Innovation Partnership – SHIP) will be facilitated under the Mission. R&D projects will be goal-oriented, time bound, and suitably scaled up to develop globally competitive technologies.
- **Skill Development:** A coordinated skill development programme will also be undertaken under the Mission.

Scope of Green Hydrogen in India

Hydrogen for Integrating Renewable Energy

- Hydrogen provides a means for storage of variable renewable energy for stabilizing its output.

Hydrogen in Industry

- In industry, hydrogen can potentially replace the coal and coke in iron and steel production.

Hydrogen has Potential to Reduce Fossil Fuel Imports

- At present, hydrogen produced from natural gas is widely utilized for production of nitrogenous fertilizers, and petrochemicals.
- Substituting this with green hydrogen could allow use of renewable energy in these important sectors and reduce import dependence.
- India's annual Ammonia consumption for fertilizer production is about 15 million tonnes, roughly 15 percent of this demand (over 2 million tonnes per annum) is currently met from imports.
- Mandating even 1 percent green ammonia share is likely to save about 0.4 million standard cubic feet per day of natural gas import.
- Use of hydrogen in the steel industry **could substitute imported coking coal**.

Hydrogen-Based Transport

- Fuel Cell Electric Vehicles (FCEVs) run on hydrogen fuel and have no harmful emissions.
- Battery Electric Vehicles (BEVs) may be suitable for light passenger vehicle segments for shorter driving range.
- For heavy duty vehicles with longer trip range, such as buses, trucks and other commercial vehicles, FCEVs are likely to become cost competitive in the coming years.

Green Hydrogen/ Green Ammonia Policy

- The Ministry of Power has notified Green Hydrogen/Green Ammonia Policy in February 2022 for production of Green Hydrogen or Green Ammonia using renewable sources of energy.
- The implementation of this Policy will provide clean fuel to the common people of the country. This will reduce dependence on fossil fuel and also reduce crude oil imports.

Provisions of the Green Hydrogen/Green Ammonia Policy

- Green Hydrogen / Ammonia manufacturers **may purchase renewable power from the power exchange** or set up renewable energy capacity themselves or through any other developer, anywhere.
- **Open access** will be granted within 15 days of receipt of application.
- The Green Hydrogen / Ammonia manufacturer can **bank his unconsumed renewable power**, up to 30 days, with a distribution company and take it back when required.
- Distribution licensees can also procure and supply Renewable Energy to the manufacturers of Green Hydrogen / Green Ammonia in their States at concessional prices which will only include the cost of procurement, wheeling charges and a small margin as determined by the State Commission.
- **Waiver of inter-state transmission charges** for a period of 25 years will be allowed to the manufacturers of Green Hydrogen and Green Ammonia for the projects commissioned before 30th June 2025.
- The manufacturers of Green Hydrogen / Ammonia and the renewable energy plant shall be given **connectivity to the grid on priority basis** to avoid any procedural delays.
- The benefit of **Renewable Purchase Obligation (RPO)** will be granted incentive to the hydrogen/Ammonia manufacturer and the Distribution licensee for consumption of renewable power.
- To ensure ease of doing business a single portal for carrying out all the activities including statutory clearances in a time bound manner will be set up by MNRE.
- Manufacturers of Green Hydrogen / Green Ammonia shall be allowed to set up bunkers near Ports for storage of Green Ammonia for export / use by shipping. The land for the storage for this purpose shall be provided by the respective Port Authorities at applicable charges.

Recent Development

Green Hydrogen Standard

In August 2023, MNRE issued the Green Hydrogen Standard for India. These standards have **defined what encompasses 'green' in green hydrogen**. It notified:

- The amount of carbon emissions that are allowed in the process of producing green hydrogen from renewable sources. This **covers both electrolysis- and biomass-based pathways.**
- It has defined green hydrogen as having a well-to-gate emission – including water treatment, electrolysis, gas purification, drying and compression of hydrogen – of **not more than 2 kg CO2 equivalent per kg of hydrogen produced.**
- The **Bureau of Energy Efficiency**, Ministry of Power, will be the nodal authority for green hydrogen production projects.

Significance of Green Hydrogen Standard

- It is a crucial step in eliminating any ambiguity regarding the criteria for classifying green hydrogen. By being among the pioneers in defining a standard for green hydrogen, India has significantly solidified its stature as a preeminent global frontrunner in this domain.
- It will also enable access to the benefit of the PLI (Production Linked Incentive) scheme of the government as per National Green Hydrogen Mission.
- The standard definition of green hydrogen in the Indian context will also help the certification and verification scheme expected to be launched by MNRE soon.

Guidelines for Implementation of Pilot Green Hydrogen Projects

- The Union Ministry of New and Renewable Energy on February 2, 2024 released scheme guidelines for implementation of pilot green hydrogen projects in the steel sector under the National Green Hydrogen Mission (NGHM).
- The government also allocated Rs 455 crore till financial year 2029-30 to promote the use of green hydrogen in the sector.
- The initiative would support steel plants for blending a small percentage of green hydrogen in their processes.
- The blending share can increase as cost economics improve and technologies advance.
- The scheme will provide support for development / selection / validation of commercially viable technologies using hydrogen in steel sector that:
 - Use 100 percent hydrogen in the direct reduced iron (DRI) process using a vertical shaft / kiln.
 - Use hydrogen in blast furnaces within prescribed limits.
 - Substitute fossil fuels with hydrogen in a gradual manner in DRI process.
 - Use hydrogen in any other innovative way to reduce carbon emissions in iron and steel production.

Nuclear Energy

Nuclear Energy

- Nuclear energy is a form of energy **released from the nucleus**, the core of atoms, made up of protons and neutrons.
- This source of energy can be produced in two ways: **fission** – when nuclei of atoms split into several parts – or **fusion** – when nuclei fuse together.

Types of Nuclear Reactions: Fission and Fusion

Nuclear Fission

- In 1938, German scientists **Otto Hahn and Fritz Strassman** discovered that when a uranium nucleus is bombarded with a neutron, it breaks up into two fragments of comparable masses with the release of energy.
- The process of **breaking up the nucleus of a heavier atom into two fragments** with the **release of a large amount of energy** is called nuclear fission. The fission is accompanied by the release of neutrons. The fission reactions with ${}_{92}\text{U}^{235}$ are represented as:
 - ${}_{92}\text{U}^{235} + {}_0\text{n}^1 \rightarrow {}_{56}\text{Ba}^{141} + {}_{36}\text{Kr}^{92} + 3 {}_0\text{n}^1 + \text{Energy}$

Chain Reaction

- Consider a neutron causing fission in a uranium nucleus producing three neutrons. The three neutrons in turn may cause fission in three uranium nuclei producing nine neutrons. These nine neutrons in turn may produce twenty seven neutrons and so on.
- A chain reaction is a **self propagating process** in which the **number of neutrons goes on multiplying** rapidly almost in a geometrical progression.
- Two types of chain reactions are possible:
 - In the **uncontrolled chain reaction**, the **number of neutrons multiply indefinitely** and the entire amount of energy is released within a fraction of a second. This type of chain reaction takes place in atom bombs.
 - In the **controlled chain reaction**, the number of **fission producing neutrons is kept constant** and is always equal to one. The reaction is sustained in a controlled manner. Controlled chain reaction takes place in a nuclear reactor.
- When a thermal neutron bombards the U^{235} nucleus, it breaks into two fission fragments and three fast neutrons. One neutron may escape and one neutron may be captured by U^{238} which decays to Np^{239} (Neptunium-239) and then to Pu^{239} (Plutonium-239). One neutron is available for carrying out chain reactions.
- The chain reaction is possible, only when the loss of neutrons is less than the neutrons produced.

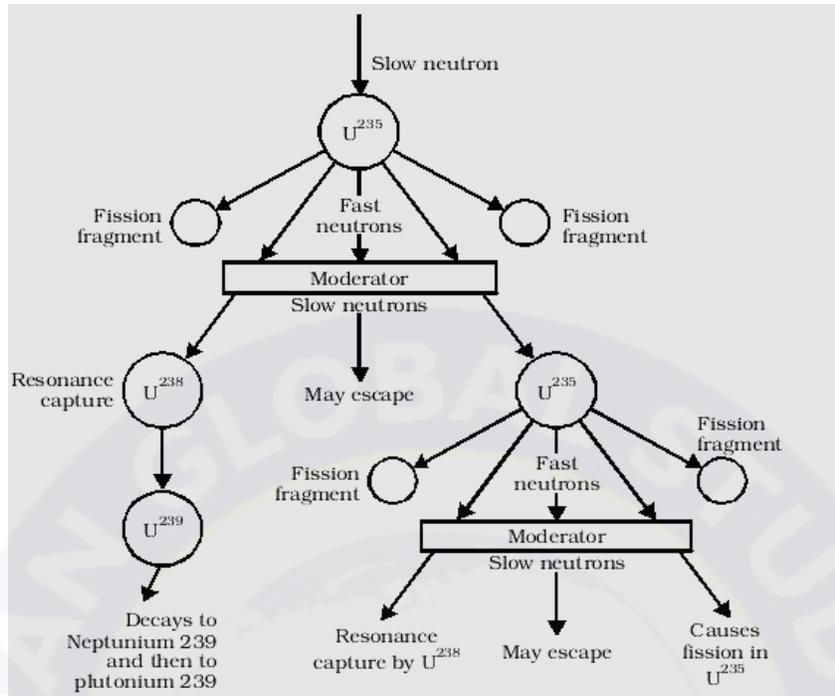


Figure. Controlled Chain Reaction

Nuclear Reactor

- A nuclear reactor is a device in which the nuclear fission reaction takes place in a self sustained and controlled manner. The **first nuclear reactor was built in 1942 at Chicago, USA.**
- Depending on the purpose for which the reactors are used, they may be classified into research reactors, production reactors and power reactors.
- Research reactors are used primarily to supply neutrons for research purposes and for production of radio-isotopes. The purpose of production reactors is to convert fertile (non-fissile but abundant) material into fissile material.
- The power reactor converts nuclear fission energy into electric power. The power reactors can be further classified into boiling water reactor, pressurized water reactor, pressurized heavy water reactor and fast breeder reactor depending upon the choice of the moderator and the coolant used.
- Numerous reactors of different designs have been constructed all over the world for a variety of purposes, but there exists a number of general features common to all the reactors.

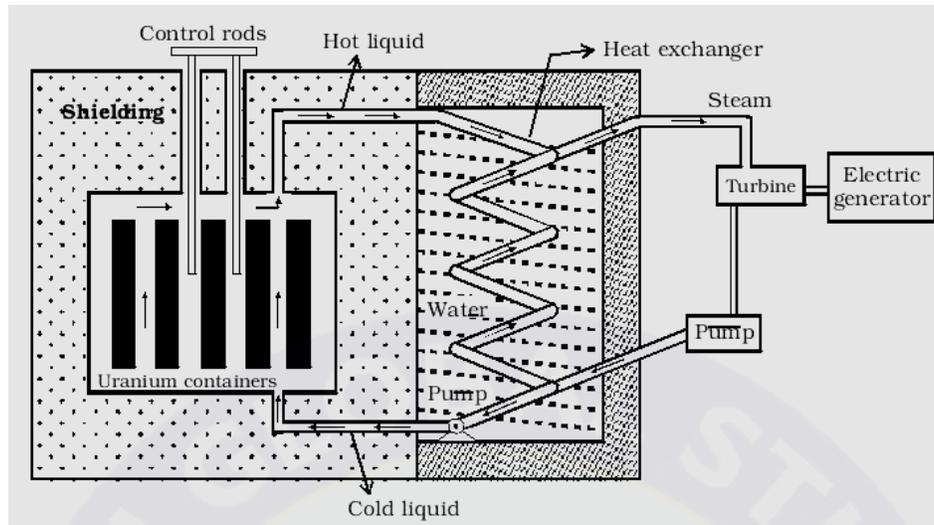


Figure. Schematic Design of a Nuclear Reactor

Fissile Material

- The fissile material or nuclear fuel generally used is ${}_{92}\text{U}^{235}$. But this exists only in a small amount (0.7%) in natural uranium.
- **Natural uranium is enriched with more ${}_{92}\text{U}^{235}$ (2 – 5%)** and this low enriched uranium is used as fuel in some reactors. Other than ${}_{92}\text{U}^{235}$, the fissile isotopes U^{233} and Pu^{239} are also used as fuel in some of the reactors.
- In the pressurized heavy water reactors (PHWR) built in India, natural uranium oxide is used as fuel. Tiny pellets of uranium oxide are packed in thin tubes of zirconium alloy and sealed to form a fuel rod. Nineteen such rods are tied together to form a fuel bundle.
- The reactor vessel which goes by the name 'Calandria' has about three hundred tubes passing through it. The fuel bundles are placed in these tubes. The part of the reactor vessel which contains the fuel rods is known as reactor core.

Moderator

- The function of a moderator is to **slow down fast neutrons** produced in the fission process. Ordinary water and heavy water are the commonly used moderators.
- A good moderator slows down neutrons by elastic collisions and it does not remove them by absorption. The moderator is present in the space between the fuel rods in a channel. Graphite is also used as a moderator in some countries.
- In fast breeder reactors, the fission chain reaction is sustained by fast neutrons and hence no moderator is required.

Neutron source

- A source of neutrons is required to initiate the fission chain reaction for the first time. **A mixture of beryllium with plutonium or radium or polonium** is commonly used as a source of neutrons.

Control Rods

- The control rods are used to control the chain reaction. They are very good absorbers of neutrons. They take up neutrons without fissioning. Lowering them into the reactor core will slow down the reaction.

- The commonly used control rods are made up of elements like **boron** or **cadmium**. By pushing them in or pulling out, the reaction rate can be controlled.

Cooling System

- The cooling system removes the heat generated in the reactor core. Ordinary water, heavy water and liquid sodium are the commonly used coolants. **A good coolant must possess a large specific heat capacity and high boiling point.**
- The coolant and the moderator are the same in the PHWR and PWR.
- In fast breeder reactors, liquid sodium is used as the coolant. A high temperature is produced in the reactor core of the fast breeder reactors.

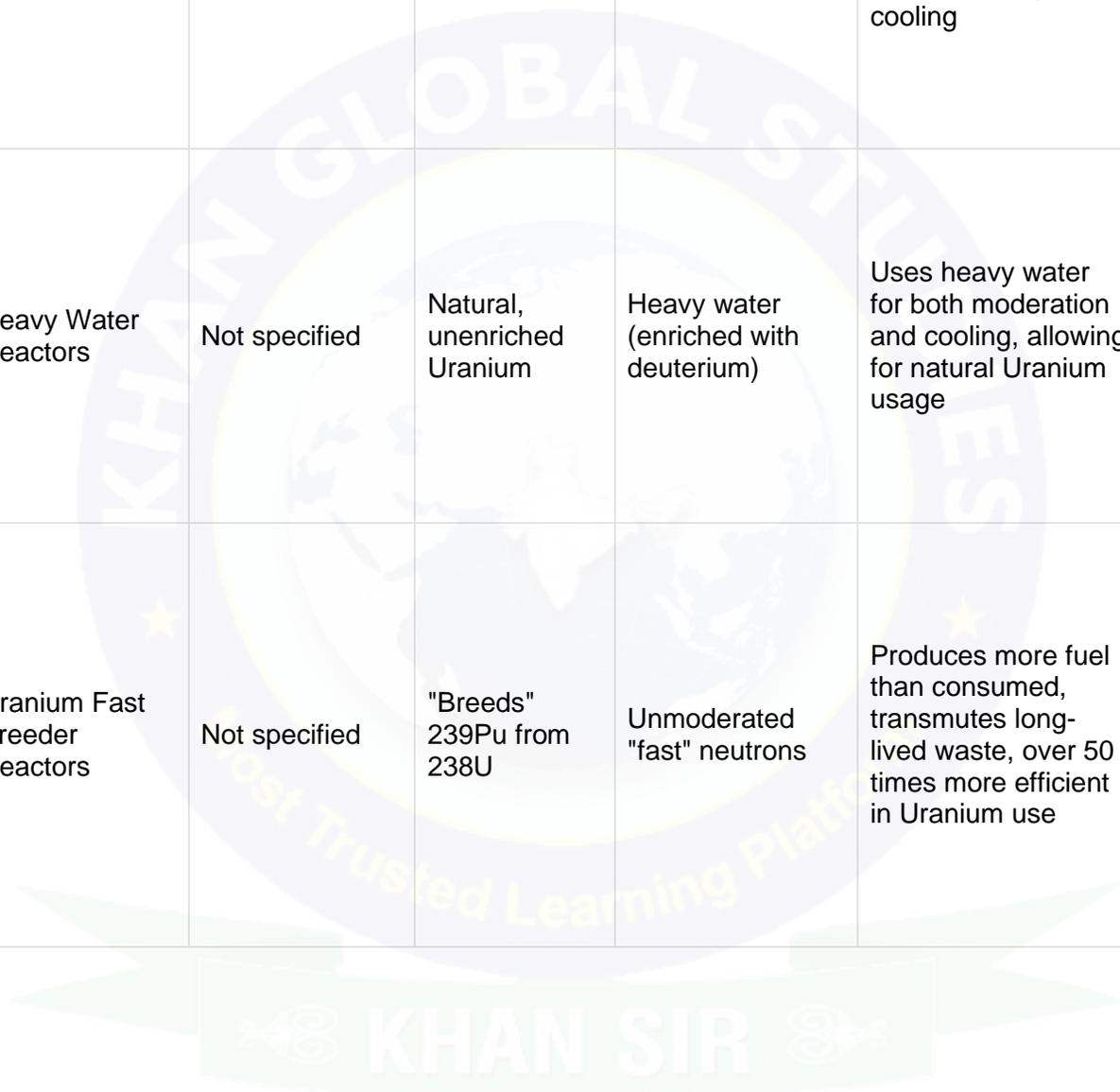
Neutron Reflectors

- Neutron reflectors **prevent the leakage of neutrons** to a large extent, by reflecting them back. In pressurized heavy water reactors the moderator itself acts as the reflector.

Different Types of Nuclear Reactors

Type of Reactor	Commonality	Fuel Used	Moderator and Coolant	Key Features and Efficiency
Pressurized Water Reactors (PWRs)	Most common	Natural Uranium	Ordinary water (separate for moderator and coolant)	Operates at 150 times atmospheric pressure for efficient heat-to-electricity conversion
Boiling Water Reactors	Second most common	Natural Uranium	Ordinary light water (combined moderator and coolant)	Direct conversion of reactor water to steam for turbine generation, no separate secondary steam cycle

High Temperature Gas Cooled Reactors	Less common	Not specified	Gas (primary coolant), mostly carbon (moderator)	Higher operating temperatures, higher efficiencies, limited power output due to less efficient gas cooling
Heavy Water Reactors	Not specified	Natural, unenriched Uranium	Heavy water (enriched with deuterium)	Uses heavy water for both moderation and cooling, allowing for natural Uranium usage
Uranium Fast Breeder Reactors	Not specified	"Breeds" ^{239}Pu from ^{238}U	Unmoderated "fast" neutrons	Produces more fuel than consumed, transmutes long-lived waste, over 50 times more efficient in Uranium use



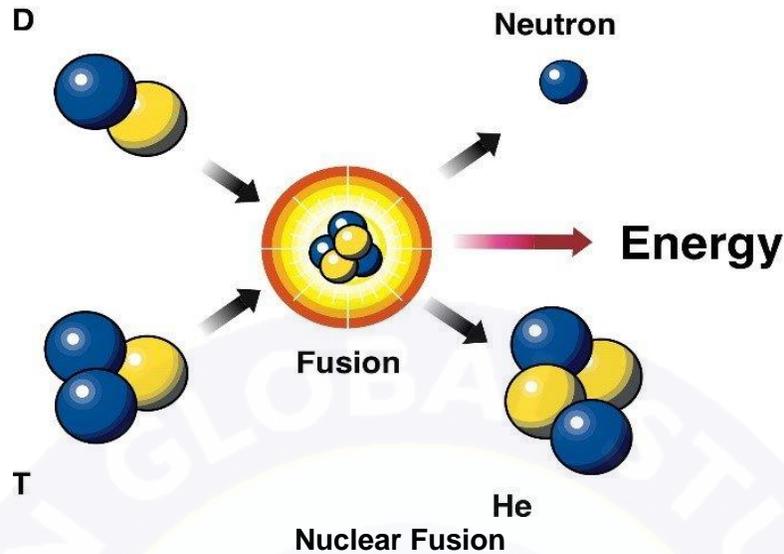
Thorium Breeder Reactors	Not specified	^{232}Th converted to ^{233}U	Utilizes thermal neutrons, generates ^{233}U from Thorium, less transuranic waste, more abundant than Uranium
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Nuclear Fusion

- Nuclear fusion is a process by which nuclear reactions between **light elements form heavier elements** (up to iron).
- In cases where the interacting nuclei belong to elements with low atomic numbers (e.g., hydrogen [atomic number 1] or its isotopes deuterium and tritium), substantial amounts of energy are released.
- Fusion is the process that **powers active stars**. The energy released from nuclear fusion reactions accounted for the longevity of the Sun and other stars as a source of heat and light.
- The prime energy producer in the Sun is the **fusion of hydrogen to form helium**. It takes four hydrogen atoms to fuse into each helium atom. During the process some of the mass is converted into energy.

Fusion Reaction

- An important fusion reaction for practical energy generation is that between deuterium and tritium (the D-T fusion reaction). It produces helium (He) and a neutron (n) and is written:
 - $\text{D} + \text{T} \rightarrow \text{He} + n$
- Fusion reactions between light elements release energy because of the mass difference between the Z protons and N neutrons considered separately and the nucleons bound together (Z + N) in a nucleus of mass M.
- M is less than (Z + N). The mass difference is converted into energy under the equation ($E=mc^2$).



Two Basic Types of Fusion Reactions

1. Reactions Preserving Protons and Neutrons
 - Most important for practical fusion energy production.
 - These reactions maintain the number of protons and neutrons during the process.
2. Reactions Involving Conversion between Protons and Neutrons
 - Crucial to the initiation of star burning.
 - These reactions involve a transformation between protons and neutrons.

Principle of Fusion Reactions

- Inhibited by the Coulomb force: Fusion reactions are hindered by the electrical repulsive force (Coulomb force) between two positively charged nuclei.
- Overcoming Electrical Repulsion: For fusion to occur, the nuclei must approach each other at high speed to overcome their electrical repulsion, achieving a separation less than one-trillionth of a centimetre.
- Dominance of the Strong Force: At this proximity, the short-range strong force becomes dominant, facilitating fusion.
- Requirement for Useful Energy Production: To produce useful amounts of energy, a large number of nuclei must undergo fusion, necessitating a gas of fusing nuclei.
- High Temperature Gas: In a gas at extremely high temperatures, nuclei possess sufficient kinetic energy for fusion.
- Creation of Plasma State: Heating an ordinary gas beyond the temperature where electrons are knocked out of their atoms results in an ionized gas of free electrons and positive nuclei, known as plasma.
- Plasma: Plasma is the fourth state of matter, and most of the matter in the universe exists in this state.

ITER (International Thermonuclear Experimental Reactor)

- ITER (meaning "the way" or "the path" in Latin) is an international nuclear fusion research and engineering megaproject **aimed at creating energy through a fusion process** similar to that of the Sun.
- It is being built next to the Cadarache facility in southern France.
- It is the **world's largest tokamak**, a magnetic fusion device that has been designed to prove the feasibility of fusion as a large-scale and carbon-free source of energy.
- The primary objective of ITER is the investigation and demonstration of burning plasmas—plasmas in which the energy of the helium nuclei produced by the fusion reactions is enough to maintain the temperature of the plasma, thereby reducing or eliminating the need for external heating.
- ITER will also test the availability and integration of technologies essential for a fusion reactor (such as superconducting magnets, remote maintenance, and systems to exhaust power from the plasma) and the validity of tritium breeding module concepts that would lead in a future reactor to tritium self-sufficiency.
- Thousands of engineers and scientists have contributed to the design of ITER since the idea for an international joint experiment in fusion was first launched in 1985.

ITER Organization

- The ITER Organization is an intergovernmental organization that was **created by an international agreement signed in 2006**, and formally established on 24 October 2007 after its ratification by all Parties.
- The Parties to the ITER Agreement (the ITER Members) are China, the European Union (through Euratom), India, Japan, Korea, Russia and the United States of America (**35 countries** in total).
- The purpose of the ITER Organization is to provide for and promote cooperation among its Members for the benefit of the ITER Project, an international collaboration to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes.
- It acts as the **overall integrator of the project** and nuclear operator of the ITER facility.

What is Tokamak?

- Construction of the ITER complex in France **started in 2013**, and assembly of the tokamak began in 2020.
- The tokamak is an experimental machine **designed to harness the energy of fusion**.
- Inside a tokamak, the energy produced through the fusion of atoms is absorbed as heat in the walls of the vessel. Just like a conventional power plant, a fusion power plant will use this heat to produce steam and then electricity by way of turbines and generators.
- The heart of a tokamak is its doughnut-shaped vacuum chamber. Inside, under the influence of extreme heat and pressure, gaseous hydrogen fuel becomes a plasma—the very environment in which hydrogen atoms can be brought to fuse and yield energy.
- The charged particles of the plasma can be shaped and controlled by the massive magnetic coils placed around the vessel; physicists use this important property to confine the hot plasma away from the vessel walls.

- The term "tokamak" comes to us from a **Russian acronym** that stands for "**toroidal chamber with magnetic coils.**"
- First developed by Soviet research in the late 1960s, the tokamak has been adopted around the world as the most promising configuration of magnetic fusion device.

JT-60SA

- It is the **world's biggest** experimental **nuclear fusion reactor.**
- It was **inaugurated in Japan** in December 2023.
- JT-60SA is a **joint initiative** between the **European Union and Japan.**
- It is a forerunner for the under-construction International Thermonuclear Experimental Reactor (ITER).
- JT-60SA and ITER both are to coax hydrogen nuclei inside to fuse into one heavier element, helium, releasing energy in the form of light and heat.

Nuclear Energy in India

- Nuclear energy is the **fifth-largest source of electricity** for India which contributes about 3% of the total electricity generation in the country.
- India entered the atomic age/nuclear age, on 4th August 1956 when **Apsara, India's first nuclear reactor**, went into operation. This reactor was designed and built by India with the nuclear fuel supplied from the United Kingdom under a lease agreement.
- India's second reactor for research purposes, CIRUS, was built with cooperation with Canada and went into operation in the early 1960's.
- India entered into a collaboration with the former Soviet Union in 1988 to build two 1000 MW reactor power units using enriched uranium as fuel.
- In 1998, India and Russia decided to embark on this project, and work at the site commenced in 2003. The first unit at Kudankulam went into operation in 2014 and the second in 2016.
- India now has 22 reactors in operation, with a combined capacity of 6780 MW. Twelve more reactors are being built.
- In 2021, the government stated in the Parliament that nuclear power generation capacity would increase to 22,480 MW by 2031. This figure was reiterated in the Parliament in 2022.
- The **Nuclear Power Corporation of India Limited**, or NPCIL, is an Indian government-owned corporation with headquarters in Mumbai that is in **charge of producing electricity using nuclear energy.**
- The Department of Atomic Energy (DEA) is responsible for running NPCIL.

List of Operational Nuclear Power Plants in India

Name	Operational Year	Location	Capacity (MWe)
Kakrapar Atomic Power Station	1993	Gujarat	440
(Kalpakkam) Madras Atomic	1984	Tamil Nadu	440

Power Station			
Narora Atomic Power Station	1991	Uttar Pradesh	440
Kaiga Nuclear Power Plant	2000	Karnataka	880
Rajasthan Atomic Power Station	1973	Rajasthan	1180
Tarapur Atomic Power Station (oldest nuclear facility)	1969	Maharashtra	1400
Kudankulam Nuclear Power Plant (Largest)	2013	Tamil Nadu	2000

India's Nuclear Energy Programme

- India's 3 stage Nuclear Power Program was **devised by Dr. Homi J Bhaba**, the father of India's Nuclear program, in 1954.
- The main aim was **to capitalize on India's vast thorium reserves** while accounting for its low uranium reserves.
- India has only about 2% of the global uranium reserves but 25% of the world's thorium reserves.
- The three stages are:
 - Natural uranium fuelled Pressurized Heavy Water Reactors (PWRH)
 - Fast Breeder Reactors (FBRs) utilizing plutonium based fuel
 - Advanced nuclear power systems for utilization of thorium

Stage 1

- The first stage involved **using natural uranium to fuel Pressurized Heavy Water Reactors** to produce electricity and producing plutonium-239 as a byproduct.
 - $U-238 \rightarrow \text{Plutonium-239} + \text{Heat}$
- Using Pressurized Heavy Water Reactors rather than Light Water Reactors was the best choice for India given its infrastructure. While Pressurized Heavy Water Reactors used unenriched uranium, Light Water Reactors required enriched uranium.
- Also, the components of PWRH could be domestically manufactured in India, as opposed to LWRs, which would need some components to be imported. Furthermore the byproduct plutonium-239 would be used in the second stage.

Stage 2

- The second stage **involves using plutonium-239 to produce mixed-oxide fuel**, which would be used in Fast Breeder Reactors.
- These reactors have two processes. Firstly plutonium 239 undergoes fission to produce energy, and metal oxide is reacted with enriched uranium reacts with mixed-oxide fuel to produce more plutonium-239.
- Furthermore once a sufficient amount of plutonium-239 is built up, thorium will be used in the reactor, to produce Uranium-233. This uranium is crucial for the third stage.

Stage 3

- The main purpose of stage-3 is to achieve a sustainable nuclear fuel cycle. The advanced nuclear system **would use a combination of Uranium-233 and Thorium**. Thus India's vast thorium would be exploited, using a thermal breeder reactor.
- Currently this stage is still in the research stage. Thus India is looking to simultaneously use its thorium in other technologies.
- The options include Accelerator Driven Systems (ADS), Advanced Heavy Water Reactor (AHWR) and Compact High Temperature Reactor (CHTR).

