GHOUSIA INSTITUTE OF TECHNOLOGY FOR WOMEN

Near Dairy Circle, Hosur Road, Bengaluru-560029, KARNATAKA

Affiliated to VTU., Belagavi, Recognized by Government of Karnataka & A.I.C.T.E., New Delhi

RENEWABLE ENERGY POWER PLANTS- BME654B

Open Elective Subject

6th Semester

B.E. Degree, VTU.

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Dept. of CSE

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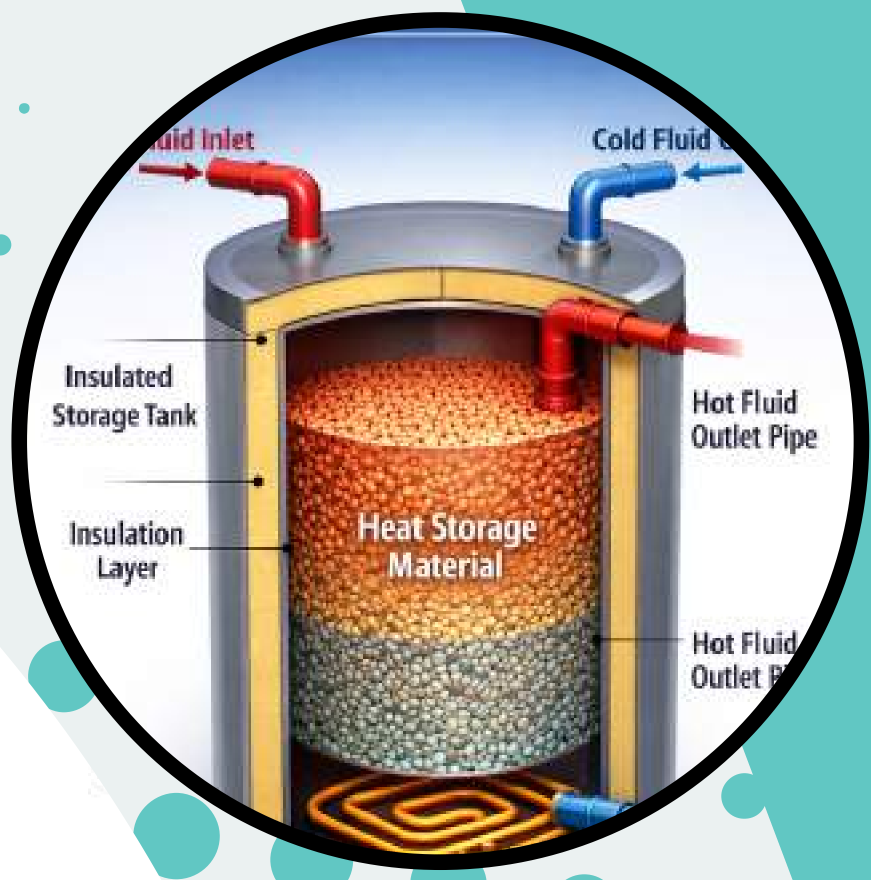
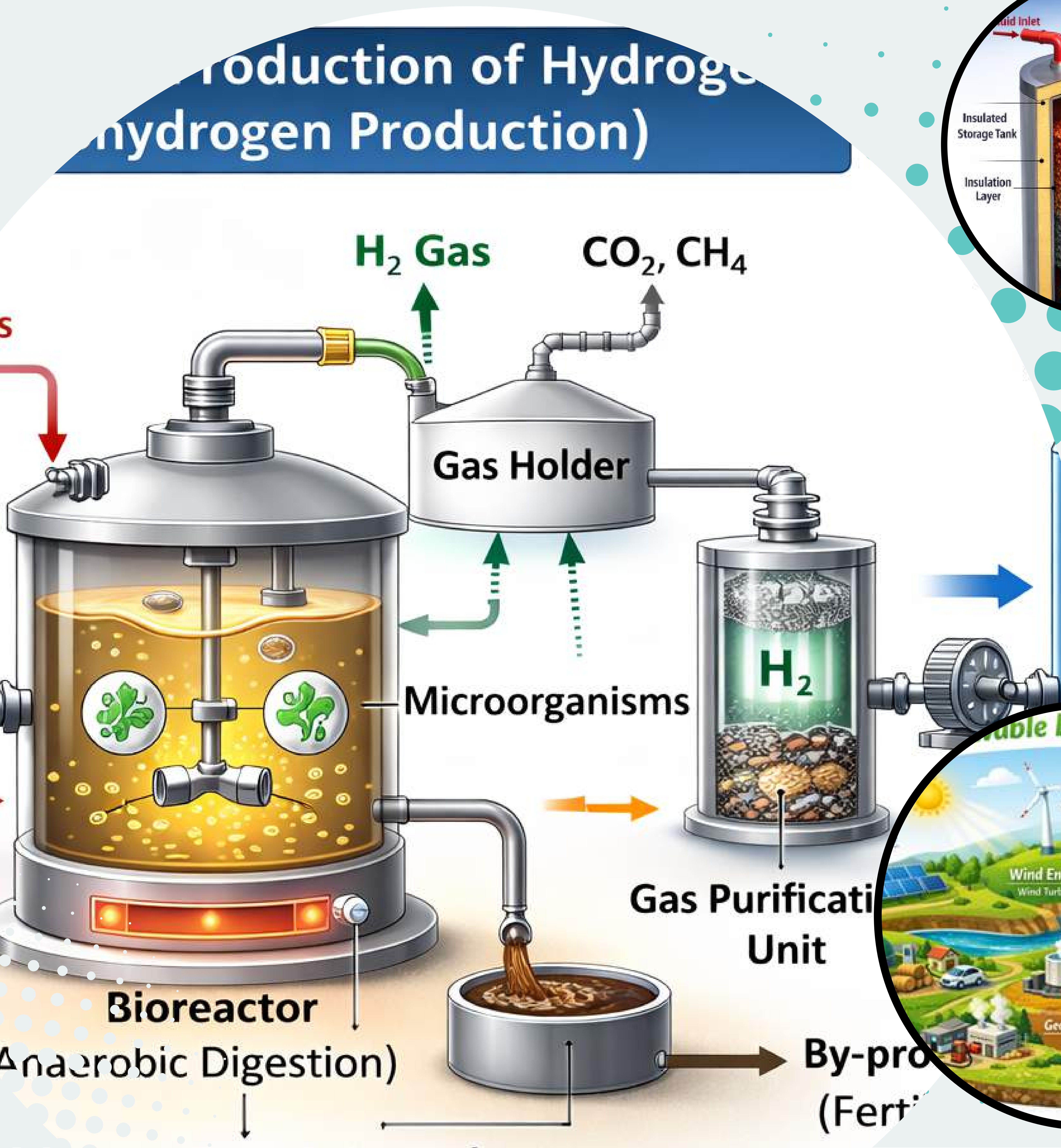
Renewable energy resources such as solar, wind, hydro, biomass, and geothermal are naturally replenished and provide clean power. They are important because they reduce dependence on fossil fuels and help control environmental pollution. It supports sustainable development and improves energy security. Its scope is growing rapidly due to technological progress and government support. These resources are used for electricity generation, heating, water pumping, and transportation. Applications range from homes and industries to rural electrification and large power plants. Overall, renewable energy plays a key role in building a cleaner and sustainable future





Renewable Energy Power Plants		Semester	6^{th}
Course Code	**BME654B**	CIE Marks	50
Teaching Hours/Week (L:T:P: S)	3:0:0:0	SEE Marks	50
Total Hours of Pedagogy	40	Total Marks	100
Credits	03	Exam Hours	03
Examination type (SEE)	Theory		

Course objectives:

- To explore society's present needs and future energy demands.
- To introduce the concepts of solar energy
- To introduce the concepts and applications of Wind energy, Biomass energy, geothermal energy and Ocean energy as alternative energy sources.
- To get exposed to energy conservation methods.

Teaching-Learning Process (General Instructions)

These are sample Strategies, which teachers can use to accelerate the attainment of the various course outcomes.

1. Use pie chart showing distribution of renewable energy sources
2. Use wind turbine models
3. Use sun path diagrams

Module-1

Introduction to Renewable Energy: Overview of global energy demand and the need for renewable energy, Comparison of renewable and non-renewable energy sources, Environmental benefits and challenges of renewable energy. **Solar Radiation**: Extra-Terrestrial radiation, spectral distribution of extra-terrestrial radiation, solar constant, solar radiation at the earth's surface, beam, diffuse and global radiation

Module-2

Solar Power Plants:

Measurement of Solar Radiation: Pyrometer, shading ring pyrheliometer, sunshine recorder, schematic diagrams and principle of working. Solar Thermal Conversion: Collection and storage, thermal collection devices.

Fundamentals of solar energy and photovoltaic (PV) technology, Types of solar power plants: grid-tied, off-grid, and hybrid systems, Design considerations for solar power plants: site selection, orientation, and shading analysis, PV system components and their functionalities, Operation, maintenance, and performance monitoring of solar power plants

Module-3

Wind Power Plants:

Basics of wind energy and wind turbine technology, Types of wind turbines: horizontal axis and vertical axis; Wind resource assessment and site selection for wind power plants, Wind farm layout optimization and wake effects, Grid integration and power system considerations for wind power plants

Geothermal Energy Conversion: Principle of working, types of geothermal station with schematic diagram, geothermal plants in the world, problems associated with geothermal conversion, scope of geothermal energy.

Module-4

Tidal Power: Tides and waves as energy suppliers and their mechanics; fundamental characteristics of tidal power, harnessing tidal energy, advantages and limitations.

Ocean Thermal Energy Conversion: Principle of working, OTEC power stations in the world, problems associated with OTEC.

Module-5

Biomass Power Plants: Biomass as a renewable energy source: types and characteristics, Conversion technologies: combustion, gasification, and anaerobic digestion, biomass feedstock selection and availability, Environmental impacts and sustainability of biomass power plants, Integration of biomass power plants with other energy systems

Hydrogen Energy: Properties of Hydrogen with respected to its utilization as a renewable form of energy, sources of hydrogen, production of hydrogen, electrolysis of water, thermal decomposition of water, thermos Chemical production bio-chemical production.

Course outcome (Course Skill Set)

At the end of the course, the student will be able to :

1. Understand the need of renewable energy resources, historical and latest developments.
2. Describe the use of solar energy and the various components used in the energy production
3. Appreciate the need of Wind Energy and the various components used in energy generation and
   the classifications.
4. Acquire the knowledge of fuel cells, wave power, tidal power and geothermal principles and Applications.
5. Understand the concept of Biomass energy resources and their classification, types of biogas Plants applications

Assessment Details (both CIE and SEE)

The weightage of Continuous Internal Evaluation (CIE) is 50% and for Semester End Exam (SEE) is 50%. The minimum passing mark for the CIE is 40% of the maximum marks (20 marks out of 50) and for the SEE minimum passing mark is 35% of the maximum marks (18 out of 50 marks). A student shall be deemed to have satisfied the academic requirements and earned the credits allotted to each subject/ course if the student secures a minimum of 40% (40 marks out of 100) in the sum total of the CIE (Continuous Internal Evaluation) and SEE (Semester End Examination) taken together.

Continuous Internal Evaluation:

- The CIE is the sum of Average of Two Internal Assessment Tests each of 25 marks and Any two Assessment methods for 25 marks.
- The first test will be administered after 40-50% of the syllabus has been covered, and the second test will be administered after 85-90% of the syllabus has been covered
- Any two assessment methods mentioned in the 22OB4.2, if an assignment is project-based then only one assignment for the course shall be planned. The teacher should not conduct two assignments at the end of the semester if two assignments are planned.
- For the course, CIE marks will be based on a scaled-down sum of two tests and other methods of assessment for a total of 50 marks.

Internal Assessment Test question paper is designed to attain the different levels of Bloom's taxonomy as per the outcome defined for the course.

Semester-End Examination:

Theory SEE will be conducted by University as per the scheduled timetable, with common question papers for the course (**duration 03 hours).**

1. The question paper will have ten questions. Each question is set for 20 marks.
2. There will be 2 questions from each module. Each of the two questions under a module (with a maximum of 3 sub-questions), **should have a mix of topics** under that module.
3. The students have to answer 5 full questions, selecting one full question from each module.
4. Marks scored shall be proportionally reduced to 50 marks

Suggested Learning Resources:

Books

1. Nonconventional Energy sources, G D Rai, Khanna Publication, Fourth Edition,
2. Energy Technology, S.Rao and Dr. B.B. Parulekar, Khanna Publication. Solar energy, Subhas P Sukhatme, TataMcGrawHill, 2ndEdition,1996
3. Principles of Energy conversion, A.W.Culp Jr. McGraw Hill, 1996
4. 4. Non-Convention Energy Resources, ShobhNath Singh, Pearson, 2018

Web links and Video Lectures (e-Resources):

- https://www.investopedia.com/terms/i/internet-energy
- E-book URL: https://www.pdfdrive.com/non-conventional-energy-sources-e10086374.html
- E-book URL: https://www.pdfdrive.com/non-conventional-energy-systems-nptel-d17376903.html
- E-book URL: https://www.pdfdrive.com/renewable-energy-sources-and-their-applications-e33423592.html
- E-book URL: https://www.pdfdrive.com/lecture-notes-on-renewable-energy-sources-e34339149.
- html https://onlinecourses.nptel.ac.in/noc18_ge09/preview

Activity Based Learning (Suggested Activities in Class)/ Practical Based learning

- Visit nearest power plants and know the principles of power production
- Seminar/poster presentation of all Renewable power plants
- Assignments
- quiz

MODULE-01 Introduction to Renewable Energy

Syllabus: Overview of global energy demand and the need for renewable energy, Comparison of renewable and nonrenewable energy sources, Environmental benefits and challenges of renewable energy. Solar Radiation: ExtraTerrestrial radiation, spectral distribution of extraterrestrial radiation, solar constant, solar radiation at the earth's surface, beam, diffuse and global radiation.

1.0 Introduction:

Renewable energy is energy obtained from natural sources that are continuously replenished and do not get exhausted with repeated use. These energy sources are naturally available and can be used again and again without affecting future generations. Solar energy from the sun, wind energy from moving air, and hydropower from flowing water are common examples. Renewable energy is considered clean and environmentally friendly because it produces very little pollution during operation.

Renewable energy differs from non-renewable energy mainly in terms of availability and environmental impact. Renewable sources such as sunlight, wind, and water are naturally replenished, whereas non-renewable sources like coal, petroleum, and natural gas are limited and take millions of years to form. The use of non-renewable fuels releases large amounts of greenhouse gases, leading to air pollution and climate change. In contrast, renewable energy sources generate minimal emissions and help protect the environment.

There are several types of renewable energy used across the world. Solar energy converts sunlight into electricity using solar panels, while wind energy uses wind turbines to generate power. Hydropower produces electricity by utilizing flowing or falling water. Bioenergy is derived from organic materials such as agricultural waste and biomass, geothermal energy uses heat from the Earth's interior, and ocean energy harnesses tidal and wave motion to produce electricity.

Renewable energy offers many advantages, including reduced greenhouse gas emissions, improved air quality, and long-term sustainability. It reduces dependence on fossil fuels and supports energy security. However, it also has some limitations. The initial cost of installation can be high, and certain renewable sources like solar and wind are dependent on weather conditions. Large renewable energy projects may also require significant land area.

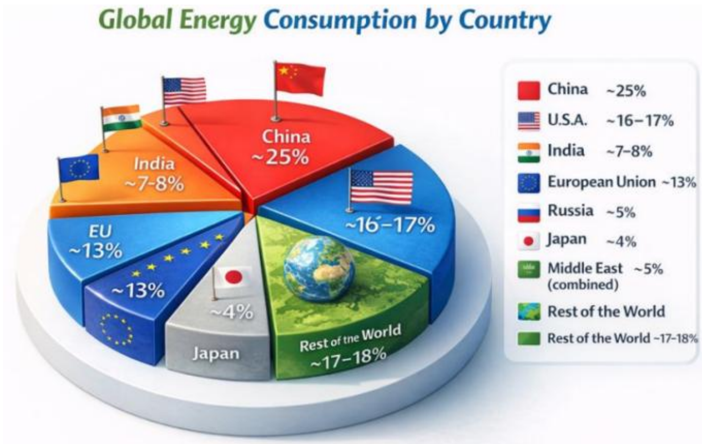
Renewable energy is widely applied in electricity generation for residential, commercial, and industrial sectors. It is used in solar street lights, water pumping systems, heating applications, and electric vehicle charging stations. Hydropower plants supply electricity to cities, while biogas plants support cooking and rural electrification. Overall, renewable energy plays a vital role In Sustainable Development And Environmental Protection.

1.1 Overview of Global Energy Demand:

Global energy demand refers to the total amount of energy required to run human activities across the world. This includes energy used for electricity generation, transportation, industries, agriculture, and domestic needs. Over the past few decades, global energy demand has increased steadily due to population growth, urbanization, industrial development, and improved living standards. Developing countries are experiencing faster growth in energy demand as they expand infrastructure and manufacturing, while developed countries show relatively stable demand due to energy efficiency improvements.

Different sectors consume energy in varying proportions. The industrial sector is the largest energy consumer globally, using energy for manufacturing, mining, steel production, cement, and chemical industries. The transportation sector is the second-largest consumer, mainly relying on petroleum fuels for road vehicles, aviation, and shipping. The residential and commercial sectors consume energy for lighting, heating, cooling, cooking, and appliances. Agriculture uses energy for irrigation, machinery, and food processing, though its share is comparatively smaller.

Energy consumption also varies widely among countries. Countries with large populations and strong industrial bases consume the most energy. China is the world's largest energy consumer due to its massive manufacturing sector and population size. The United States is another major consumer because of high per-capita energy use, advanced industries, and extensive transportation systems. India's energy demand is rapidly growing due to economic development, urban growth, and rising electricity access. Developed regions such as the European Union and Japan also consume significant energy but focus more on efficiency and renewable sources.



Energy demand plays a crucial role in a country's economy. Energy is essential for industrial production, job creation, infrastructure development, and overall economic growth. A reliable and affordable energy supply improves productivity and attracts investment. Countries with sufficient energy resources or strong energy infrastructure tend to have more stable economies. At the same time, high dependence on imported energy can affect economic stability due to price fluctuations and supply risks.

1.2 The Need for Renewable Energy:

The growing global energy demand has traditionally been met using non-renewable energy resources such as coal, petroleum, and natural gas. These resources have supported industrialization and economic growth, but they suffer from several serious drawbacks. Non-renewable energy sources are limited in quantity and will eventually be exhausted.

For example, coal and oil reserves are depleting rapidly due to continuous use for power generation and transportation.

In addition, the extraction and burning of fossil fuels release large amounts of greenhouse gases such as carbon dioxide, leading to global warming and climate change. Thermal power plants and diesel vehicles are major contributors to air pollution, causing health problems like respiratory diseases.

Another major drawback of non-renewable energy is environmental degradation. Mining of coal and drilling for oil and gas result in deforestation, land degradation, water pollution, and loss of biodiversity. Oil spills in oceans and gas leakages cause long-term ecological damage. Moreover, many countries depend heavily on imported fossil fuels, which makes their economies vulnerable to fuel price fluctuations and supply disruptions.

For example, rising crude oil prices directly increase transportation and electricity costs, affecting overall economic stability.

Due to these limitations, there is an urgent need to shift towards renewable energy resources. Renewable energy sources such as solar, wind, hydropower, biomass, and geothermal energy are naturally replenished and will not be exhausted. They produce very low greenhouse gas emissions and significantly reduce air and water pollution.

For instance, solar power plants and rooftop solar systems generate electricity without emitting carbon dioxide, and wind farms provide clean energy using natural wind flow.

Renewable energy also supports sustainable economic development and energy security. Countries investing in renewable energy reduce their dependence on fossil fuel imports and create new employment opportunities in manufacturing, installation, and maintenance.

For example, India's large-scale solar parks and wind energy projects are helping meet growing electricity demand while reducing carbon emissions. Electric vehicles powered by renewable electricity further reduce fuel consumption and pollution.

In conclusion, the drawbacks of non-renewable energy resources—such as depletion, pollution, climate change, and economic instability—make it essential to focus on renewable energy. Renewable energy offers a clean, sustainable, and reliable solution to meet present and future energy needs while protecting the environment and supporting economic growth.

Different renewable and non renewable energy sources:

Renewable Energy Sources

Solar Energy

Solar energy is obtained from sunlight and converted into electricity or heat using solar panels or solar thermal systems. It is clean, abundant, and widely used for power generation, water heating, and lighting. Solar energy reduces dependence on fossil fuels and is ideal for both small homes and large power plants.

Wind Energy

Wind energy is produced by converting the kinetic energy of moving air into electricity using wind turbines. It is commonly used in wind farms located in coastal areas and open plains where wind speed is high. Wind energy is renewable and pollution-free but depends on weather conditions.

Hydropower (Water Energy)

Hydropower is generated from flowing or falling water in rivers and dams. The water rotates turbines connected to generators to produce electricity. It is a reliable renewable source with high efficiency, but large dams may affect ecosystems and nearby communities.

Biomass Energy

Biomass energy comes from organic materials such as agricultural waste, wood, animal dung, and food waste. These materials are burned or converted into biogas or biofuels to produce energy. Biomass helps manage waste and provides rural employment, but improper use can cause air pollution.

Geothermal Energy

Geothermal energy uses heat from inside the Earth to generate electricity or provide direct heating. Hot water or steam from underground reservoirs drives turbines. It provides continuous power but is limited to regions with suitable geothermal resources.

Non-Renewable Energy Sources

Coal

Coal is a fossil fuel widely used in thermal power plants to generate electricity. It is abundant and inexpensive but produces large amounts of carbon dioxide and air pollutants, contributing to climate change and health problems.

Petroleum (Oil)

Petroleum is mainly used as fuel in vehicles and industries and for producing chemicals and plastics. It provides high energy output but causes air pollution and greenhouse gas emissions. Oil reserves are limited and will eventually be exhausted.

Natural Gas

Natural gas is used for cooking, power generation, and industrial heating. It burns cleaner than coal and oil but is still a fossil fuel and contributes to global warming. Its availability is also limited.

Nuclear Energy

Nuclear energy is produced by splitting uranium atoms in nuclear reactors. It generates large amounts of electricity with low carbon emissions. However, it involves high cost, radioactive waste disposal, and safety concerns.

Summary:

Category	Energy Source	Brief Explanation
Renewable	Solar Energy	Uses sunlight to produce electricity or heat through solar panels/collectors; clean and abundant.
Renewable	Wind Energy	Converts moving air into electricity using wind turbines; pollution-free but weather dependent.
Renewable	Hydropower	Generates power from flowing or falling water using dams and turbines; efficient but affects ecosystems.
Renewable	Biomass Energy	Obtained from organic waste like wood, crop residue, and animal dung; useful for biogas and biofuels.
Renewable	Geothermal Energy	Uses heat from inside the Earth for power and heating; continuous supply but location specific.
Non-Renewable	Coal	Fossil fuel used in thermal power plants; cheap but causes heavy pollution and CO_2 emissions.
Non-Renewable	Petroleum (Oil)	Used mainly in transport and industries; high energy output but limited and polluting.
Non-Renewable	Natural Gas	Used for cooking and power generation; cleaner than coal but still contributes to global warming.
Non-Renewable	Nuclear Energy	Produces electricity using uranium fission; very high output but costly with safety and waste issues.

1.3 Comparison of Renewable and Nonrenewable Energy Sources:

Parameter	Renewable Energy Sources	Non-Renewable Energy Sources
Definition	Energy obtained from sources that are naturally replenished	Energy obtained from sources that are limited and exhaustible
Availability	Available continuously and will not run out	Limited and will be exhausted over time
Examples	Solar, wind, hydropower, biomass, geothermal	Coal, petroleum, natural gas, nuclear fuel
Source of Energy	Sunlight, wind, water, organic matter, Earth's heat	Fossil fuels and mined nuclear materials
Environmental Impact	Very low pollution and greenhouse gas emissions	High pollution and greenhouse gas emissions
Effect on Climate Change	Helps reduce global warming	Major cause of climate change
Sustainability	Sustainable for long-term use	Not sustainable
Cost of Fuel	Free or very low (sunlight, wind, water)	High and increasing fuel cost
Initial Cost	High initial installation cost	Moderate initial cost
Operating Cost	Low operating and maintenance cost	High operating and fuel cost
Energy Security	Reduces dependence on imports	Often dependent on imports
Examples (Live)	Rooftop solar panels, wind farms, hydropower dams	Thermal power plants, petrol/diesel vehicles

1.4 Environmental Benefits of Renewable Energy:

Renewable energy offers many important environmental benefits because it produces energy with very little harm to nature. Unlike fossil fuels such as coal, petrol, and diesel, renewable energy sources do not release large amounts of harmful gases into the air.

For example, electricity generated from solar panels or wind turbines does not produce carbon dioxide during operation. This helps reduce air pollution and slows down climate change caused by greenhouse gas emissions.

One major environmental benefit of renewable energy is the reduction of global warming. Burning fossil fuels in thermal power plants and vehicles releases carbon dioxide, which traps heat in the atmosphere. Renewable energy sources such as solar, wind, and hydropower produce clean electricity without burning fuel.

For instance, a solar power plant can supply electricity to thousands of homes without emitting smoke or greenhouse gases, helping to protect the Earth's climate.

Renewable energy also helps in improving air quality and public health. Fossil fuel-based power plants release pollutants such as sulfur dioxide and nitrogen oxides, which cause respiratory problems and acid rain. In contrast, wind farms and solar parks operate silently and cleanly.

For example, replacing diesel generators with solar power in villages reduces smoke, improves air quality, and creates a healthier living environment.

Another important benefit is the protection of water resources. Thermal and nuclear power plants require large quantities of water for cooling and often discharge hot or polluted water into rivers. Renewable energy sources such as solar and wind require very little or no water to generate electricity.

For example, solar panels installed in dry regions generate power without consuming water, helping to conserve valuable water resources.

Renewable energy also reduces damage to land and ecosystems. Mining coal and drilling oil destroy forests and natural habitats, while oil spills can severely damage marine life. Renewable energy projects, when properly planned, have much lower environmental impact.

For instance, rooftop solar systems use existing building space and do not disturb natural ecosystems.

In conclusion, renewable energy provides clean power, reduces pollution, conserves natural resources, protects ecosystems, and improves human health. By using renewable energy sources, countries can meet their energy needs while preserving the environment for future generations.

Summary:

Environmental Aspect	Benefit of Renewable Energy	Simple Example
Air Pollution	Produces very low air pollution	Solar panels generate electricity without smoke
Climate Change	Reduces greenhouse gas emissions	Wind farms do not release carbon dioxide
Global Warming	Helps slow down global temperature rise	Solar power replaces coal-based electricity
Public Health	Improves air quality and reduces diseases	Solar street lights reduce diesel generator use
Water Conservation	Requires little or no water	Solar and wind plants need no cooling water
Ecosystem Protection	Causes less damage to land and wildlife	Rooftop solar uses existing buildings
Waste Generation	Produces minimal waste	No ash or toxic waste from wind energy
Noise Pollution	Operates quietly	Solar panels produce no noise
Resource Conservation	Saves fossil fuel resources	Using solar power reduces coal consumption

1.5 Challenges of Renewable Energy:

Renewable energy is essential for sustainable development, but its large-scale adoption faces several challenges. One of the major challenges is the high initial cost of installation. Although solar and wind energy are among the cheapest sources in terms of long-term electricity generation, the upfront investment is high.

For example, installing a large-scale solar power plant costs nearly twice as much per kilowatt as a gas-fired power plant. This makes investors perceive renewable projects as high-risk compared to conventional fossil fuel plants.

Another important challenge is the lack of suitable infrastructure. Most existing power grids and transmission systems were designed for coal, gas, and nuclear power plants, not for decentralized and variable renewable energy sources. In addition, renewable energy generation does not always match peak demand hours. Solar power is generated mainly during the daytime, while electricity demand often peaks in the evening. Affordable large-scale energy storage systems are still limited, making it difficult to store excess energy for later use.

Technical and operational challenges also slow down renewable energy deployment. Solar and wind systems require skilled technicians for installation, operation, and maintenance. In many regions, such skilled manpower is not easily available.

For example, wind turbines need regular inspection, and solar inverters require expert maintenance. In desert regions such as Rajasthan, dust accumulation on solar panels reduces efficiency and requires frequent cleaning, increasing operational costs. Hard water used for cleaning panels also forces companies to invest in water treatment technologies.

Renewable energy also faces strong competition from the well-established fossil fuel industry. Fossil fuels have been used for decades and are deeply integrated into national economies. Despite government incentives for renewable energy, coal, oil, and gas industries still receive large subsidies and policy support. This makes it difficult for renewable energy to compete on equal terms in the energy market.

Geographical inequality is another major issue. Most renewable energy investments are concentrated in developed countries and China, which together account for more than 80% of global renewable investments. Many developing and emerging economies lag behind due to lack of capital, technology, and policy support.

For example, green energy investments in parts of Southeast Asia declined in recent years, slowing renewable energy growth in the region.

Dependence on imported raw materials and rare earth metals also poses a serious challenge. Renewable technologies such as solar panels and wind turbines require materials like silicon, lithium, and rare earth elements. Countries like India rely heavily on imports of solar cells and modules from China and Vietnam, making the sector vulnerable to supply chain disruptions and global price fluctuations.

Environmental and land-use concerns further complicate renewable energy expansion. Large solar parks require vast land areas, which may compete with agriculture and local livelihoods. Studies estimate that India may need tens of thousands of square kilometers of land to meet its net-zero targets. Converting agricultural land for solar projects may affect food security in the long run. Additionally, large-scale renewable projects in sensitive ecosystems such as deserts can disturb biodiversity and natural habitats.

In conclusion, while renewable energy offers clean and sustainable power, challenges such as high costs, infrastructure gaps, technical limitations, land use conflicts, and economic inequalities must be carefully addressed. With proper planning, technological innovation, policy support, and public awareness, these challenges can be overcome to ensure a smooth transition towards a renewable-based energy future.

Summary:

Challenge	Explanation	Example
High Initial Cost	Renewable energy systems require high upfront investment compared to fossil fuel plants	Solar plant ≈ $2000/kW, Gas plant ≈ $1000/kW
Lack of Infrastructure	Existing power infrastructure is designed mainly for fossil fuel and nuclear plants	Grid not fully ready for large-scale solar and wind
Inadequate Energy Storage	Renewable energy is not available all the time and storage systems are expensive	Solar power not available at night
Technical Challenges	Installation and maintenance require skilled technicians and advanced technology	Wind turbines and solar inverters need expert handling
Fossil Fuel Monopoly	Fossil fuel industry is deeply rooted and strongly supported economically	Coal and oil still receive major subsidies
Geographical Inequality	Renewable energy investment is uneven across regions	Developed countries & China >80% of investments
Supply Chain Disruptions	Natural disasters and global events affect availability and pricing of materials	COVID-19 affected solar module supply
Operational Challenges	Dust, water quality, and maintenance increase operational cost	Rajasthan solar plants need frequent cleaning
Raw Material Dependency	Heavy dependence on imported raw materials and rare earth metals	India imports most solar cells from China
Lack of Awareness	Public awareness about renewable technologies is still low	People hesitant to install rooftop solar
Environmental Impact	Large projects may affect biodiversity and ecosystems	Solar parks in deserts disturb ecosystems
Feasibility & Viability	Economic and technical feasibility may vary with location and climate	Uncertainty in long-term performance
Competition for Resources	Renewable projects compete for land and water	Solar parks compete with agriculture
Land Use Challenge	Large land area required for utility-scale projects	India may need 50,000–75,000 sq. km land
Impact on Food Security	Use of agricultural land may reduce food production	400,000 hectares needed by 2030

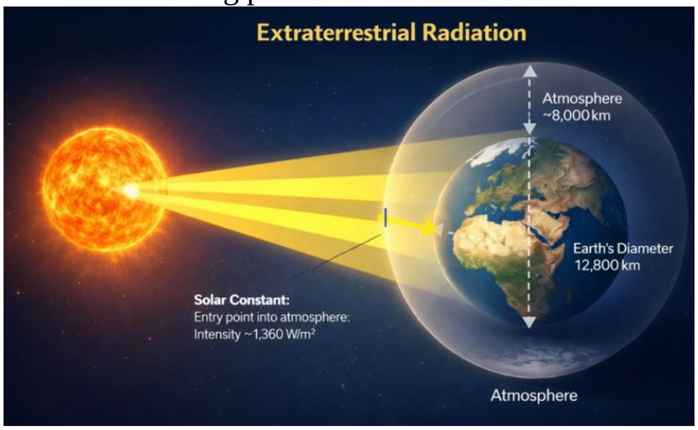
1.6 Solar Radiation:

Solar radiation is the energy emitted by the Sun in the form of electromagnetic waves, mainly as visible light, infrared, and ultraviolet radiation. This energy travels through space and reaches the Earth, where it becomes the primary source of energy for almost all natural and human activities. Solar radiation is the basic reason for daylight, weather patterns, plant growth through photosynthesis, and the Earth's climate system. When solar radiation reaches the Earth's surface, it can be absorbed, reflected, or scattered by the atmosphere and the ground.

Solar radiation is highly significant because it is the most abundant and clean source of energy available to the Earth. It provides the energy needed to sustain life, drive the water cycle, and regulate global temperatures. From an energy perspective, solar radiation is the foundation of solar power technologies such as photovoltaic panels and solar thermal systems, which convert sunlight into electricity and heat. Even fossil fuels are indirectly derived from ancient solar energy stored in plants over millions of years. Due to its vast availability, renewability, and minimal environmental impact, solar radiation plays a crucial role in meeting global energy demands and supporting a sustainable and low-carbon energy future.

1.7 Extra Terrestrial Radiation:

Extraterrestrial radiation refers to the solar energy received outside the Earth's atmosphere, before it undergoes any absorption, scattering, or reflection by atmospheric gases, dust, or clouds. As shown in the given figure, the Sun emits energy uniformly in all directions, and a small portion of this energy reaches the Earth. The solar energy reaching the outer boundary of the Earth's atmosphere is called extraterrestrial radiation. It represents the maximum possible solar energy available and is the starting point for all solar radiation calculations.



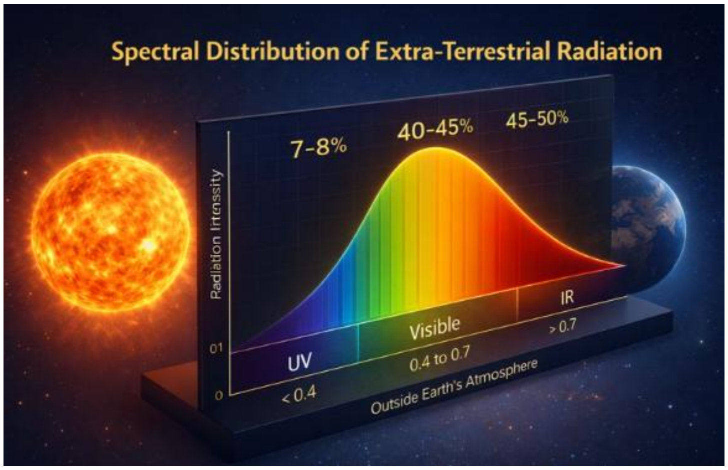
The figure shows the Sun on the left emitting parallel rays toward the Earth. At the top of the Earth's atmosphere, this incoming solar energy has a nearly constant intensity known as the solar constant. The solar constant is the amount of solar power received per unit area on a surface perpendicular to the Sun's rays at the mean Earth–Sun distance. Its average value is approximately 1360 W/m^2, as indicated in the figure. This value is measured outside the atmosphere and does not account for any atmospheric losses.

Extraterrestrial radiation depends on the Earth–Sun distance, which varies slightly throughout the year due to the elliptical orbit of the Earth around the Sun. When the Earth is closer to the Sun (around January), extraterrestrial radiation is slightly higher, and when it is farther away (around July), it is slightly lower. This variation is small but important in accurate solar energy analysis and system design.

Extraterrestrial radiation is very important in solar energy studies because it provides a reference value for estimating how much solar energy will be available at the Earth's surface under different atmospheric conditions. Engineers and scientists use extraterrestrial radiation to calculate solar radiation on horizontal and tilted surfaces, to estimate daily and monthly solar energy availability, and to design solar photovoltaic and solar thermal systems.

1.8 Spectral Distribution of Extraterrestrial

The spectral distribution of extraterrestrial radiation describes how the Sun's energy arriving at the top of the Earth's atmosphere is distributed over different wavelengths of electromagnetic radiation. The Sun behaves approximately like a black-body radiator at a temperature of about 6000 K, and therefore it emits energy over a wide range of wavelengths, including ultraviolet (UV), visible, and infrared (IR) radiation. Extraterrestrial radiation is defined outside the Earth's atmosphere, so this distribution is not affected by absorption or scattering by atmospheric gases.



Ultraviolet (UV) Region:

The ultraviolet region of extraterrestrial radiation lies at wavelengths below 0.4 μm. This region contributes about 7–8% of the total solar radiation received outside the Earth's atmosphere. Although the energy content is relatively small, ultraviolet radiation is very energetic and plays an important role in atmospheric processes. When extraterrestrial UV radiation enters the Earth's atmosphere, a large portion of it is absorbed by the ozone layer, protecting living organisms from harmful radiation. Because of this strong absorption, only a small amount of UV radiation reaches the Earth's surface. In solar energy applications, UV radiation has limited direct use but is important in understanding material degradation and atmospheric interactions.

Visible Region:

The visible region lies between 0.4 μm and 0.7 μm and contains the maximum portion of extraterrestrial radiation, contributing around 40–45% of the total solar energy. This is the region to which the human eye is sensitive, which is why sunlight appears bright. The peak of the solar spectrum occurs in this region, making it the most significant part of solar radiation. Visible radiation plays a crucial role in natural processes such as photosynthesis and daylight illumination. In solar energy systems, photovoltaic (PV) cells are mainly designed to convert visible radiation efficiently into electrical energy, making this region extremely important for solar power generation.

Infrared (IR) Region:

The infrared region consists of wavelengths greater than 0.7 μm and accounts for about 45–50% of the total extraterrestrial radiation. Although infrared radiation is invisible to the human eye, it carries a large amount of energy and is primarily responsible for the heating effect of sunlight. This region is especially important for solar thermal applications such as water heaters, solar cookers, and concentrating solar power systems. When infrared radiation enters the Earth's atmosphere, part of it is absorbed by water vapour and carbon dioxide, influencing the greenhouse effect and Earth's temperature balance.

The spectral distribution of extraterrestrial radiation shows that solar energy is mainly concentrated in the visible and infrared regions, with a smaller portion in the ultraviolet region, and this distribution forms the basis for solar energy conversion, climate studies, and atmospheric science.

1.9 Solar constant:

The solar constant is an important parameter in solar energy studies and represents the intensity of solar radiation received at the top of the Earth's atmosphere. It is defined as the rate at which solar energy arrives from the Sun on a unit area, placed perpendicular to the direction of the Sun's rays, at the mean distance between the Earth and the Sun. Since it is measured outside the atmosphere, it does not include any losses due to absorption, scattering, or reflection by atmospheric gases.

The National Aeronautics and Space Administration (NASA) has standardized the value of the solar constant. Its average value is approximately 1360 W/m^2, which means that every square meter facing the Sun at the top of the atmosphere receives about 1360 watts of solar power. This value can also be expressed as 1165 $kcal/m^2$ per hour or 429.2 Btu/ft^2 per hour, depending on the unit system used. These different units are useful for engineers and scientists working in various fields such as thermal engineering, meteorology, and renewable energy.

Although the solar constant is called a "constant," its value is not perfectly constant throughout the year. This variation occurs because the Earth revolves around the Sun in an elliptical orbit, not a perfectly circular one. As a result, the distance between the Earth and the Sun changes slightly during the year. When the Earth is closer to the Sun (around early January), the solar radiation received is slightly higher, and when it is farther away (around early July), the radiation is slightly lower.

This seasonal variation in solar radiation can be estimated using the relation:

$$\frac{I}{I_{sc}} = 1 + 0.033 \cos\left(\frac{360n}{365}\right)$$

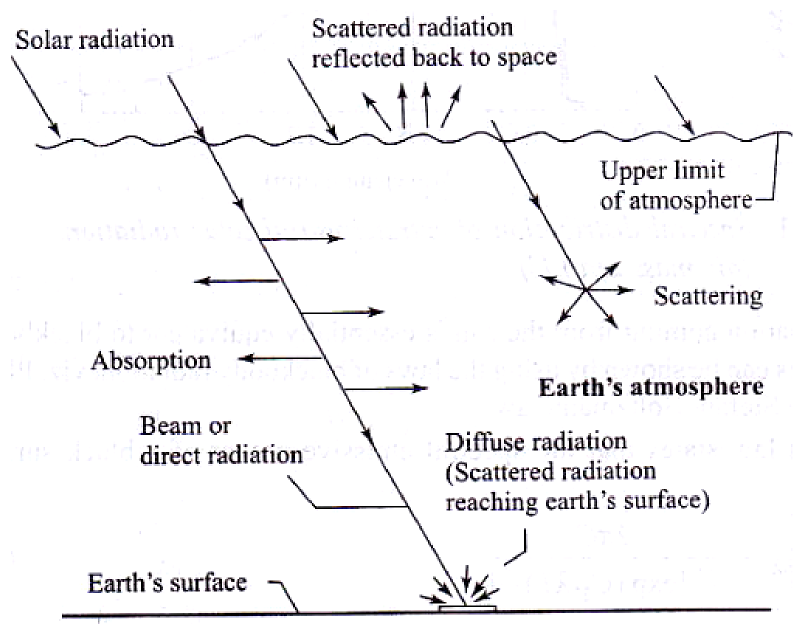
where (I) is the solar radiation reaching the Earth on a given day, (I_{sc}) is the solar constant, and (n) is the day number of the year (with January 1 as (n = 1)). The factor 0.033 represents the maximum fractional variation (about ±3.3%) in solar radiation due to the changing Earth–Sun distance. This equation helps engineers calculate the actual extraterrestrial solar radiation for any day of the year.

The concept of the solar constant is extremely important in solar energy system design. It forms the reference value for estimating extraterrestrial radiation, calculating beam and global radiation, and predicting the performance of solar photovoltaic and solar thermal systems. It is also widely used in climate modeling and atmospheric studies to understand the Earth's energy balance.

In conclusion, the solar constant represents the maximum solar energy available at the top of the Earth's atmosphere and serves as a fundamental basis for all solar radiation calculations.

1.10 Solar Radiation at the Earth's Surface, Beam, Diffuse and Global Radiation:

Solar Radiation: Solar radiation is the energy received from the Sun at the Earth's surface after passing through the atmosphere. As shown in the figure, when solar radiation enters the Earth's atmosphere, part of it is absorbed by atmospheric gases, part is scattered in different directions, and part is reflected back into space. The remaining portion reaches the Earth's surface as useful solar energy. This incoming energy is responsible for heating the Earth and is the basic input for solar energy systems.



Beam (Direct) Radiation

Beam radiation, also called direct radiation, is the portion of solar radiation that reaches the Earth's surface in a straight line without being scattered by the atmosphere. In the figure, this is shown as a single straight path directly from the Sun to the Earth's surface. Beam radiation is strongest on clear, sunny days and produces sharp shadows. It is very important for solar concentrator systems and photovoltaic panels that are directly facing the Sun.

Diffuse Radiation

Diffuse radiation is the portion of solar radiation that is scattered by air molecules, dust, and clouds in the atmosphere before reaching the Earth's surface. In the figure, this is shown as scattered rays arriving at the surface from many directions. Diffuse radiation is dominant on cloudy or hazy days when direct sunlight is weak or absent. Even when the Sun is not clearly visible, diffuse radiation still provides useful solar energy.

Global Radiation

Global radiation is the total solar radiation received at the Earth's surface and is the sum of beam (direct) radiation and diffuse radiation. As illustrated in the figure, it includes both the straight-line radiation from the Sun and the scattered radiation reaching the surface. Global radiation represents the actual solar energy available at a location and is the most important parameter used for designing and evaluating solar energy systems.

QUESTION BANK:

5-MARK QUESTIONS (Short Answer Type)

1. Define renewable energy. Explain its importance in modern energy systems.
2. What is meant by global energy demand? Briefly explain the factors affecting it.
3. List the major sectors consuming global energy and mention the highest energy-consuming sector.
4. State the need for renewable energy with any two drawbacks of non-renewable energy sources.
5. Compare renewable and non-renewable energy sources with respect to availability and environmental impact.
6. List any four environmental benefits of renewable energy with suitable examples.
7. What are the major challenges of renewable energy adoption? Explain any two.
8. Define solar radiation and explain its significance.
9. What is extraterrestrial radiation? Why is it important in solar energy calculations?
10. Define solar constant and state its standard value.
11. What is meant by beam (direct) solar radiation?
12. Differentiate between beam radiation and diffuse radiation.
13. What is global solar radiation? How is it related to beam and diffuse radiation?
14. Write a short note on the visible region of extraterrestrial solar radiation.
15. Mention the spectral regions of extraterrestrial radiation and their approximate energy distribution.

10-MARK QUESTIONS (Descriptive / Long Answer Type)

1. Explain renewable energy in detail. Discuss its types, advantages, limitations, and applications.
2. Describe the overview of global energy demand. Explain sector-wise and country-wise energy consumption and its relation to economic growth.
3. Explain the need for renewable energy by highlighting the major drawbacks of non-renewable energy resources with suitable examples.
4. Compare renewable and non-renewable energy sources in detail using appropriate parameters and examples.
5. Explain the environmental benefits of renewable energy with live examples.
6. Discuss the major challenges of renewable energy in detail with suitable examples.
7. Explain solar radiation in detail. Discuss its significance for life and energy generation.
8. Explain extraterrestrial radiation with reference to the Earth–Sun system and the given diagram.
9. Explain the spectral distribution of extraterrestrial radiation. Describe ultraviolet, visible, and infrared regions separately.
10. Define solar constant. Explain its significance, standard value, seasonal variation, and governing equation.
11. Explain solar radiation at the Earth’s surface. Describe beam, diffuse, and global radiation with neat sketches.
12. Explain how solar radiation is modified while passing through the Earth’s atmosphere.
13. Explain different sources of renewable and non renewable energy sources.

MODULE-02 SOLAR POWER PLANTS

Syllabus: Measurement of Solar Radiation: Pyrometer, shading ring pyrheliometer, sunshine recorder, schematic diagrams and principle of working. Solar Thermal Conversion: Collection and storage, thermal collection devices. Fundamentals of solar energy and photovoltaic (PV) technology, Types of solar power plants: gridtied, offgrid, and hybrid systems, Design considerations for solar power plants: site selection, orientation, and shading analysis, PV system components and their functionalities, Operation, maintenance, and performance monitoring of solar power plants

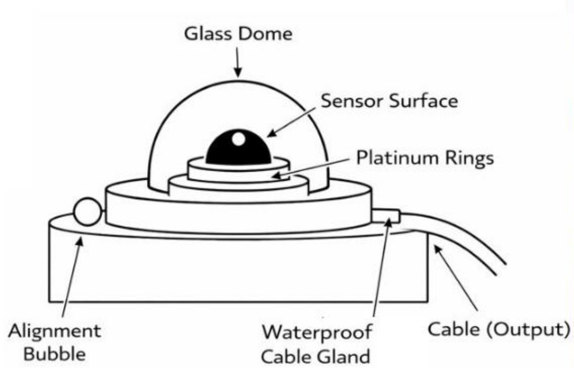
A solar power plant is a renewable energy facility that converts solar radiation into electrical energy using photovoltaic panels or solar thermal systems. It operates by capturing sunlight and transforming it into usable power without the combustion of fuels, making it an environmentally friendly source of electricity. Solar power plants play an important role in reducing greenhouse gas emissions and minimizing dependence on fossil fuels. They can be installed at both large utility scale and small distributed levels, such as rooftop systems.

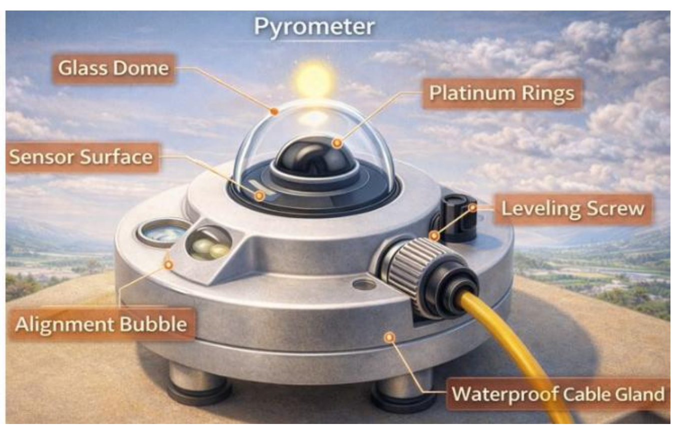
2.0 Measurement of Solar Radiation:

Measurement of solar radiation refers to determining the amount of sunlight reaching the Earth's surface using scientific instruments such as pyranometers for global radiation and pyrheliometers for beam (direct) radiation. These instruments measure solar energy in watts per square meter and help estimate how much usable solar power is available at a location. Accurate measurement is essential for designing solar photovoltaic and solar thermal systems, predicting their performance, and selecting suitable sites for solar plants. It is also widely used in meteorology and climate studies to understand weather patterns and energy balance. Overall, solar radiation measurement provides the basic data needed for effective solar energy planning and utilization.

2.1 Construction & Working of Pyrometer:

A pyranometer is an instrument used to measure global solar radiation, including both beam and diffuse radiation, on a horizontal surface.





Construction details:

Sl. No	Part Name	Function
1	Glass Dome	Allows solar radiation to pass and protects the sensor
2	Sensor Surface (Thermopile)	Converts solar radiation into electrical signal
3	Platinum Rings	Improve uniform heat distribution on sensor
4	Alignment Bubble	Helps in proper horizontal leveling
5	Levelling Screws	Used to adjust instrument position
6	Waterproof Cable Gland	Prevents dust and moisture entering the system
7	Output Cable	Transfers signal to display/data logger

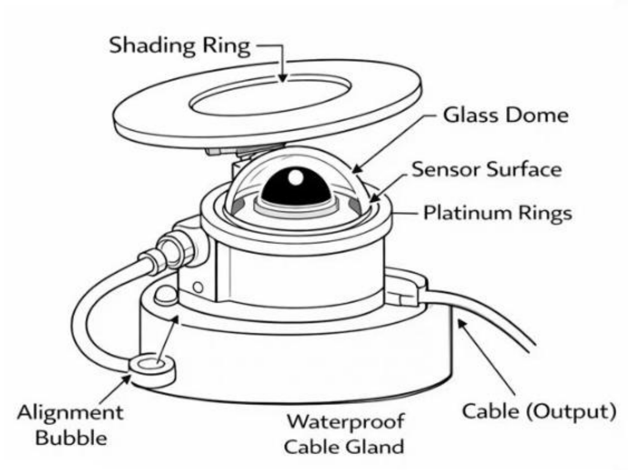
Operating Principle:

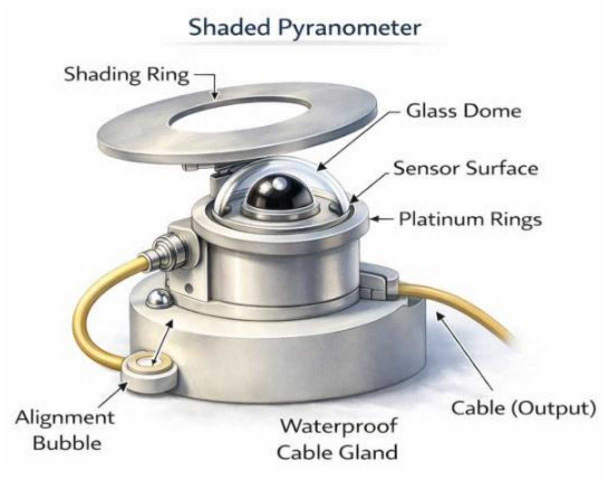
The working principle of a pyranometer is based on the conversion of solar radiation into an electrical signal using a thermopile sensor. As shown in the figure, solar radiation enters through the glass dome and falls on the blackened sensor surface. The sensor absorbs both direct and diffuse radiation and produces a temperature difference, which generates a small electrical voltage proportional to the incoming solar energy. Platinum rings ensure uniform heat distribution, while levelling screws and alignment bubble help keep the instrument horizontal for accurate measurement. The output signal is transmitted through a cable to a data logger or display unit, where global solar radiation is recorded in terms of W/m^2. Thus, the pyranometer provides continuous measurement of total solar radiation at a location.

Merits, Demerits & Applications:

A pyranometer offers accurate and continuous measurement of global solar radiation and has no moving parts, which makes it reliable and suitable for long-term outdoor use. However, it requires regular cleaning and calibration, is sensitive to environmental conditions such as dust and temperature, and high-quality instruments are relatively expensive. Despite these limitations, pyranometers are widely used in meteorological stations, solar power plants for site assessment and performance monitoring of photovoltaic systems, climate research, agricultural studies, and environmental monitoring, making them an important tool in solar energy and atmospheric applications.

2.2 Shading Ring Pyranometer: A shading ring pyranometer is a solar measuring instrument used to measure diffuse solar radiation by blocking direct sunlight with the help of a shading ring. It is commonly used in solar energy and meteorological studies to separate diffuse radiation from global radiation.





Construction Details:

Sl. No	Part Name	Function
1	Shading Ring	Blocks direct sunlight and allows only diffuse radiation to reach the sensor
2	Glass Dome	Allows solar radiation to pass and protects the sensor
3	Sensor Surface (Thermopile)	Converts absorbed solar radiation into electrical signal
4	Platinum Rings	Improve uniform heat distribution on the sensor
5	Alignment Bubble	Helps in proper horizontal leveling
6	Levelling Screws	Used to adjust and level instrument position
7	Waterproof Cable Gland	Prevents dust and moisture from entering the system
8	Output Cable	Transfers electrical signal to display or data logger

Operating Principle:

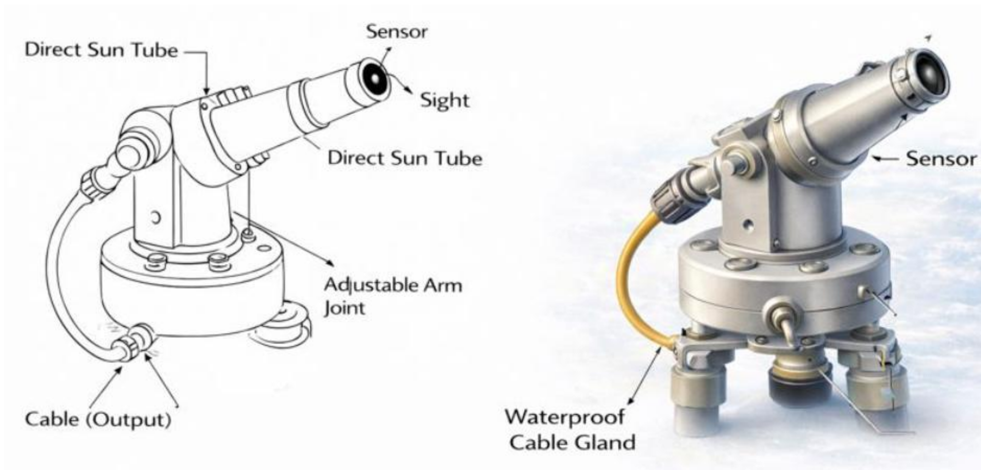
The working principle of a shaded pyranometer is based on the conversion of **diffuse solar radiation** into an electrical signal using a thermopile sensor. As shown in the figure, the shading ring blocks direct sunlight, allowing only scattered radiation from the atmosphere to reach the glass dome. This diffuse radiation enters through the dome and falls on the blackened sensor surface. The sensor absorbs the radiation and produces a temperature difference, which generates a small electrical voltage proportional to the incoming diffuse solar energy. Platinum rings ensure uniform heat distribution, while levelling screws and alignment bubble help keep the instrument horizontal for accurate measurement. The output signal is transmitted through a cable to a data logger or display unit, where diffuse solar radiation is recorded in W/m^2. Thus, the shaded pyranometer provides continuous measurement of diffuse solar radiation at a location.

Merits, Demerits & Applications:

A shaded pyranometer provides accurate and continuous measurement of diffuse solar radiation and has no moving parts, making it reliable for long-term outdoor use. However, it requires periodic cleaning of the glass dome and shading ring, regular calibration, and proper alignment, and high-quality instruments are relatively expensive. Despite these limitations, shaded pyranometers are widely used in meteorological stations, atmospheric research, climate studies, and solar energy assessment. They are especially useful for separating diffuse radiation from global radiation and for estimating direct radiation using the relation **Direct = Global − Diffuse**, making them important instruments in solar energy engineering and environmental monitoring.

2.3 Pyrheliometer:

A pyrheliometer is a solar measuring instrument used to measure direct beam solar radiation coming straight from the Sun. It works by aligning a narrow tube toward the Sun and sensing the incoming radiation with a detector.



Construction Details:

Sl. No	Part Name	Function
1	Direct Sun Tube	Allows only direct sunlight to reach the sensor
2	Sensor	Converts received solar radiation into electrical signal
3	Sight	Helps align the instrument accurately toward the Sun
4	Adjustable Arm Joint	Allows angular adjustment for Sun tracking
5	Base Housing	Supports and holds the instrument
6	Levelling Screws	Used to level the instrument horizontally
7	Waterproof Cable Gland	Protects cable entry from dust and moisture
8	Output Cable	Transfers signal to data logger or display unit

Operating Principle:

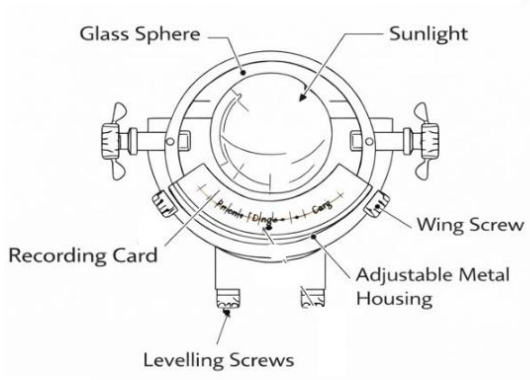
The working principle of a pyrheliometer is based on measuring direct solar radiation using a narrow tube aligned with the Sun. As shown in the figure, sunlight enters through the direct sun tube and falls on the sensor. The sensor absorbs this radiation and converts it into an electrical signal proportional to the solar intensity. The sight and adjustable arm joint help point the instrument precisely toward the Sun, while levelling screws ensure correct horizontal positioning. The generated electrical signal is transmitted through the output cable to a display or data logger. Thus, the pyrheliometer provides accurate measurement of direct beam solar radiation.

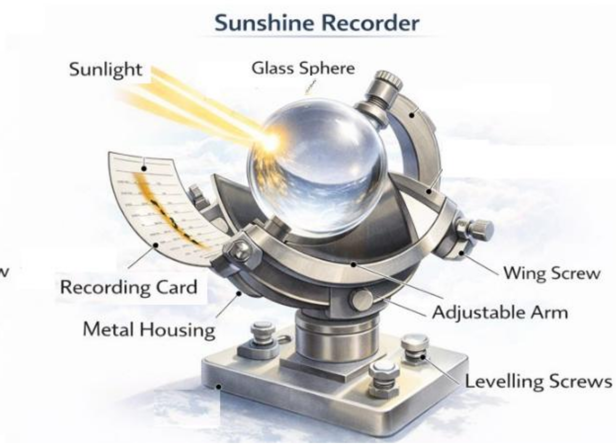
Merits, Demerits & Applications:

A pyrheliometer provides accurate measurement of direct solar radiation and is essential for solar resource assessment and system design. It is reliable and suitable for scientific studies, but it requires continuous alignment with the Sun, regular cleaning, and skilled operation, and it is relatively expensive. Despite these limitations, pyrheliometers are widely used in meteorological stations, solar power plants, atmospheric research, climate studies, and renewable energy site evaluation, making them important instruments in solar energy engineering.

2.4 Sunshine Recorder:

A sunshine recorder is an instrument used to measure the duration of bright sunshine hours in a day. It works by focusing sunlight through a glass sphere onto a recording card, producing a burn trace.





Construction Details:

Sl. No	Part Name	Function
1	Glass Sphere	Focuses sunlight onto the recording card
2	Recording Card	Records sunshine duration by burn marks
3	Adjustable Metal Housing	Holds sphere and card in correct position
4	Wing Screws	Used to fix and adjust the recording card
5	Adjustable Arm	Helps align the instrument
6	Levelling Screws	Used to level the recorder horizontally
7	Base Stand	Supports the entire instrument

Operating Principle:

The sunshine recorder works on the principle of focusing solar rays using a glass sphere. As shown in the figure, sunlight passes through the glass sphere and is concentrated onto a specially prepared recording card placed behind it. When bright sunshine is present, the focused rays burn a trace on the card. As the Sun moves across the sky, this burn mark progresses along the card. The length of the burnt trace corresponds to the duration of bright sunshine during the day. At the end of the day, the card is removed and the sunshine hours are calculated from the markings.

Merits, Demerits and Applications:

A sunshine recorder is simple in construction, requires no electrical power, and provides direct measurement of sunshine duration. However, it cannot measure solar intensity, does not record during cloudy conditions, and needs manual replacement of recording cards daily. Despite these limitations, it is widely used in meteorological stations, climate studies, agricultural planning, and solar energy assessment to estimate sunshine hours, making it an important tool in weather monitoring and renewable energy applications.

Comparison:

Parameter	Pyranometer	Shading Ring Pyranometer	Pyrheliometer	Sunshine Recorder
Type of Radiation Measured	Global radiation (direct + diffuse)	Diffuse radiation only	Direct beam radiation	Duration of bright sunshine
Main Principle	Thermopile converts radiation to electrical signal	Shading ring blocks direct rays; thermopile measures diffuse radiation	Narrow tube aligned to Sun measures direct radiation	Glass sphere focuses sunlight to burn trace on card
Key Component	Glass dome with sensor	Pyranometer with shading ring	Direct sun tube with sensor	Glass sphere and recording card
Need for Sun Tracking	Not required	Periodic ring adjustment	Required (must point at Sun)	Not required
Output	Electrical signal (W/m²)	Electrical signal (W/m²)	Electrical signal (W/m²)	Burn mark indicating sunshine hours
Typical Applications	Solar plant design, meteorology	Diffuse radiation studies, climate research	Direct radiation measurement, CSP studies	Weather stations, agriculture
Accuracy / Complexity	High, simple operation	High, needs ring alignment	Very high, requires precise tracking	Moderate, simple mechanical device
Cost & Maintenance	Moderate, periodic cleaning/calibration	Higher, needs alignment & calibration	High, needs skilled handling	Low, only card replacement

2.4 Solar Thermal Conversion:

Solar thermal conversion is the process of converting solar radiation into useful thermal energy. In this method, sunlight is absorbed by a collector surface and converted into heat, which is used directly for heating or indirectly to generate electricity. Unlike solar photovoltaic systems that produce electricity directly, solar thermal systems first generate heat and then utilize it for various applications.

The working principle involves collecting solar radiation using solar collectors, transferring the absorbed heat to a working fluid such as water or oil, and finally using this heat for domestic water heating, space heating, industrial processes, or steam generation for turbines.

Solar thermal systems are classified into

1. Non-concentrating collectors (flat-plate and evacuated tube) for low- and medium-temperature uses, and

2. Concentrating systems (parabolic troughs, solar towers, and dish systems) for high-temperature power generation.

An important advantage of solar thermal conversion is the ease of thermal energy storage using hot water or molten salts, which allows energy use even when sunlight is not available. Solar thermal systems reduce fossil fuel consumption and greenhouse gas emissions, supporting sustainable development. However, they require large land areas, depend on sunny weather, and involve high initial investment.

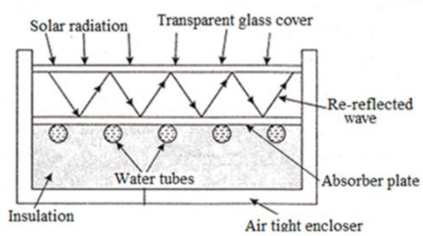
Solar thermal conversion is widely applied in solar water heaters, solar cookers, industrial heating, desalination plants, and concentrating solar power stations. In conclusion, solar thermal conversion is an effective renewable technology that converts sunlight into heat for useful applications and electricity generation, playing a key role in clean and sustainable energy systems.

2.5 Collection and Storage:

Collection and storage are important steps in solar thermal systems. Collection refers to capturing solar energy using devices such as flat plate collectors or concentrating collectors. The collected heat is transferred to a working fluid like water or oil. Storage involves saving this thermal energy in insulated tanks or storage materials so it can be used when sunlight is not available. This improves reliability and ensures continuous energy supply.

2.6 Flat Plate Collectors:

A flat plate collector (FPC) is a solar thermal device used to collect solar radiation and convert it into heat for heating water or other fluids. It works by absorbing sunlight on a flat absorber plate and transferring the heat to flowing fluid tubes.



Construction Details:

Sl. No	Part Name	Function
1	Transparent Cover (Glass)	Allows sunlight to enter and reduces heat loss
2	Absorber Plate	Absorbs solar radiation and converts it into heat
3	Fluid Tubes / Water Tubes	Carry the working fluid and remove heat from absorber
4	Frame	Supports and holds all components together
5	Thermal Insulation	Reduces heat loss from bottom and sides
6	Back Plate	Provides structural support and protects insulation
7	Airtight Enclosure	Prevents air leakage and improves efficiency

Operating Principle:

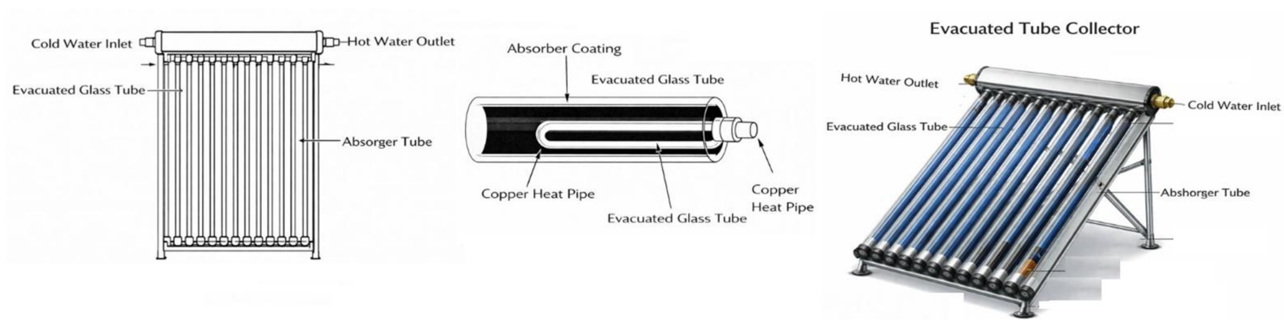
The working principle of a flat plate collector is based on absorbing solar radiation and converting it into thermal energy. As shown in the figure, sunlight passes through the transparent glass cover and falls on the blackened absorber plate. The absorber plate converts this radiation into heat, which is transferred to the fluid flowing through the attached tubes. The heated fluid is then circulated to a storage tank or used directly for applications. The glass cover reduces heat loss by reflection and convection, while thermal insulation at the back minimizes heat loss to the surroundings. Thus, the flat plate collector continuously converts solar energy into useful heat.

Merits, Demerits & Applications:

A flat plate collector is simple in construction, reliable, has no moving parts, and can utilize both direct and diffuse solar radiation. It requires low maintenance and is suitable for moderate temperature applications. However, it has lower efficiency at high temperatures, occupies large area, and performance depends on weather conditions. Despite these limitations, flat plate collectors are widely used in solar water heaters, space heating, swimming pool heating, industrial process heat, and solar drying systems, making them an important component of solar thermal energy utilization.

2.7 Evacuated Tube Collectors:

An evacuated tube collector is a solar thermal device that uses evacuated glass tubes to collect solar radiation and convert it into heat for heating water or other fluids. The vacuum inside the tubes reduces heat loss and improves efficiency.



Construction Details:

Sl. No	Part Name	Function
1	Evacuated Glass Tube	Allows sunlight to enter and provides vacuum insulation
2	Absorber Coating / Absorber Tube	Absorbs solar radiation and converts it into heat
3	Copper Heat Pipe	Transfers heat from absorber to manifold
4	Manifold / Header	Collects heat from all tubes and heats flowing water
5	Cold Water Inlet	Supplies cold water to the system
6	Hot Water Outlet	Delivers heated water
7	Support Frame	Holds tubes at proper tilt angle

Operating Principle:

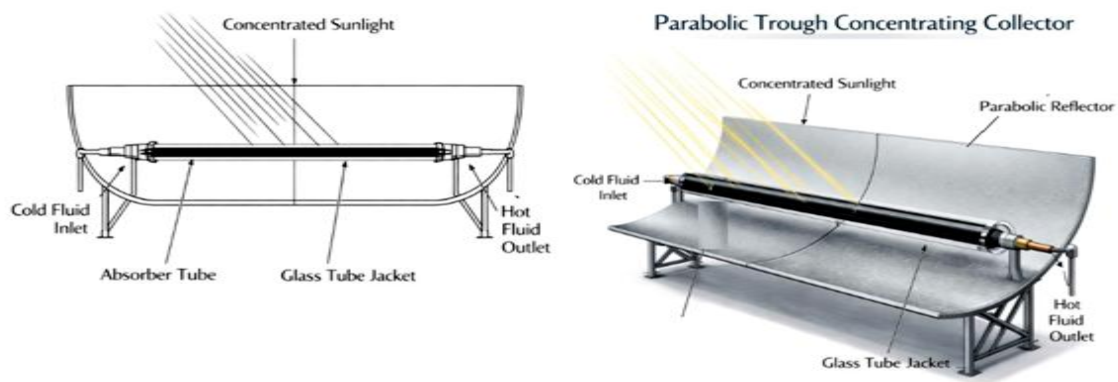
The working principle of an evacuated tube collector is based on absorbing solar radiation inside evacuated glass tubes and transferring the heat to flowing water. Sunlight passes through the outer glass tube and falls on the absorber coating, which converts it into heat. The vacuum between the glass layers prevents heat loss by convection and conduction. The generated heat is transferred to the copper heat pipe, which carries it to the manifold where water flows. Cold water enters through the inlet, absorbs heat in the manifold, and exits as hot water through the outlet. Thus, the evacuated tube collector efficiently converts solar energy into thermal energy.

Merits, Demerits & Applications:

Evacuated tube collectors offer high efficiency, work well even in cold or cloudy weather, and have lower heat losses due to vacuum insulation. However, they are more expensive than flat plate collectors, fragile glass tubes require careful handling, and replacement cost is higher. Despite these limitations, they are widely used in domestic solar water heaters, hospitals, hotels, industries, space heating systems, and solar thermal applications, making them an important technology for renewable heating.

2.8 Parabolic Trough Concentrating Collectors:

A Parabolic Trough Concentrating Collector (PTC) is a solar thermal device that uses a curved parabolic mirror to concentrate sunlight onto a receiver tube placed at its focal line. The concentrated heat is transferred to a fluid for power generation or heating applications



Construction Details:

Sl. No	Part Name	Function
1	Parabolic Reflector	Reflects and concentrates sunlight onto absorber tube
2	Absorber Tube (Receiver)	Absorbs concentrated solar energy and heats the fluid
3	Glass Tube Jacket	Reduces heat loss and protects absorber tube
4	Cold Fluid Inlet	Supplies cold heat-transfer fluid
5	Hot Fluid Outlet	Delivers heated fluid
6	Support Structure / Frame	Holds reflector and receiver in position
7	Tracking Mechanism	Keeps collector aligned with Sun (single-axis)

Operating Principle:

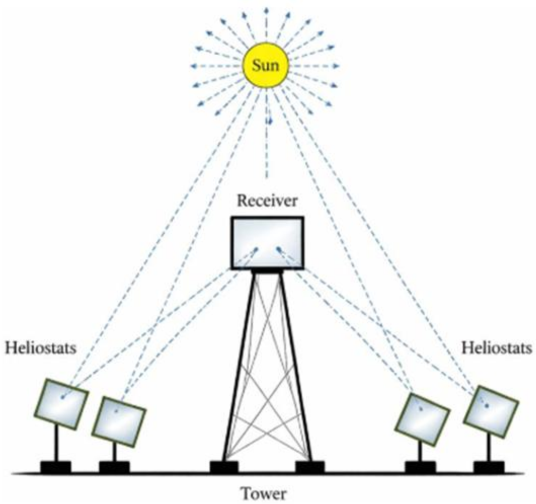
The working principle of a parabolic trough concentrating collector is based on concentrating solar radiation using a parabolic reflector. As shown in the figure, sunlight falling on the curved mirror is reflected and focused onto the absorber tube located along the focal line. The absorber tube, enclosed in a glass jacket, absorbs this concentrated energy and transfers heat to the fluid flowing inside. Cold fluid enters through the inlet, gets heated while passing through the receiver, and exits as hot fluid through the outlet. A tracking mechanism keeps the collector aligned with the Sun to maintain focus throughout the day. Thus, the system converts solar radiation into useful thermal energy.

Merits, Demerits & Applications:

Parabolic trough collectors provide high-temperature heat, offer good efficiency, and are suitable for large-scale power generation. However, they require precise Sun tracking, large land area, and high initial investment, and work best only in regions with strong direct sunlight. Despite these limitations, they are widely used in concentrating solar power plants, industrial process heating, steam generation, desalination, and large solar thermal projects, making them important systems for utility-scale renewable energy production.

2.9 Solar Tower Collectors:

A Solar Tower Collector is a concentrating solar power system in which many mirrors (heliostats) reflect sunlight onto a receiver mounted on a tall tower. The concentrated heat is used to generate steam and produce electricity.



Construction Details:

Sl. No	Part Name	Function
1	Heliostats (Mirrors)	Track the Sun and reflect sunlight toward the receiver
2	Tower	Supports the receiver at a high elevation
3	Solar Receiver	Absorbs concentrated sunlight and converts it into heat
4	Heat Transfer Fluid System	Carries heat from receiver to power block
5	Power Generation Unit	Converts thermal energy into electricity
6	Control & Tracking System	Controls mirror movement to follow the Sun
7	Foundation / Support Structure	Provides mechanical stability

Operating Principle:

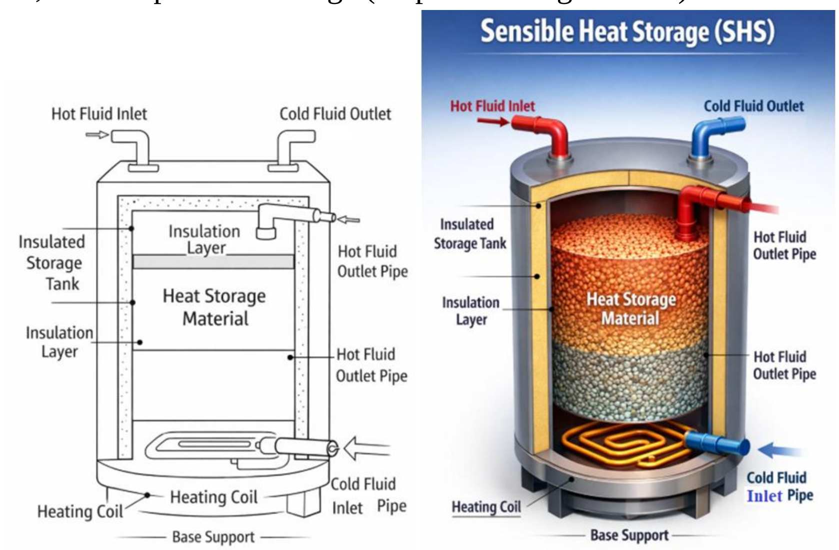
The working principle of a solar tower collector is based on concentrating solar radiation using a large field of heliostats. As shown in the figure, each heliostat continuously tracks the Sun and reflects sunlight toward the receiver located at the top of the tower. The receiver absorbs this concentrated energy and heats a working fluid such as molten salt or water. The hot fluid is then sent to the power generation unit, where steam is produced to drive a turbine and generate electricity. After releasing heat, the fluid is recycled back to the receiver. Thus, the solar tower system converts solar energy into electrical energy through high-temperature thermal conversion.

Merits, Demerits & Applications:

Solar tower collectors can achieve very high temperatures, provide good efficiency, and allow thermal energy storage for power generation even after sunset. However, they require large land areas, high initial investment, complex control systems, and strong direct sunlight. Despite these limitations, they are widely used in large concentrating solar power plants, grid-scale electricity generation, thermal energy storage systems, industrial heating, and renewable power research projects.

2.10 Sensible Heat Storage (SHS):

Sensible Heat Storage (SHS) is a thermal energy storage method in which heat is stored by raising the temperature of a solid or liquid material. The stored energy depends on the material's mass, specific heat, and temperature change (no phase change occurs).



Construction Details:

Sl. No.	Component	Description
1	Hot fluid inlet	Pipe through which hot heat-transfer fluid enters the tank
2	Cold fluid outlet	Pipe through which cooled fluid leaves after heat transfer
3	Insulated storage tank	Outer container that holds the storage material and reduces heat loss
4	Insulation layer	Minimizes heat loss to surroundings
5	Heat storage material	Medium (water/rocks/pebbles/concrete etc.) that stores heat sensibly
6	Hot fluid outlet pipe	Carries heated fluid during discharge
7	Heating coil / heat exchanger	Transfers heat between fluid and storage material
8	Cold fluid inlet pipe	Supplies cold fluid during charging
9	Base support	Mechanical support for the system

Operating Principle:

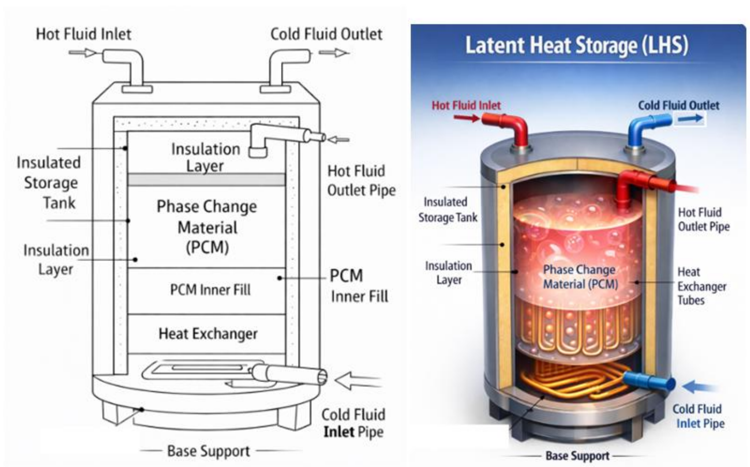
In sensible heat storage, thermal energy is stored by increasing the temperature of a storage material such as water, stones, or concrete. During charging, hot fluid enters through the inlet and transfers its heat to the storage material via the heating coil or direct contact. The material temperature rises and energy is stored as sensible heat. During discharging, cold fluid is passed through the system; it absorbs heat from the hot storage material and exits as hot fluid for use. The process involves only temperature change of the material, without any phase change.

Merits, Demerits, and Applications:

SHS systems are simple in design, low in cost, and use easily available materials. They are reliable, environmentally friendly, and suitable for large-scale storage. Maintenance is minimal, and the technology is well proven.They have low energy density, so large storage volume is required. Heat losses can occur over long storage periods. Also, temperature drops during discharge, giving non-constant output temperature.Sensible heat storage is used in solar thermal power plants, solar water heaters, space heating in buildings, waste-heat recovery systems, and industrial process heat storage.

2.11 Latent Heat Storage (LHS):

Latent Heat Storage (LHS) is a thermal energy storage method in which heat is stored and released during the phase change of a material from liquid to vapour and vapour to liquid. Large amount of energy is stored at nearly constant temperature during evaporation and condensation.



Construction Details:

Sl. No.	Component	Description
1	Hot fluid inlet	Pipe through which hot heat-transfer fluid enters
2	Cold fluid outlet	Pipe through which cooled fluid leaves
3	Insulated storage tank	Outer container holding PCM and reducing heat loss
4	Insulation layer	Minimizes heat loss to surroundings
5	Phase Change Material (PCM)	Storage medium that changes from liquid to vapour
6	PCM inner fill	Holds PCM around heat exchanger
7	Heat exchanger / tubes	Transfers heat between fluid and PCM
8	Hot fluid outlet pipe	Delivers heated fluid during discharge
9	Cold fluid inlet pipe	Supplies cold fluid during charging
10	Base support	Supports the whole system

Operating Principle:

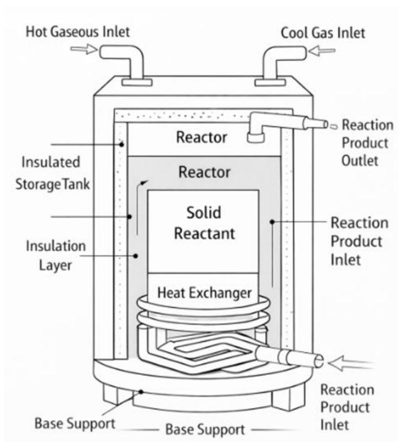
In latent heat storage, thermal energy is stored when the Phase Change Material absorbs heat and changes phase from liquid to vapour during charging. Hot fluid flows through the heat exchanger and transfers heat to the PCM, causing evaporation while storing large energy at almost constant temperature. During discharging, cold fluid is circulated; the vapour PCM releases its stored heat while condensing back to liquid, and the fluid leaves as hot fluid. Thus energy storage and recovery mainly occur through evaporation and condensation.

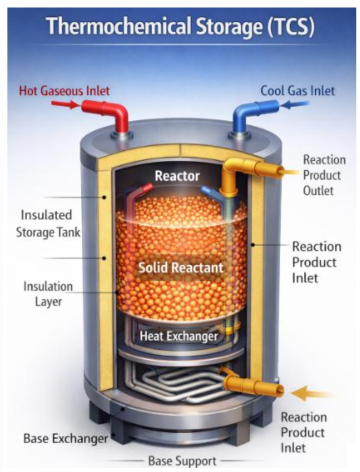
Merits, Demerits, and Applications:

LHS provides very high energy storage density and needs less storage space. It delivers nearly constant temperature during operation and stores more energy compared to sensible heat storage.System cost is high and design is complex. Heat transfer may be slow. Vapour-based PCMs require sealed containers and pressure control, increasing maintenance.Latent heat storage using liquid–vapour transition is used in solar thermal plants, refrigeration systems, air-conditioning, waste heat recovery, and industrial thermal energy storage.

2.12 Thermochemical Storage (TCS):

Thermochemical Storage (TCS) is a thermal energy storage method in which heat is stored and released using reversible chemical reactions. Energy is stored in chemical bonds during charging and released as heat during discharging.





Construction Details:

Sl. No.	Component	Description
1	Hot gaseous inlet	Supplies heat to start the chemical reaction
2	Cool gas inlet	Used during discharge or for reaction control
3	Insulated storage tank	Outer container that holds all components
4	Insulation layer	Reduces heat loss to surroundings
5	Reactor	Chamber where chemical reactions take place
6	Solid reactant	Main material used to store energy chemically
7	Heat exchanger	Transfers heat to and from the reactor
8	Reaction product inlet	Feeds reactants during reverse reaction
9	Reaction product outlet	Removes products formed during charging
10	Base support	Supports the complete system

Operating Principle:

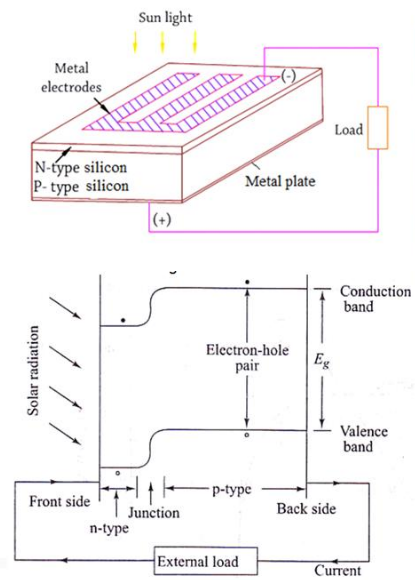
In thermochemical storage, heat is stored by driving an endothermic chemical reaction using external heat during charging. This breaks chemical bonds in the reactant and stores energy in chemical form. During discharging, the reaction is reversed (exothermic), and the reactants recombine, releasing the stored heat. The heat exchanger collects this heat for use. Since energy is stored chemically, it can be kept for long periods with very little loss.

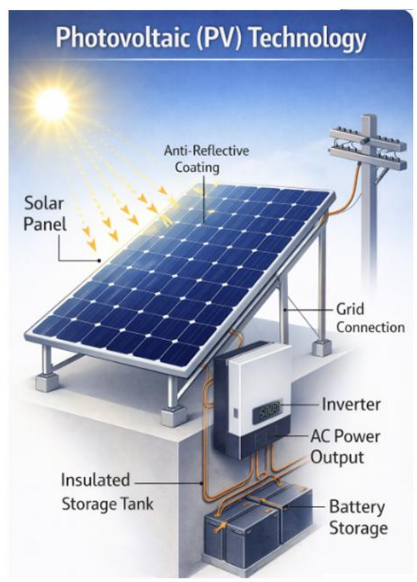
Merits, Demerits, and Applications:

TCS offers very high energy storage density and almost no heat loss during long-term storage. It is suitable for seasonal energy storage and provides heat when required.The system is expensive and complex. Chemical reactions are difficult to control, and materials may degrade after repeated use.Thermochemical storage is used in solar thermal power plants, seasonal heat storage, industrial waste heat recovery, and advanced thermal energy systems.

2.13 Photovoltaic (PV) Technology:

Photovoltaic (PV) technology converts sunlight directly into electrical energy using semiconductor solar cells. It works on the photovoltaic effect, where light falling on a solar cell produces DC electricity.





Construction Details:

Sl. No.	Component	Description
1	Solar panel (PV module)	Group of solar cells that convert sunlight into DC electricity
2	Solar cells	Semiconductor devices (usually silicon) that generate electricity
3	Anti-reflective coating	Reduces reflection and increases light absorption
4	Junction box	Collects electrical output from panels
5	DC cables	Carry DC power from panel to inverter
6	Inverter	Converts DC power to AC power
7	Mounting structure	Holds panels at proper angle
8	Battery (optional)	Stores electrical energy for later use
9	Charge controller (optional)	Controls battery charging
10	Grid connection (optional)	Supplies excess power to utility grid

Operating Principle:

When solar rays with energy greater than the band gap energy are absorbed in the cell material, some of the electrons get excited & jump across the band gap from the valence band to the conduction band leaving behind holes in the valence band. This results in electron hole pair creation. The n-type silicon has excess electrons, while the p-type has excess holes. As these two materials are joined together, excess electrons from the n-type diffuse to recombine with the holes in the p-type. Similarly excess holes from the p-type diffuse to the n-type. As a result, the n-type material becomes positively charged, while the p-type is negatively charged. This creates a 'built-in' potential at the junction. The consequent electric field is adequate to separate the electrons and holes and cause a direct electric current to flow in the externals load.

Merits, Demerits, and Applications:

PV systems are clean, renewable, and silent. They have low maintenance, long life, and reduce electricity bills. They can be installed on rooftops and remote areas.Initial cost is high. Power generation depends on sunlight and weather. Large area is needed for higher output, and batteries increase cost.Photovoltaic technology is used in rooftop solar systems, solar street lights, calculators, satellites, water pumping, rural electrification, and grid-connected power plants.

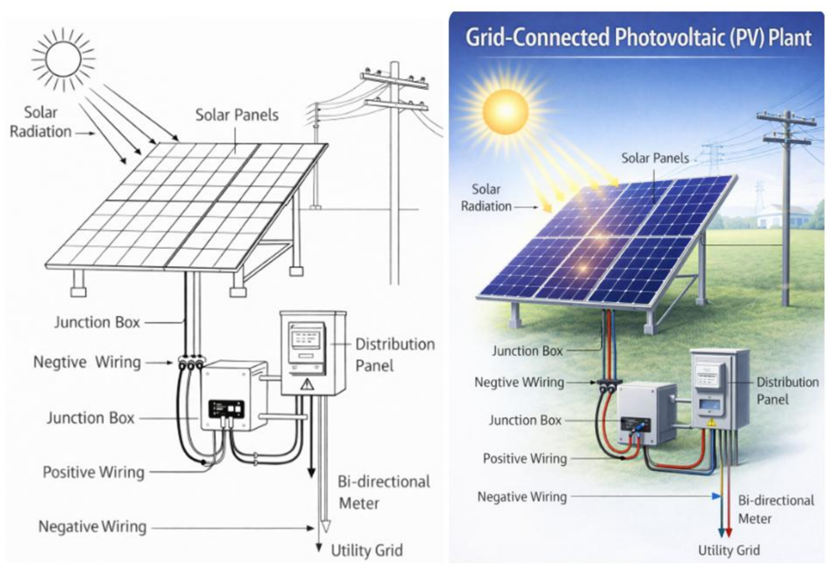
2.14 Solar Power Plants:

Solar power plants generate electricity by converting sunlight into usable energy using solar panels. They are clean, renewable, and reduce dependence on fossil fuels. The generated power can be used locally or supplied to the utility grid.

Solar power plants are mainly of three types: grid-connected systems, which send excess power to the grid; off-grid (without grid) systems, which use batteries to store energy for remote areas; and hybrid systems, which combine solar, batteries, and grid supply for continuous power. Solar plants are widely used in homes, industries, and large power stations for sustainable energy generation.

2.15 Grid-Connected Photovoltaic (PV) Plant:

A Grid-Connected Photovoltaic (PV) Plant is a solar power system that converts sunlight into electricity and directly supplies it to the utility grid. Excess generated power is exported to the grid, and power can be imported when solar generation is low.



Construction Details:

Sl. No.	Component	Description
1	Solar panels (PV modules)	Convert sunlight into DC electricity
2	Mounting structure	Holds panels at proper tilt and direction
3	Junction box / DC combiner	Collects DC output from panels
4	DC cables	Carry DC power to inverter
5	Grid-tie inverter	Converts DC to AC and synchronizes with grid
6	AC distribution panel	Distributes AC power safely
7	Bi-directional energy meter	Measures import and export of electricity
8	Protection devices	MCBs, isolators, surge protection for safety
9	Utility grid	Receives or supplies power
10	Earthing system	Protects equipment and users

Operating Principle:

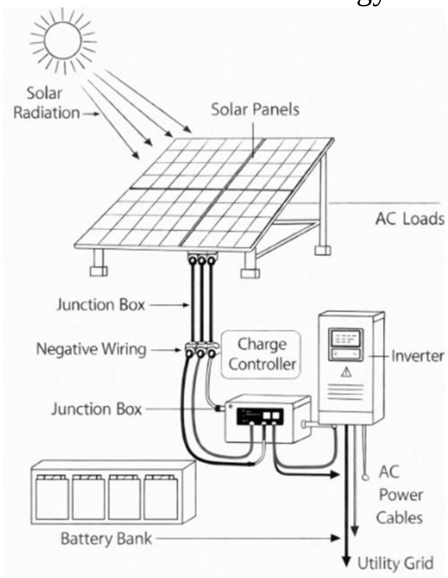
When sunlight falls on the solar panels, DC electricity is produced by the PV cells. This DC power is sent through junction boxes to the grid-tie inverter, where it is converted into AC power with the same voltage and frequency as the utility grid. The AC power is first used by local loads, and any excess energy is exported to the grid through a bi-directional meter. When solar power is insufficient (night or cloudy weather), electricity is automatically drawn from the grid. Thus, the system works without batteries and remains synchronized with the utility supply.

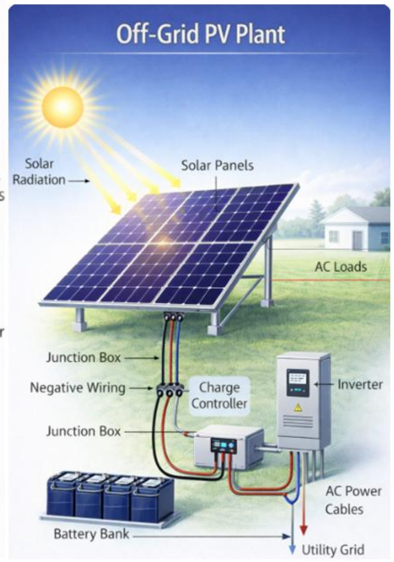
Merits, Demerits, and Applications:

Grid-connected PV plants are clean and renewable, reduce electricity bills, and need no batteries. They have low maintenance and allow selling excess power to the grid. They depend on sunlight and do not work during grid failure (safety shutdown). Initial installation cost is high, and power output varies with weather. Used in rooftop solar systems, commercial buildings, industries, educational institutions, solar parks, and large grid-connected solar power plants.

2.16 Off-Grid PV Plant:

An Off-Grid PV Plant is a solar power system that operates independently without connection to the utility grid. It uses batteries to store energy and supplies electricity directly to local loads.





Construction Details:

Sl. No.	Component	Description
1	Solar panels (PV modules)	Convert sunlight into DC electricity
2	Mounting structure	Holds panels at proper tilt
3	Junction box	Collects DC output from panels
4	DC cables	Carry DC power to controller
5	Charge controller	Regulates battery charging and prevents overcharging
6	Battery bank	Stores electrical energy
7	Inverter	Converts DC power to AC power
8	AC power cables	Carry AC power to loads
9	AC loads	Electrical appliances
10	Earthing system	Provides safety from electrical faults

Operating Principle:

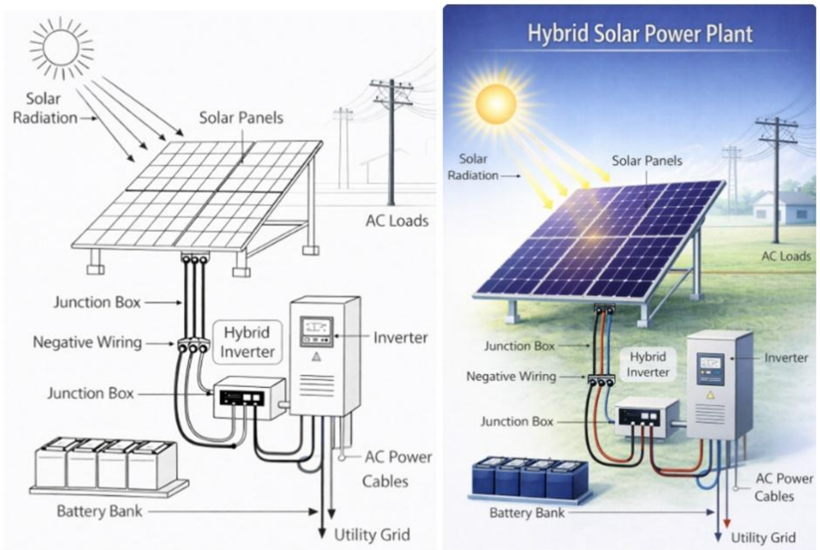
When sunlight falls on the solar panels, DC electricity is produced. This DC power passes through the junction box to the charge controller, which regulates charging of the battery bank. The batteries store energy for use during night or cloudy conditions. The inverter converts stored DC power into AC power and supplies it to AC loads. Since there is no grid connection, all power is generated and used locally.

Merits, Demerits, and Applications:

Off-grid PV plants provide power in remote areas where grid is unavailable. They offer energy independence and use clean renewable energy. They are reliable when properly designed. Initial cost is high due to batteries. Battery maintenance and replacement are required. Power supply depends on sunlight availability.Used in rural electrification, remote homes, telecom towers, water pumping, street lighting, and isolated locations such as islands and villages.

2.17 Hybrid Solar Power Plant:

A Hybrid Solar Power Plant is a solar energy system that works with both batteries and the utility grid.It supplies power from solar panels, stores excess energy in batteries, and uses grid power when needed.



Construction Details:

Sl. No.	Component	Description
1	Solar panels (PV modules)	Convert sunlight into DC electricity
2	Mounting structure	Supports panels at proper tilt
3	Junction box	Collects DC output from panels
4	DC cables	Carry DC power to inverter
5	Hybrid inverter	Manages solar, battery, and grid power
6	Battery bank	Stores excess solar energy
7	AC power cables	Supply AC power to loads
8	AC loads	Electrical appliances
9	Utility grid	Provides backup power and receives excess energy
10	Earthing system	Protects system from electrical faults

Operating Principle:

When sunlight falls on the solar panels, DC electricity is generated and sent to the hybrid inverter. The inverter first supplies power to the loads and then charges the battery bank. If solar power is excess, it is stored in batteries or exported to the grid. When solar energy is insufficient, power is taken from the batteries, and if batteries are low, electricity is drawn from the grid. Thus, the hybrid system ensures continuous power supply by combining solar, battery, and grid sources.

Merits, Demerits, and Applications:

Hybrid systems provide uninterrupted power, reduce electricity bills, and use clean renewable energy. They offer backup during power cuts and improve energy reliability.Initial cost is high due to batteries and hybrid inverter. Battery maintenance and replacement are required. System design is more complex.Used in homes, commercial buildings, hospitals, educational institutions, telecom towers, and areas with frequent power cuts.

2.18 Comparison of Solar PV System Types:

Sl. No.	Parameter	Grid-Connected PV Plant	Off-Grid PV Plant	Hybrid Solar Power Plant
1	Definition	Connected to utility grid; supplies loads and exports excess power (no batteries)	Standalone system using batteries; works without grid	Uses solar, batteries, and grid together for continuous supply
2	Grid connection	Yes	No	Yes
3	Battery usage	Not used	Mandatory	Used
4	Power during grid failure	Not available (safety shutdown)	Available	Available
5	Energy storage	No storage	Stored in batteries	Stored in batteries
6	Initial cost	Low	High	Highest
7	System complexity	Simple	Moderate	High
8	Reliability	Depends on grid	Fully independent	Very high
9	Excess solar energy	Exported to grid	Cannot export	Stored or exported
10	Maintenance	Low	High (battery care)	High (battery + inverter)
11	Typical applications	Homes, industries, solar parks	Remote villages, telecom towers	Homes, hospitals, offices

2.19 Design considerations for solar power plants:

Designing a solar power plant requires careful planning across technical, economic, environmental, and operational aspects to achieve maximum efficiency, reliability, and long service life.

1. Site Selection and Solar Resource Assessment

Site selection is the first and most important step in solar power plant design. The location must receive adequate solar irradiance, which is evaluated using historical weather data and satellite measurements. Geographical factors such as latitude, altitude, and local climate directly influence energy generation. Sufficient land area with suitable terrain is required, along with easy access to grid infrastructure. Environmental and social impacts, including zoning regulations, ecological effects, and permitting requirements, must also be considered.

2. Orientation and Tilt Angle

Proper orientation and tilt of solar panels significantly affect power output. In India, panels are generally oriented toward the south to capture maximum sunlight. The tilt angle is usually kept close to the local latitude for year-round performance. Adequate spacing between panel rows is maintained to avoid shading losses, especially during early morning and late evening hours.

3. Technology Choice

The plant designer must choose between Photovoltaic (PV) and Concentrated Solar Power (CSP) technologies. PV systems convert sunlight directly into electricity using semiconductor panels, while CSP systems concentrate sunlight using mirrors or lenses to produce heat for power generation. Component selection includes choosing monocrystalline, polycrystalline, or thin-film

PV modules, or CSP collectors such as parabolic troughs and solar towers, based on efficiency, cost, climatic conditions, and site availability.

4. System Configuration

Solar power plants can be grid-connected, off-grid, or hybrid. Grid-connected systems export excess energy to the utility grid. Off-grid systems operate independently using batteries for energy storage. Hybrid systems combine solar power with batteries and grid or generator backup for continuous supply. Proper system sizing of solar panels, inverters, and batteries is essential and depends on expected load demand and solar energy availability.

5. Financial and Economic Considerations

Economic feasibility plays a major role in plant design. Capital costs include panels, inverters, mounting structures, installation, and grid connection. Financial evaluation is done using parameters such as Levelized Cost of Energy (LCOE) and return on investment. Government incentives, subsidies, tax benefits, and financing schemes help reduce initial investment and improve project viability.

6. Grid Integration and Energy Management

For grid-connected systems, compliance with utility standards and grid codes is mandatory. Energy Management Systems (EMS) are used to monitor, control, and optimize power flow between solar panels, batteries, loads, and the grid. Net metering allows bidirectional energy exchange, enabling users to export surplus power and import electricity when solar generation is insufficient.

7. Operation and Maintenance

Efficient operation requires continuous performance monitoring using SCADA or remote monitoring systems. Regular maintenance activities include panel cleaning, inspection of electrical connections, and inverter servicing. Designers also consider system degradation over time and plan for component replacement or system upgrades to maintain performance throughout the plant's lifetime.

8. Safety and Regulatory Compliance

Safety is ensured by following national and international standards. Proper grounding, fire protection, surge protection, and structural safety measures are incorporated in the design. Risk management includes protection against natural disasters, electrical faults, and equipment failure, supported by suitable insurance coverage.

9. Scalability and Future-Proofing

Modern solar plants are designed with modular architecture so that capacity can be expanded in the future. Designers also consider emerging technologies such as higher-efficiency panels and advanced energy storage systems, allowing easy integration when upgrades are required.

Summary:

Sl. No.	Design Aspect	Brief Description
1	Site Selection & Solar Resource	Check solar irradiance, climate, land availability, terrain, grid access, and environmental impact.
2	Orientation & Tilt Angle	Panels face south (in India) with tilt near local latitude to maximize energy; avoid shading.
3	Technology Choice	Select PV or CSP. Choose suitable panels/collectors based on efficiency, cost, and location.

Sl. No.	Design Aspect	Brief Description
4	System Configuration	Decide grid-connected, off-grid, or hybrid. Size panels, inverters, and storage as per load.
5	Financial Considerations	Estimate capital cost, ROI/LCOE, and use subsidies or financing if available.
6	Grid Integration & Energy Management	Follow grid codes, use EMS, and apply net metering for grid systems.
7	Operation & Maintenance	Monitor performance, clean panels, service equipment, and consider long-term degradation.
8	Safety & Regulations	Follow standards, provide grounding and fire protection, and manage risks with insurance.
9	Scalability & Future-Proofing	Use modular design and allow for future expansion and technology upgrades.

2.20 Shading Analysis:

Shading analysis is an important part of solar power plant design because even small shadows on panels can greatly reduce power output. Proper shading study helps in maximizing energy generation throughout the year.

1. Sun Path and Solar Angles

The movement of the sun changes daily and seasonally. Designers study the sun's path using solar charts or software to understand the sun's position at different times of the day and year. This helps predict when and where shadows will fall on solar panels. It is especially important to consider winter mornings and evenings when the sun is low and shadows are longer.

2. Nearby Obstacles

All surrounding objects such as trees, buildings, poles, water tanks, and hills can cast shadows on solar panels. These obstacles are identified and their height and distance from the panels are measured. Designers ensure panels are placed far enough away or obstacles are removed to avoid shading, particularly during peak sunlight hours.

3. Panel Row Spacing

In large solar plants, panels are arranged in rows. If rows are too close, one row can shade the next, especially when the sun is low. Proper spacing between rows is calculated based on panel height, tilt angle, and sun position to prevent self-shading and ensure uniform sunlight on all panels.

4. Tilt Angle and Orientation

The tilt angle and direction of panels affect shadow formation. Panels are usually tilted near the local latitude and oriented toward the equator (south-facing in India). Correct tilt and orientation reduce shading losses and improve overall energy collection.

5. Seasonal Shading

Shadow patterns change with seasons. In winter, shadows are longer due to low sun angle, while in summer they are shorter. Designers analyze shading for the worst-case condition (usually winter) to make sure panels receive sunlight throughout the year.

6. Impact on Electrical Performance

Shading not only reduces light but also affects electrical output. Even partial shading on one cell can reduce power from the entire string of panels. Therefore, system layout, string design, and use of bypass diodes are planned carefully to minimize energy loss due to shading.

7. Use of Shading Analysis Tools

Modern design uses software tools and on-site instruments such as solar pathfinders to simulate shadows and estimate losses. These tools help designers optimize panel placement and predict annual energy production accurately.

Proper shading analysis ensures maximum sunlight reaches the panels, improves system efficiency, and increases the financial return of solar power plants.

Summary:

Sl. No.	Parameter	Brief Explanation
1	Sun Path & Solar Angles	Studies sun movement to predict shadow direction and length during different times of the year.
2	Nearby Obstacles	Identifies trees, buildings, poles, etc., that may cast shadows on panels.
3	Panel Row Spacing	Proper distance between rows to avoid panels shading each other.
4	Tilt Angle & Orientation	Correct tilt and south-facing direction (in India) reduce shading losses.
5	Seasonal Shading	Considers longer winter shadows to ensure year-round sunlight.
6	Electrical Impact of Shading	Partial shading reduces string output; layout and bypass diodes minimize losses.
7	Shading Analysis Tools	Software and site tools are used to model shadows and optimize layout.

2.21 PV system components and their functionalities:

A photovoltaic (PV) system consists of several important components that work together to convert sunlight into usable electrical energy. Each part has a specific role in ensuring safe and efficient operation.

1. Solar Panels (PV Modules):

Solar panels are the main part of a PV system. They capture sunlight and convert it directly into DC electricity using the photovoltaic effect. The panels are made mainly from silicon-based semiconductor materials. Different types of panels such as monocrystalline, polycrystalline, and thin-film are available, each with different efficiency and cost. The amount of power produced depends on sunlight intensity and panel quality.

2. Inverter

The inverter converts the DC electricity produced by solar panels into AC electricity, which is required for household appliances and industries. In grid-connected systems, the inverter also matches the voltage and frequency of the utility grid. Common inverter types include string inverters, central inverters, and microinverters. It plays a key role in overall system performance.

3. Charge Controller

The charge controller controls the flow of electricity from solar panels to batteries. It prevents overcharging and deep discharging, which helps extend battery life. This component is mainly used in off-grid and hybrid systems. Advanced charge controllers use MPPT or PWM techniques to improve energy collection.

4. Battery Storage

Batteries store excess solar energy for later use, especially during night or cloudy periods. They are essential in off-grid and hybrid systems to ensure continuous power supply. Common battery types include lead-acid and lithium-ion. Proper battery sizing and maintenance are important for system reliability.

5. Wiring and Electrical Components

Wires connect all parts of the PV system and carry electricity safely. DC cables transfer power from panels to inverter or charge controller, while AC cables supply power to loads or the grid. This category also includes safety devices such as fuses, switches, combiner boxes, and surge protectors to protect the system from faults.

6. Mounting Structures

Mounting structures hold the solar panels firmly and at the correct tilt and direction. They ensure panels receive maximum sunlight. Structures may be fixed or movable (single-axis or dual-axis trackers). Strong mounting improves system efficiency and protects panels from wind and weather.

7. Monitoring and Control System

Monitoring systems track energy production, consumption, and equipment condition. They help detect faults early and improve performance. Many systems allow remote monitoring through mobile apps or computers, making maintenance easier.

8. Balance of System (BOS) Components

Balance of System includes all supporting parts apart from panels and inverter, such as mounting hardware, wiring, electrical enclosures, protection devices, and tracking systems. Though often unnoticed, BOS components greatly affect the cost, safety, and reliability of the PV system.

All PV system components work together to convert sunlight into electricity safely and efficiently. Understanding their functions helps in proper design, installation, and maintenance of solar power plants.

Summary:

Sl. No.	Component	Function
1	Solar Panels (PV Modules)	Convert sunlight directly into DC electricity.
2	Inverter	Converts DC power into AC power for use in homes and industries.
3	Charge Controller	Controls battery charging and prevents overcharging (used in off-grid/hybrid systems).
4	Battery Storage	Stores excess solar energy for night or cloudy periods.
5	Wiring & Electrical Components	Connect all parts and provide protection using cables, fuses, switches, and combiner boxes.
6	Mounting Structures	Support panels and maintain proper tilt and direction for maximum sunlight.
7	Monitoring & Control System	Monitors performance and helps detect faults early.
8	Balance of System (BOS)	Includes all supporting parts such as mounts, wiring, enclosures, and safety devices.

2.22 Maintenance of Solar Power Plants:

Proper maintenance of solar power plants is essential to keep the system working efficiently, safely, and for a long time. Maintenance is mainly divided into Preventive (Scheduled) Maintenance **and** Corrective (Unscheduled) Maintenance**.**

A. Preventive (Scheduled) Maintenance

Preventive maintenance is done regularly to avoid problems before they occur.

1. Panel Cleaning

Solar panels must be cleaned to remove dust, dirt, bird droppings, and other deposits that block sunlight and reduce power output. Cleaning is done using soft brushes, clean water, or robotic cleaners to avoid scratching the panels. The cleaning frequency depends on site conditions; dusty areas need more frequent cleaning.

2. Visual and Thermal Inspections

Regular visual checks help find cracks, loose wires, or damaged panels. Thermal inspections using infrared cameras or drones detect hot spots and defective cells. Early detection prevents major failures and energy loss.

3. Electrical and Structural Checks

Wires and connectors are inspected for looseness, corrosion, or damaged insulation. Mounting structures are checked for rust, misalignment, or loose bolts. Inverters are monitored for proper cooling, abnormal noise, and error messages to ensure smooth operation.

4. Battery and Charge Controller Maintenance (if used)

In off-grid and hybrid systems, batteries are checked for voltage, capacity, and electrolyte level (for lead-acid batteries). Charge controllers are inspected to confirm correct voltage and current regulation. Software updates may be done when required.

5. Vegetation Control

Plants and grass around the solar panels are trimmed regularly to prevent shading. Proper landscaping ensures panels receive maximum sunlight.

B. Corrective (Unscheduled) Maintenance

Corrective maintenance is carried out when faults or unexpected problems occur.

1. Repair or Replacement of Faulty Parts

Damaged or underperforming panels are replaced. Inverters are repaired or replaced if serious faults appear. Broken cables and connectors are fixed immediately to avoid safety risks and power loss.

2. Handling Unexpected Shading

Shading caused by tree growth, new buildings, or dust storms is corrected by trimming vegetation, adjusting panel positions, or increasing cleaning frequency.

3. Emergency Generator Maintenance (in Hybrid Systems)

If backup generators are used, fuel and oil levels are checked regularly to ensure they operate properly during low solar production or power outages.

Regular preventive maintenance improves performance, while quick corrective maintenance reduces downtime. Together, they help ensure reliable and long-lasting operation of solar power plants.

Summary:

Sl. No.	Type of Maintenance	Activity	Purpose
1	Preventive	Panel cleaning	Removes dust and dirt to improve sunlight absorption.
2	Preventive	Visual & thermal inspection	Detects cracks, hot spots, and wiring faults early.
3	Preventive	Electrical & structural checks	Ensures safe wiring, strong mounts, and proper inverter operation.
4	Preventive	Battery & charge controller care	Maintains battery health and correct charging (off-grid/hybrid).
5	Preventive	Vegetation control	Prevents shading from plants and grass.
6	Corrective	Repair/replace faulty parts	Restores performance by fixing panels, inverters, or cables.
7	Corrective	Remove unexpected shading	Clears shadows from trees, buildings, or dust.
8	Corrective	Generator maintenance (hybrid)	Ensures backup power during low solar or outages.

2.23 Performance Monitoring of Solar Power Plants:

Performance monitoring is essential to ensure that a solar power plant operates efficiently, safely, and reliably. By continuously tracking system output and component health, operators can detect faults early, improve energy yield, and plan maintenance activities effectively. Performance monitoring mainly involves key performance metrics and monitoring systems/tools.

A. Key Performance Metrics

Key performance metrics help evaluate how well a solar power plant is operating.

a) Energy Yield (KWh): It represents the total electrical energy generated by the plant over a specific period such as a day, month, or year. It directly shows the amount of usable electricity produced.

b) Performance Ratio (PR): It indicates how efficiently the plant converts available solar radiation into electrical energy. It compares the actual energy produced with the theoretical energy expected under ideal conditions. A higher PR means better system performance.

c) Capacity Utilization Factor (CUF): It measures how effectively the installed capacity is used. It is defined as the ratio of actual energy generated to the maximum possible energy if the plant operated at full power continuously. CUF helps assess overall plant productivity.

d) Inverter Efficiency (%): It shows how effectively the inverter converts DC power from solar panels into AC power. Higher inverter efficiency results in lower conversion losses and better system output.

e) Battery State of Charge (SoC) (in off-grid and hybrid systems): It indicates the amount of energy stored in batteries. Monitoring SoC helps manage energy availability and prevents overcharging or deep discharge.

B. Monitoring Systems and Tools

Various monitoring tools are used to collect data and analyze plant performance.

a) SCADA (Supervisory Control and Data Acquisition) systems: It provide centralized real-time monitoring of voltage, current, temperature, and power from panels and inverters. SCADA enables remote operation, data storage, and automatic alarms during faults.

b) Remote Monitoring Platforms: These are cloud-based systems that collect data from one or multiple solar plants. They display performance through dashboards and allow users to analyze real-time and historical data from any location.

c) Data Loggers and Weather Stations: It record electrical parameters and environmental conditions such as solar irradiance, temperature, wind speed, and humidity. This information is used to calculate performance ratio and identify losses due to weather or equipment.

e) Thermal Imaging and Drone Surveys: It uses infrared cameras mounted on drones to detect hot spots, cracked modules, or wiring problems across large solar fields. This method reduces manual inspection time and improves fault detection accuracy.

f) Analytics and Machine Learning tools: It uses advanced algorithms to identify early signs of degradation, predict power generation, and optimize maintenance schedules. These technologies help improve reliability and reduce operational costs.

Summary:

Sl. No.	Category	Parameter / Tool	Purpose
1	Key Metric	Energy Yield (KWh)	Measures total electricity generated.
2	Key Metric	Performance Ratio (PR)	Shows how efficiently solar energy is converted to electricity.
3	Key Metric	Capacity Utilization Factor (CUF)	Indicates how effectively installed capacity is used.
4	Key Metric	Inverter Efficiency	Measures DC to AC conversion efficiency.
5	Key Metric	Battery State of Charge (SoC)	Shows available battery energy (off-grid/hybrid).
6	Monitoring Tool	SCADA	Provides real-time monitoring and fault alarms.
7	Monitoring Tool	Remote Monitoring Platforms	Enables cloud-based performance tracking.
8	Monitoring Tool	Data Loggers & Weather Stations	Records electrical data and weather conditions.
9	Monitoring Tool	Thermal Imaging & Drones	Detects hot spots and faulty modules quickly.
10	Monitoring Tool	Analytics & Machine Learning	Predicts faults and optimizes maintenance.

QUESTION BANK:

5-Mark Questions (Short/Medium Answer Type)

1. Define a solar power plant. Explain its importance in renewable energy systems.
2. Explain the construction and working principle of a pyranometer.
3. What is a shading ring pyranometer? State its principle and applications.
4. Describe the construction and working of a pyrheliometer.
5. Explain the working principle of a sunshine recorder with neat sketch.
6. Compare pyranometer, shading ring pyranometer, pyrheliometer, and sunshine recorder.
7. Explain solar thermal conversion and list its applications.
8. Describe the construction and working of a flat plate collector.
9. Explain the working of an evacuated tube collector.
10. Write short notes on parabolic trough concentrating collectors.

11. Explain the working principle of a solar tower collector.
12. Define Sensible Heat Storage (SHS) and explain its operation.
13. Explain Latent Heat Storage (LHS) with principle and applications.
14. Write short notes on Thermochemical Storage (TCS).
15. Explain the working principle of Photovoltaic (PV) technology.
16. List the main components of a PV system and state their functions.
17. Explain the working of a Grid-Connected PV Plant.
18. Explain the working of an Off-Grid PV Plant.
19. Explain the working of a Hybrid Solar Power Plant.
20. Write short notes on maintenance of solar power plants.
21. Define Performance Ratio (PR) and Capacity Utilization Factor (CUF).
22. List key performance monitoring parameters of solar power plants.
23. Explain any three design considerations for solar power plants.
24. What is shading analysis? State its importance.
25. Write short notes on SCADA and remote monitoring in solar plants.

10-Mark Questions (Long Answer / Descriptive Type)

1. Explain in detail the measurement of solar radiation, including pyranometer, shading ring pyranometer, pyrheliometer, and sunshine recorder with comparison.
2. Describe solar thermal conversion and explain flat plate collectors, evacuated tube collectors, parabolic trough collectors, and solar tower collectors with working principles.
3. Explain thermal energy storage methods: Sensible Heat Storage (SHS), Latent Heat Storage (LHS), and Thermochemical Storage (TCS) with construction, working, merits, and applications.
4. Explain Photovoltaic (PV) technology in detail and describe the construction and working of a PV system.
5. Describe Grid-Connected, Off-Grid, and Hybrid Solar PV Plants with neat block diagrams and compare their features.
6. Explain the design considerations for solar power plants, including site selection, orientation, technology choice, system configuration, financial aspects, and safety.
7. Explain shading analysis in solar power plants. Discuss major parameters such as sun path, obstacles, row spacing, seasonal shading, and electrical impact.
8. Explain PV system components and their functionalities in detail.
9. Describe maintenance of solar power plants, covering preventive and corrective maintenance.
10. Explain performance monitoring of solar power plants, including key performance metrics (Energy Yield, PR, CUF, inverter efficiency, SoC) and monitoring tools (SCADA, data loggers, drones, analytics).

MODULE-03 WIND POWER PLANTS & GEOTHERMAL ENERGY CONVERSION

Syllabus: Basics of wind energy and wind turbine technology, Types of wind turbines: horizontal axis and vertical axis; Wind resource assessment and site selection for wind power plants, Wind farm layout optimization and wake effects, Grid integration and power system considerations for wind power plants.
Geothermal Energy Conversion: Principle of working, types of geothermal station with schematic diagram, geothermal plants in the world, problems associated with geothermal conversion, scope of geothermal energy.

3.1 Introduction:

Basics of Wind Energy

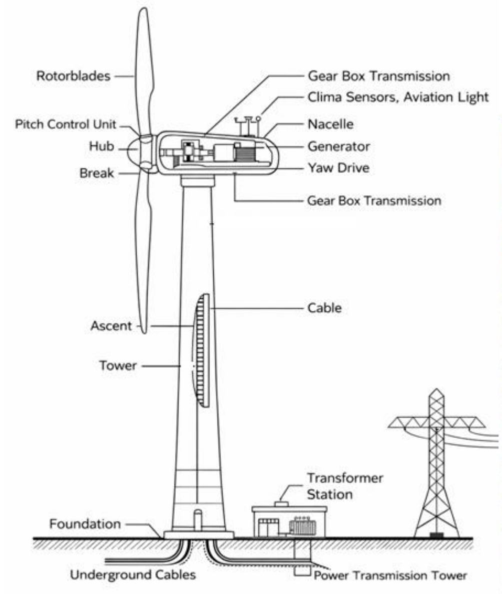
Wind energy is a form of renewable energy obtained from the kinetic energy of moving air. Wind is produced due to uneven heating of the Earth's surface by the sun, which creates pressure differences in the atmosphere. When air moves from high-pressure regions to low-pressure regions, wind is generated. This moving air contains kinetic energy that can be converted into useful mechanical or electrical energy. Wind energy is clean, abundant, and does not produce harmful emissions during operation. The amount of energy available from wind depends on wind speed, air density, and the area swept by turbine blades. Wind speed increases with height, so wind turbines are installed on tall towers to capture stronger and more consistent winds. Wind energy is widely used for electricity generation in onshore and offshore wind farms. However, wind availability is variable and depends on weather and location.

Wind Turbine Technology

Wind turbine technology is used to convert wind energy into electrical energy. A wind turbine consists mainly of blades, a rotor, a nacelle, a gearbox, a generator, a tower, and control systems. When wind flows over the blades, lift is created, causing the rotor to rotate. This mechanical rotation is transmitted through a shaft to the generator, where electricity is produced. Modern wind turbines use aerodynamic blade designs to maximize efficiency. Gearboxes are used to increase rotational speed, while some turbines use direct-drive generators. Control systems such as yaw and pitch mechanisms help orient the turbine toward the wind and regulate power output. Wind turbines can be classified as horizontal-axis and vertical-axis types, with horizontal-axis turbines being more common. Advances in materials, electronics, and control systems have improved turbine efficiency, reliability, and power capacity.

3.2 Horizontal Axis Wind Turbines:

A Horizontal Axis Wind Turbine (HAWT) power plant generates electricity by converting wind energy into electrical energy using a turbine whose rotor rotates parallel to the ground. It is the most commonly used wind power plant for large-scale electricity generation.



Construction Details:

Sl. No.	Component	Description
1	Rotor blades	Capture wind energy and rotate due to aerodynamic force
2	Hub	Connects blades to the main shaft
3	Pitch control unit	Adjusts blade angle to control speed and power
4	Nacelle	Houses gearbox, generator, brake, and control systems
5	Low-speed shaft	Transfers rotation from rotor to gearbox
6	Gearbox	Increases shaft speed for generator operation
7	High-speed shaft	Drives the generator
8	Generator	Converts mechanical energy into electrical energy
9	Yaw system	Rotates nacelle to face wind direction
10	Tower	Supports turbine at a height to access strong winds
11	Transformer & cables	Step up voltage and transmit power to grid
12	Foundation	Provides structural stability

Operating Principle

When wind blows over the rotor blades, aerodynamic lift causes them to rotate. This rotation turns the low-speed shaft connected to the hub. The gearbox increases the rotational speed and drives the generator through a high-speed shaft. The generator converts mechanical energy into electrical energy. The yaw system keeps the turbine facing the wind, while the pitch control regulates blade angle for safe and efficient operation. The generated electricity is transmitted through cables and transformer to the power grid.

Merits, Demerits and Applications :

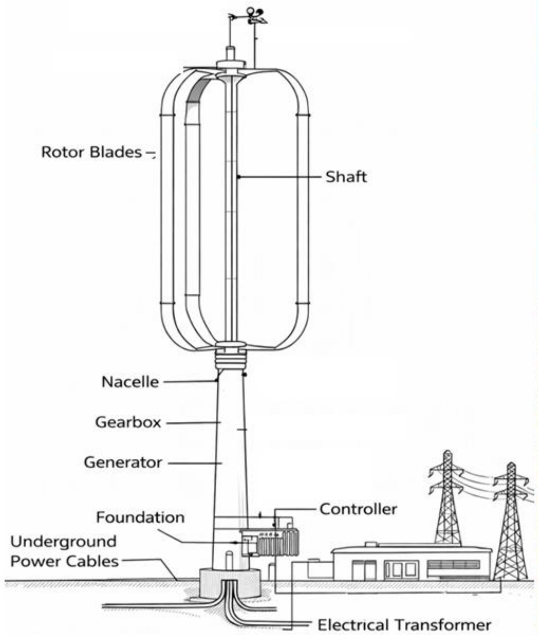
Horizontal axis wind turbines have high efficiency and generate large amounts of power. They are suitable for utility-scale power generation and produce clean, renewable energy without fuel cost.They require high initial investment and large land area. Power generation depends on wind availability, and maintenance at tall heights can be difficult. It is used in wind farms for grid-connected electricity generation, offshore wind plants, rural electrification, and supplying power to industries and commercial buildings.

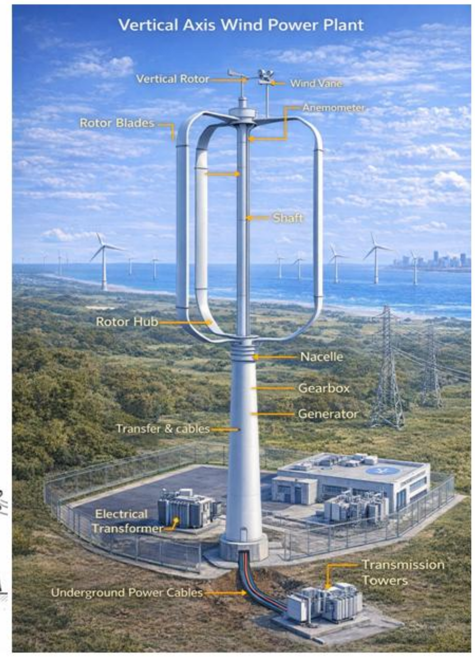
Types of horizontal axis wind turbines:

Basis of Classification	Type	Definition / Description
Based on Rotor Orientation	Upwind HAWT	The rotor is placed in front of the tower, facing the wind. It avoids tower shadow effects and is the most commonly used design.
	Downwind HAWT	The rotor is placed behind the tower. Wind passes through the tower before hitting the blades, which may cause vibration and noise.
Based on Number of Blades	Single-blade turbine	Uses one blade with a counterweight; low material cost but less stable and rarely used.
	Two-blade turbine	Has two blades; lighter and cheaper than three-blade turbines but produces more noise and vibration.
	Three-blade turbine	Uses three blades; offers smooth operation, high efficiency, and is the most widely used type.
	Multi-blade turbine	Has many blades; mainly used for mechanical applications like water pumping rather than electricity generation.
Based on Application & Scale	Small-scale wind turbine	Produces power up to a few KW; used for homes, farms, and remote areas.
	Medium-scale wind turbine	Generates power in tens to hundreds of KW; used for community or small industrial power supply.
	Large-scale wind turbine	Produces power in MW range; used in onshore and offshore wind farms for grid-connected power generation.

3.3 Vertical Axis Wind Turbines:

A Vertical Axis Wind Power Plant generates electricity using a wind turbine whose rotor rotates about a vertical axis, perpendicular to the ground. It can operate efficiently regardless of wind direction.





Construction Details:

Sl. No.	Component	Description
1	Rotor blades	Curved or straight blades that capture wind energy
2	Vertical shaft	Transfers rotational motion from blades
3	Rotor hub	Connects blades to the shaft
4	Nacelle	Houses gearbox and generator
5	Gearbox	Increases rotational speed
6	Generator	Converts mechanical energy into electrical energy
7	Controller	Regulates power output and safety
8	Tower	Supports the turbine structure
9	Electrical cables	Transmit generated power
10	Transformer	Steps up voltage for transmission
11	Foundation	Provides mechanical stability

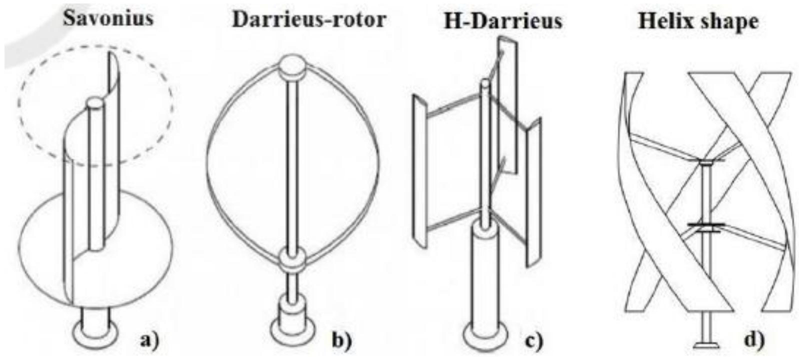
Operating Principle:

When wind flows around the rotor blades, aerodynamic forces cause the blades to rotate about the vertical axis. This rotation turns the vertical shaft connected to the gearbox. The gearbox increases the speed and drives the generator, which converts mechanical energy into electrical energy. The generated electricity is carried through cables and stepped up by a transformer before being supplied to the grid or local loads. Since the turbine does not need to face the wind, no yaw mechanism is required.

Merits, Demerits and Applications:

Vertical axis wind turbines can operate with wind from any direction and work well in turbulent wind conditions. They have simple design, lower tower height, and easier maintenance since major components are located near the ground.They have lower efficiency compared to horizontal axis turbines. Starting torque is low, and large-scale power generation is limited. Used in small-scale power generation, urban areas, rooftops, remote locations, battery charging systems, and hybrid renewable energy systems.

Types of Vertical Axis Wind Turbines:



Type	Definition	Purpose	Merits	Demerits	Applications
Savonius Rotor	A drag-type vertical axis turbine using two or more scooped blades.	Designed to capture wind at low speed and produce high starting torque.	Simple design, self-starting, works well at low wind speeds, easy maintenance.	Low efficiency, large size for low power output.	Water pumping, ventilation, small power generation, battery charging.
Darrieus Rotor (Egg-beater type)	A lift-type VAWT with curved blades forming an oval or circular shape.	Generates electricity using aerodynamic lift.	Higher efficiency than Savonius, lighter structure.	Not self-starting, complex design, higher stress on blades.	Medium-scale power generation, research applications.
H-Darrieus Rotor	A modified Darrieus turbine with straight vertical blades connected to a central shaft.	Improves structural strength and ease of manufacturing.	Easier construction, better control, higher efficiency than Savonius.	Poor self-starting ability, lower efficiency than HAWT.	Urban wind energy systems, rooftop installations.
Helical (Twisted) Darrieus Rotor	A Darrieus turbine with blades twisted in a helix shape.	Reduces torque fluctuation and vibration.	Smooth rotation, reduced noise and vibration, improved performance.	Costly manufacturing, complex blade design.	Urban areas, hybrid renewable systems, small to medium power plants.

3.4 Wind resource assessment: (parameters effecting wind extraction)

Wind resource assessment is the systematic process of evaluating the wind potential of a site to determine its suitability for wind power generation. It is a critical step in the planning and design of wind energy projects, as it directly affects energy production, economic feasibility, and turbine selection.Wind resource assessment is carried out by analyzing several key parameters that together determine the feasibility and performance of a wind power project.

1. Wind Speed

Wind speed is the most critical parameter in wind resource assessment because the power available in wind is proportional to the cube of wind speed. Therefore, even a small increase in wind speed leads to a large increase in power output. Wind speed is measured using anemometers installed at different heights over a long period to obtain reliable average values.
The annual mean wind speed is used to judge whether a site is suitable for wind energy applications such as wind pumps or wind turbines. The general viability of wind energy systems based on wind speed is given below:

Annual Mean Wind Speed	Wind Energy Viability
< 3 m/s	Not viable (only in special circumstances).
3 – 4 m/s	Possibly viable for wind pumps; usually not suitable for wind turbines.
4 – 5 m/s	Wind pumps become competitive with diesel pumps; small wind turbines may be viable.
5 – 6 m/s	Both wind pumps and wind turbines are viable.
> 6 m/s	Excellent conditions for wind pumps and wind turbines.

2. Wind Direction

Wind direction indicates the prevailing direction from which wind blows at a site. It is measured using wind vanes and represented using wind rose diagrams. Understanding wind direction helps in proper orientation and spacing of wind turbines to reduce wake losses and improve overall plant efficiency.

3. Wind Speed Distribution

Wind does not blow at a constant speed; hence statistical models such as Weibull or Rayleigh distributions are used to describe wind speed frequency. These distributions help estimate how often wind blows at different speeds, which is essential for accurate calculation of annual energy production.

4. Wind Power Density

Wind power density represents the amount of power available in the wind per unit area and is expressed in W/m^2. It depends on wind speed and air density. Higher wind power density indicates better suitability of the site for wind power generation and is commonly used for site classification.

5. Turbulence Intensity

Turbulence intensity measures fluctuations in wind speed over short time intervals. High turbulence can cause mechanical stress, fatigue, and reduced life of wind turbine components. Therefore, sites with lower turbulence are preferred for long-term reliability and safe operation of turbines.

6. Height and Wind Shear

Wind speed generally increases with height due to reduced surface friction. Wind shear refers to the variation of wind speed with height and is estimated using wind profile equations. This parameter is important for selecting the appropriate tower height and turbine hub height to maximize energy capture.

7. Terrain and Surface Roughness

Terrain features such as hills, buildings, trees, and water bodies affect wind flow patterns. Surface roughness causes wind speed reduction and turbulence. Flat and open terrains with low roughness are ideal for wind farms, while complex terrains require advanced modeling.

8. Air Density

Air density affects the kinetic energy available in wind and depends on altitude, temperature, and pressure. Sites at lower altitude with cooler temperatures have higher air density, resulting in greater power output for the same wind speed.

9. Long-Term Wind Data Correlation

Since on-site measurements are usually short-term, they are correlated with long-term meteorological data from nearby stations. This process, called Measure-Correlate-Predict (MCP)**,** improves the accuracy of long-term wind energy estimates and reduces financial risk.

10. Annual Energy Production (AEP)

Using all the above parameters, the annual energy production of a wind turbine or wind farm is estimated. AEP is a key indicator for technical feasibility and economic evaluation of a wind power project.

Summary:

Sl. No.	Parameter	Description / Significance
1	Wind Speed	Most important parameter; wind power ∝ cube of wind speed. Measured using anemometers at different heights. Higher wind speed gives higher energy output.
2	Annual Mean Wind Speed – Viability	<3 m/s: Not viable; 3–4 m/s: Suitable mainly for wind pumps; 4–5 m/s: Pumps competitive, small turbines possible; 5–6 m/s: Pumps and turbines viable; >6 m/s: Excellent for wind turbines.
3	Wind Direction	Indicates prevailing wind direction. Studied using wind rose diagrams to optimize turbine orientation and reduce wake losses.
4	Wind Speed Distribution	Wind speed varies with time. Weibull/Rayleigh distributions are used to estimate frequency of different wind speeds and annual energy output.
5	Wind Power Density	Power available per unit area (W/m^2). Higher power density indicates better site suitability for wind energy projects.
6	Turbulence Intensity	Measures short-term wind fluctuations. High turbulence causes mechanical stress and reduces turbine life; low turbulence is preferred.
7	Wind Shear (Height Effect)	Wind speed increases with height. Used to select proper hub height and tower height for maximum energy capture.
8	Terrain & Surface Roughness	Hills, buildings, trees, and water bodies affect wind flow. Open and flat terrain is ideal for wind farms.
9	Air Density	Depends on altitude, temperature, and pressure. Higher air density results in higher power output for the same wind speed.
10	Long-term Wind Data Correlation (MCP)	Short-term on-site data is correlated with long-term meteorological data to improve accuracy of wind energy prediction.
11	Annual Energy Production (AEP)	Estimated yearly electrical energy output of a turbine or wind farm. Used for technical and economic feasibility studies.

Power Available in Wind for a Horizontal Axis Wind Turbine

For a horizontal axis wind turbine, the power available in the wind passing through the rotor is given by:

$$P = \frac{1}{2}\rho A V^3$$

where:

- P = Power available in the wind (W)
- ρ = Air density (kg/m^3), approximately **1.2 kg/m^3** at sea level and 15°C
- A = Swept area of the rotor (m^2) $A = \pi R^2$ where R is the blade length (radius of the rotor).
- V = Wind velocity (m/s)

This equation gives the theoretical power available in the wind, not the actual power generated. A horizontal axis wind turbine can extract only a portion of this power due to physical limits such as the Betz limit (maximum 59.3%). Actual power output is further reduced due to mechanical and electrical losses.

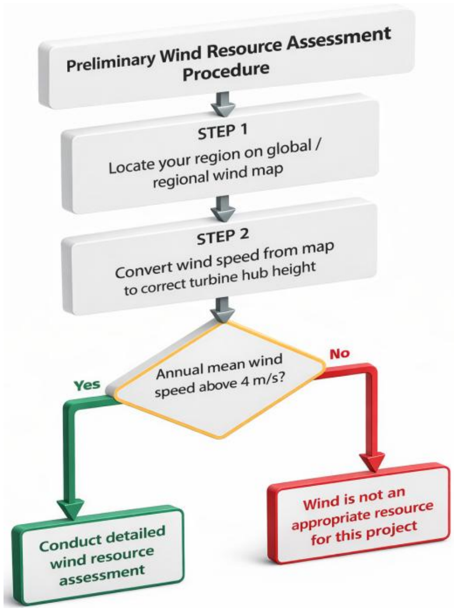
$$P_{actual} = \frac{1}{2}\rho A V^3 C_p \eta$$

where:

- C_p = Power coefficient (≤ 0.593)
- η = Mechanical and electrical efficiency

Flowchart for Preliminary Wind Energy Site Assessment:

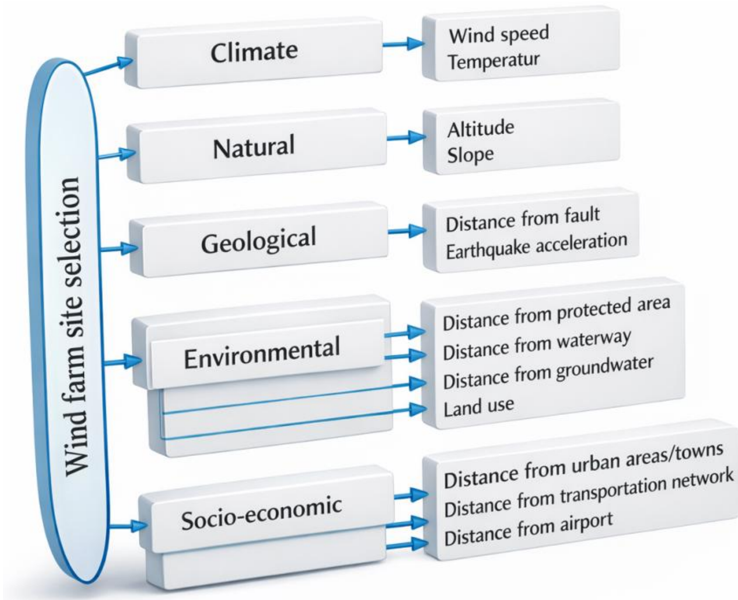
A flowchart for preliminary wind resource assessment shows the step-by-step process used to decide whether a location has sufficient wind speed (above 4 m/s) to justify detailed wind energy evaluation.



First, identify your location on a global or regional wind map to understand the general wind conditions. Next, adjust the wind speed values from the map to the actual height at which the wind turbine will be installed (hub height). Then, check whether the annual mean wind speed at that height is greater than 4 m/s. If it is above 4 m/s, a detailed wind resource assessment should be carried out. If it is below 4 m/s, wind energy is generally not suitable for that location.

3.5 Site Selection Parameters for Wind Power Plants:

Wind farm site selection considers climatic, natural, geological, environmental, and socio-economic factors to ensure safe, efficient, and sustainable wind power generation.

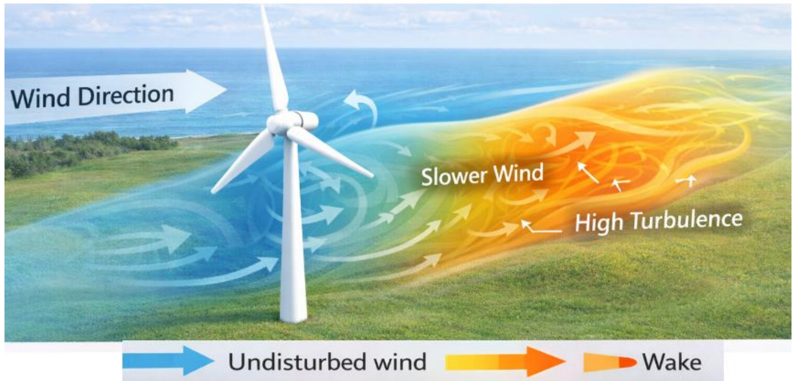


Sl. No.	Category	Parameter	Explanation
1	Climate	Wind speed	Determines energy potential; higher average wind speed gives higher power output.
		Temperature	Affects air density and turbine performance.
2	Natural	Altitude	Influences air density and wind characteristics.
		Slope	Gentle slopes are preferred for easy construction and turbine stability.
3	Geological	Distance from fault	Turbines should be away from fault lines to avoid structural damage.
		Earthquake acceleration	Low seismic activity areas are preferred for safety.
4	Environmental	Distance from protected area	Avoids disturbance to wildlife and ecological zones.
		Distance from waterway	Prevents water pollution and environmental damage.
		Distance from groundwater	Protects groundwater resources during construction.
		Land use	Land should be suitable without affecting agriculture or forests.
5	Socio-economic	Distance from urban areas/towns	Reduces noise, visual impact, and public disturbance.
		Distance from transportation network	Ensures easy access for installation and maintenance.
		Distance from airport	Prevents interference with aviation safety and radar systems.

Wind farm layout optimization and wake effects:

3.6 Wake Effects in Wind Farms:

Wake effects refer to the disturbance created in the airflow downstream of a wind turbine as it extracts energy from the wind. When wind passes through a turbine rotor, part of its kinetic energy is converted into mechanical and electrical energy. As a result, the wind behind the turbine has reduced speed and increased turbulence, forming a region called the wake**.**



Characteristics of Wake:

The wake has two main features. First, there is a velocity deficit, meaning the wind speed behind the turbine is lower than normal wind speed. Second, there is high turbulence, where the wind flow becomes irregular and unsteady. These effects make the wind less useful for turbines placed behind.

Impact on Power Generation:

Turbines operating inside the wake of other turbines receive slower and unstable wind, which reduces their power output. Since wind power depends strongly on wind speed, even a small decrease in wind speed causes a large loss in electricity generation. If turbines are placed too close together, wake effects can reduce total wind farm output by 10–40%.

Mechanical Stress and Fatigue:

The turbulent wind in the wake causes repeated forces on turbine blades, tower, and mechanical parts. This results in higher stress, vibration, and wear, which can damage components over time. As a result, maintenance costs increase and turbine life may reduce.

Wake Recovery:

As the wake moves farther away from the turbine, the wind gradually returns to normal speed due to mixing with surrounding air. This process is called wake recovery. Wake recovery happens faster when wind speed is high, terrain is rough, and turbines are spaced properly.

3.7 Wind Farm Layout Optimization:

Wind farm layout optimization focuses on placing wind turbines in the best possible positions to reduce wake effects and maximize power generation. The main parameters involved are explained below.

1. Wake Effect Consideration

Wake effect is the primary reason layout optimization is needed. When wind passes through a turbine, wind speed reduces and turbulence increases behind it. If another turbine is placed in this wake, it produces less power and experiences higher mechanical stress. Layout optimization aims to reduce the impact of this wake on downstream turbines.

2. Turbine Spacing

Proper spacing between turbines is the most important layout parameter. Turbines are generally placed 5–9 rotor diameters apart in the wind direction **and** 3–5 rotor diameters apart sideways. Adequate spacing allows wind speed to recover before reaching the next turbine, reducing wake losses.

3. Prevailing Wind Direction

Wind farm layouts are designed based on the dominant wind direction at the site. Wind rose diagrams are used to identify this direction. Turbines are aligned so that wakes occur less frequently along the main wind direction, improving overall energy production.

4. Turbine Arrangement (Row and Staggered Layouts)

Turbines can be placed in straight rows or staggered patterns. Staggered layouts are preferred because the wake from one turbine does not directly hit the next turbine. This arrangement reduces wake overlap and improves power output.

5. Wake Recovery Distance

Wake recovery refers to the distance required for wind speed to return close to normal after passing a turbine. Layout design ensures enough distance between turbines so that wind has time to recover. Faster wake recovery improves downstream turbine performance.

6. Yaw Control and Wake Steering

Modern wind farms use advanced control methods such as wake steering. In this method, upstream turbines are slightly rotated away from the wind direction to divert the wake away from downstream turbines. This reduces wake impact and increases total farm output.

7. Terrain and Land Constraints

Terrain features such as hills, slopes, and surface roughness affect wind flow and wake behavior. Layout optimization considers terrain conditions to avoid areas with high turbulence. Land availability and environmental restrictions also influence turbine placement.

8. Use of Wake Models and Simulation Tools

Computer-based wake models and simulation software are used to study wake behavior and test different turbine layouts. These tools help designers choose the most efficient layout before actual construction.

Summary:

Sl. No.	Parameter	Brief Explanation
1	Wake Effect	Reduced wind speed and increased turbulence behind turbines lower power output of downstream turbines.
2	Turbine Spacing	Proper spacing (5–9 rotor diameters in wind direction) allows wind to recover and reduces wake losses.
3	Prevailing Wind Direction	Layout is aligned with dominant wind direction to minimize frequent wake interactions.
4	Turbine Arrangement	Staggered layouts reduce direct wake impact compared to straight-line layouts.
5	Wake Recovery Distance	Adequate distance ensures wind speed recovers before reaching next turbine.
6	Yaw Control / Wake Steering	Slightly turning upstream turbines diverts wake away from downstream turbines.
7	Terrain & Land Constraints	Terrain roughness and slopes affect wind flow and wake behavior.
8	Wake Modeling & Simulation	Software tools predict wake behavior and help select optimal turbine placement.

3.8 Grid Integration and Power System Considerations for Wind Power Plants:

Grid integration refers to the process of connecting wind power plants to the electrical power grid so that the generated electricity can be safely and reliably supplied to consumers. Since wind power is variable in nature, special power system considerations are required to maintain grid stability and quality.

1. Variability and Intermittency of Wind Power

Wind speed changes continuously due to weather conditions. As a result, wind power generation is not constant and may increase or decrease suddenly. The power grid must be able to handle these fluctuations without affecting supply to consumers. Backup power sources, energy storage systems, and good forecasting help manage this variability.

2. Voltage Regulation

When wind turbines inject power into the grid, voltage levels at the connection point may rise or fluctuate. Proper voltage control is required to keep voltage within safe limits. Wind farms use transformers, capacitor banks, and power electronic converters to maintain stable voltage.

3. Frequency Control

Grid frequency must remain constant (50 Hz in India). Sudden changes in wind power can affect frequency balance. Modern wind turbines support frequency control by adjusting power output and participating in grid frequency regulation.

4. Power Quality Issues

Wind power plants can introduce power quality problems such as voltage flicker, harmonics, and reactive power imbalance. Power electronic converters, filters, and reactive power compensation devices are used to improve power quality and meet grid standards.

5. Grid Codes and Standards

Wind power plants must follow grid codes specified by utilities and regulatory authorities. These codes define requirements for voltage limits, frequency response, fault ride-through capability, and protection systems. Compliance ensures safe and reliable grid operation.

6. Fault Ride-Through Capability

During grid faults such as short circuits or voltage dips, wind turbines should remain connected and support grid recovery instead of disconnecting. This capability, called fault ride-through, is essential for maintaining grid stability.

7. Transmission and Distribution Constraints

Large wind farms are often located in remote areas with strong wind resources. Adequate transmission lines and substations are required to carry power to load centers. Weak grids may require reinforcement before wind integration.

8. Reactive Power Management

Wind turbines must supply or absorb reactive power as required by the grid. Reactive power control helps maintain voltage stability and reduces transmission losses.

9. Energy Storage and Hybrid Systems

Energy storage systems such as batteries or pumped hydro are used to smooth wind power output and improve grid reliability. Hybrid systems combining wind with solar or conventional power plants enhance grid integration.

10. Forecasting and System Operation

Accurate wind forecasting helps grid operators plan power generation and reserve capacity. Advanced forecasting tools reduce uncertainty and improve grid scheduling.

Summary:

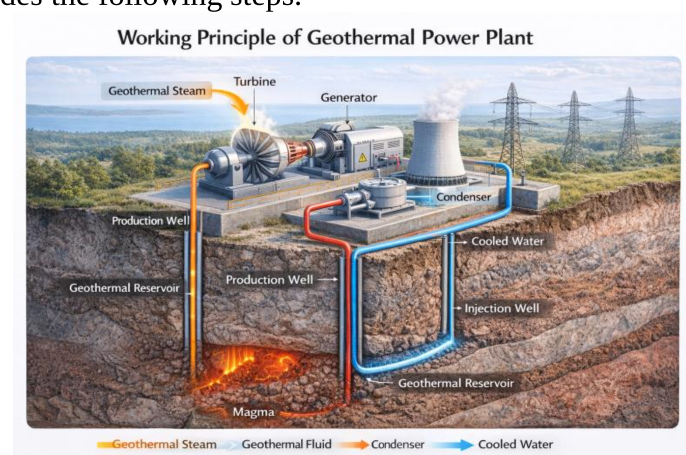
Sl. No.	Parameter	Brief Explanation
1	Variability of Wind Power	Wind speed changes cause fluctuating power output; grid must handle variations.
2	Voltage Regulation	Maintains voltage within limits using transformers and power electronics.
3	Frequency Control	Ensures grid frequency stability during sudden power changes.
4	Power Quality	Controls harmonics, flicker, and reactive power using filters and converters.
5	Grid Codes & Standards	Wind plants must follow utility rules for safe grid operation.
6	Fault Ride-Through	Turbines stay connected during grid faults to support stability.
7	Transmission Constraints	Adequate transmission lines are needed, especially for remote wind farms.
8	Reactive Power Management	Supplies or absorbs reactive power to maintain voltage stability.
9	Energy Storage / Hybrid Systems	Smooths power output and improves grid reliability.
10	Wind Power Forecasting	Helps grid operators plan generation and reserve capacity.

Geothermal Energy Conversion:

Geothermal Energy Conversion is the process of converting heat energy stored inside the Earth into useful electrical power or heat energy. Heat from hot rocks, underground water, or steam is brought to the surface through wells. This heat is then used to produce steam, which drives a turbine connected to a generator to produce electricity. In some systems, hot water directly provides heating without electricity generation. Geothermal power plants are reliable, operate continuously, and produce very low emissions. However, they are location-specific and require suitable geothermal reservoirs.

3.9 Working Principle of Geothermal Power Plant:

Geothermal power plants work in a closed-loop cycle using Earth's heat to generate electricity continuously. It includes the following steps.



Step 1: Heat Source and Geothermal Reservoir Formation

Geothermal energy originates from heat stored deep inside the Earth. Molten magma heats surrounding rocks and underground water, forming a geothermal reservoir that contains hot water and steam at high temperature and pressure.

Step 2: Extraction of Hot Geothermal Fluid

A production well is drilled into the geothermal reservoir. Due to high pressure, hot water or steam naturally rises to the surface through the well, carrying thermal energy.

Step 3: Steam Expansion and Turbine Rotation

The high-pressure steam is directed to the turbine. As the steam expands and strikes the turbine blades, it causes the turbine to rotate, converting thermal energy into mechanical energy.

Step 4: Electricity Generation

The rotating turbine shaft is connected to a generator. The generator converts mechanical energy into electrical energy, which is then supplied to the electrical grid.

Step 5: Condensation of Steam

After leaving the turbine, the steam enters the condenser. Here it is cooled and converted back into liquid water using cooling systems such as cooling towers or air cooling.

Step 6: Reinjection into the Earth

The cooled water is injected back into the ground through an injection well. This maintains reservoir pressure and allows the water to be reheated by hot rocks.

Step 7: Continuous Energy Cycle

The reinjected water gets reheated, forms steam again, and repeats the cycle. This allows geothermal power plants to operate continuously and provide reliable base-load power.

Summary:

Step No.	Process	Brief Explanation
1	Heat Source & Reservoir Formation	Heat from magma heats rocks and underground water, forming a geothermal reservoir with hot water and steam.
2	Extraction of Hot Fluid	Hot water or steam rises to the surface through a production well due to high pressure.
3	Steam Expansion & Turbine Rotation	High-pressure steam expands and rotates turbine blades, producing mechanical energy.
4	Electricity Generation	The turbine drives a generator, converting mechanical energy into electrical energy.
5	Condensation of Steam	Used steam is cooled in a condenser and converted into liquid water.
6	Reinjection into Earth	Cooled water is injected back underground through an injection well.
7	Continuous Energy Cycle	Reheated water forms steam again, allowing continuous power generation.

3.10 Types of Geothermal Station:

Geothermal energy is obtained from heat stored inside the Earth and can be extracted from four main sources.

1) Hydrothermal systems,

2) Geopressurized systems,

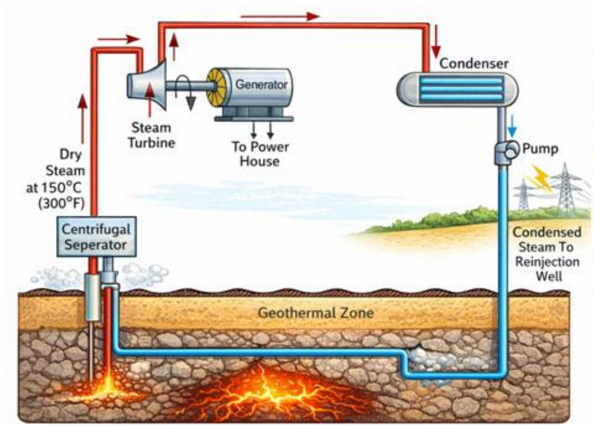
3) Hot Dry Rock (HDR) systems, and

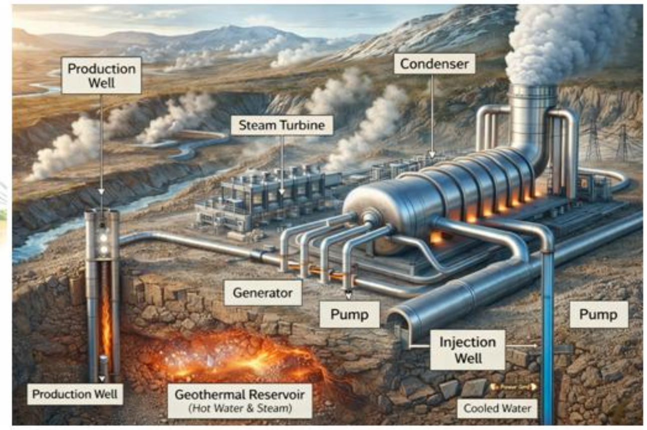
4) Magma sources.

Hydrothermal systems are the most commonly used and contain naturally available hot water or steam for electricity generation. Geopressurized systems have hot water under high pressure along with dissolved natural gas, but they are less widely used due to high cost and complexity. Hot dry rock systems involve injecting water into hot underground rocks, heating it, and bringing it back to the surface, and this technology is still developing. Magma sources use heat directly from molten magma and have very high energy potential, but they are still in the research stage due to technical and safety challenges.

3.11 Hydrothermal systems (Dry Steam Type):

A steam-type hydrothermal geothermal power plant generates electricity using naturally available dry steam from underground geothermal reservoirs. The high-pressure steam directly drives a turbine–generator system to produce electrical energy.





Construction Details:

Component	Description
Geothermal reservoir	Underground source containing dry steam at high temperature
Production well	Brings dry steam directly from the reservoir to the surface
Steam turbine	Converts thermal energy of steam into mechanical energy
Generator	Converts mechanical energy into electrical energy
Condenser	Cools exhaust steam and converts it into water
Pump	Circulates condensed water
Injection well	Returns condensed water back into the reservoir
Cooling system	Removes excess heat from the condenser
Power transmission system	Delivers generated electricity to the grid

Operating Principle:

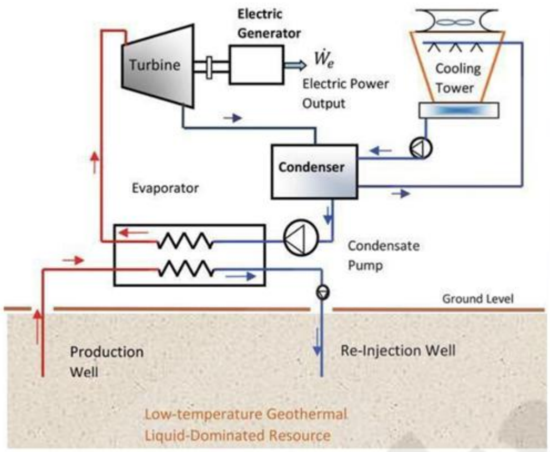
In a steam-type hydrothermal geothermal power plant, dry steam from a naturally heated underground reservoir is brought directly to the surface through a production well. This steam is sent straight to a steam turbine, where it expands and rotates the turbine blades. The rotating turbine drives a generator, producing electricity. After leaving the turbine, the steam is cooled in a condenser and converted into water. The condensed water is then pumped back into the Earth through an injection well, where it is reheated naturally, enabling continuous power generation.

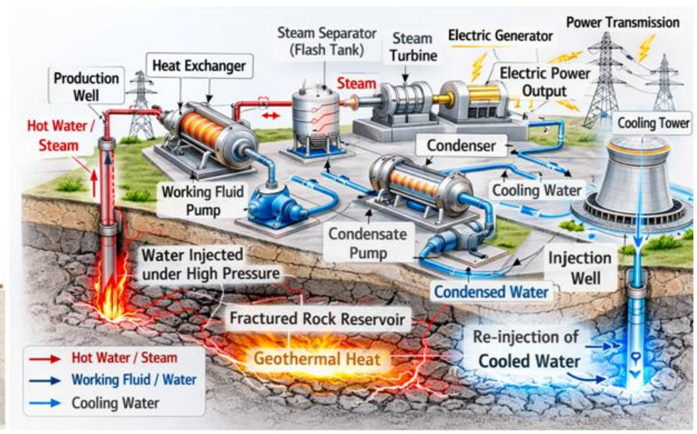
Merits, Demerits & Applications:

Steam-type hydrothermal power plants produce clean and renewable energy with very low greenhouse gas emissions. They provide reliable base-load power and have simple plant design since no steam separation is required. However, they are highly location-specific and can operate only where natural dry steam reservoirs exist. Initial drilling costs are high, and there may be minor environmental effects. These plants are mainly used for electricity generation, district heating, and industrial heat supply.

3.12 Hydrothermal systems (Water Type):

A hot water–type hydrothermal geothermal power plant generates electricity using high-temperature hot water stored in underground geothermal reservoirs. As shown in the figure, the hot water is brought to the surface, where it is converted into steam using an evaporator (flash unit), and the steam then drives a turbine–generator system to produce electrical energy.





Construction Details:

Component	Description
Geothermal reservoir	Underground liquid-dominated reservoir containing hot water
Production well	Brings high-temperature hot water from the reservoir to the surface
Evaporator / Flash chamber	Converts hot water into steam by pressure reduction
Steam turbine	Converts steam energy into mechanical energy
Generator	Converts mechanical energy into electrical energy
Condenser	Cools exhaust steam and converts it back into water
Cooling tower	Removes excess heat from condenser cooling water
Condensate pump	Circulates condensed water
Injection well	Returns cooled water back into the geothermal reservoir
Power transmission system	Supplies generated electricity to the grid

Operating Principle:

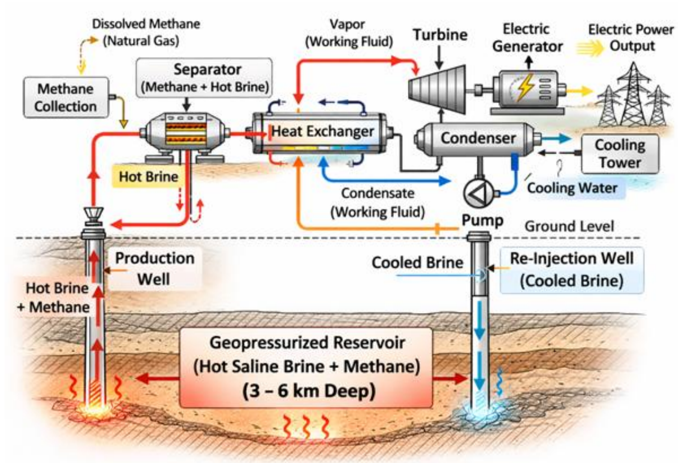
In a hot water–type hydrothermal geothermal power plant, high-temperature hot water from a liquid-dominated geothermal reservoir is brought to the surface through a production well, as shown in the figure. The hot water enters an evaporator (flash chamber), where a sudden drop in pressure causes part of the water to flash into steam. This steam is directed to the steam turbine, where it expands and rotates the turbine blades. The rotating turbine drives a generator, producing electrical energy. After leaving the turbine, the steam enters the condenser, where it is cooled and converted into water using a cooling tower. The condensed water is then pumped back into the ground through an injection well, maintaining reservoir pressure and enabling continuous power generation.

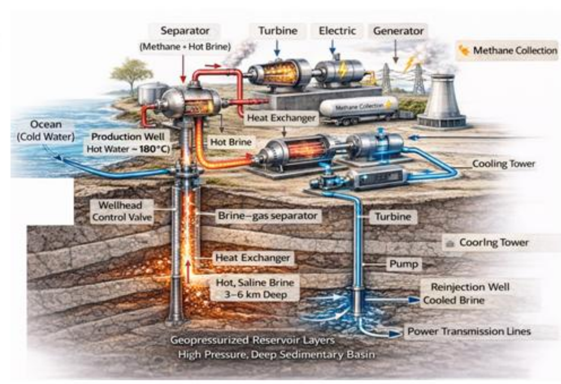
Merits, Demerits & Applications:

Hot water–type hydrothermal power plants generate clean and renewable energy with low emissions and provide reliable base-load power. They are suitable for regions where hot water reservoirs are available and are more common than dry-steam plants. However, the plant design is more complex due to the need for an evaporator and condenser. Initial drilling and installation costs are high, and the plant is location-specific. These plants are widely used for electricity generation, district heating, industrial process heat, and greenhouse heating.

3.12 Geopressurized systems:

A geopressurized geothermal system uses hot, high-pressure underground water (brine) found deep in sedimentary basins to produce energy. Along with heat, these reservoirs also contain dissolved natural gas (methane), which can be recovered as an additional energy source.





Construction Details:

Component	Description
Geopressurized reservoir	Deep underground layer containing hot, high-pressure saline water and methane
Production well	Brings hot pressurized brine to the surface
Wellhead control valve	Controls pressure and flow of the fluid
Brine–gas separator	Separates dissolved methane gas from hot brine
Heat exchanger	Transfers heat from hot brine to a working fluid
Turbine	Converts thermal energy into mechanical energy
Generator	Converts mechanical energy into electrical energy
Condenser	Cools exhaust vapor and converts it into liquid
Pump	Circulates fluids in the system
Injection well	Sends cooled brine back into the reservoir
Cooling system	Removes excess heat from the condenser
Power transmission lines	Deliver electricity to the grid

Operating Principle:

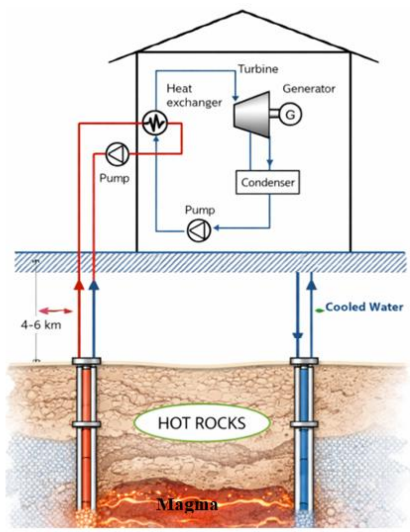
In a geopressurized system, hot and highly pressurized saline water containing dissolved methane is brought to the surface through a production well. As the pressure reduces, methane gas is separated in a brine–gas separator and collected for use as fuel. The hot brine then passes through a heat exchanger, where its heat is transferred to a secondary working fluid that vaporizes and drives a turbine. The rotating turbine runs a generator to produce electricity. After heat extraction, the cooled brine is pumped back underground through an injection well, maintaining reservoir pressure and enabling continuous operation.

Merits, Demerits & Applications:

Geopressurized systems provide multiple energy outputs—electricity, heat, and natural gas—making them highly efficient. They offer reliable base-load power and better energy recovery compared to conventional geothermal plants. However, they require very deep drilling, involve high initial costs, and face problems like corrosion due to saline brine. These systems are mainly used for electricity generation, methane recovery, industrial heat applications, and combined heat and power (CHP) in suitable sedimentary basins.

3.13 Hot Dry Rock (HDR) systems:

A Hot Dry Rock (HDR) or Enhanced Geothermal System (EGS) generates energy by extracting heat from deep underground hot rocks that contain little or no natural water. Water is artificially injected into fractured hot rocks, heated, and then recovered to produce electricity.



Construction Details:

Component	Description
Hot dry rock reservoir	Deep underground hot rock formation (4–6 km depth)
Injection well	Injects cold water into hot rocks
Production well	Brings heated water back to the surface
Artificial fractures	Cracks created in rocks to allow water circulation
Pump (injection pump)	Forces water into the injection well
Heat exchanger	Transfers heat from hot water to a working fluid
Turbine	Converts thermal energy into mechanical energy
Generator	Converts mechanical energy into electrical energy
Condenser	Cools working fluid after turbine
Cooling system	Removes excess heat
Reinjection system	Returns cooled water back underground

Operating Principle:

In an HDR/EGS system, cold water is pumped deep underground through an injection well into hot, dry rocks. The water flows through artificially created fractures, absorbs heat from the rocks, and becomes hot. This heated water is brought back to the surface through a production well. The heat is transferred to a secondary working fluid using a heat exchanger, which then drives a turbine connected to a generator to produce electricity. After heat extraction, the cooled water is reinjected into the ground, creating a continuous closed-loop system.

Merits, Demerits & Applications:

HDR/EGS systems provide a vast and reliable renewable energy source and can be developed in many regions, not just volcanic areas. They produce clean base-load power with very low emissions. However, they require deep drilling, high initial costs, and can sometimes cause minor induced seismic activity. HDR systems are mainly used for electricity generation, district heating, and future large-scale geothermal energy development.

3.14 Magma Source Geothermal Power Plant:

A magma source geothermal power plant is a geothermal system that uses heat directly from molten magma present deep inside the Earth. Magma is the hottest geothermal source, with temperatures often above 600–1000°C, making it a very high-energy but technically challenging resource.

Operating Principle:

In a magma source geothermal plant, deep wells are drilled close to a magma chamber. Water or another suitable working fluid is injected into the hot rock zone surrounding the magma. Due to extremely high temperatures, the fluid absorbs a large amount of heat and may turn into high-pressure steam or superheated fluid. This hot fluid is brought to the surface through a production well and directed to a turbine. The turbine rotates and drives a generator to produce electricity. After energy extraction, the fluid is cooled in a condenser and reinjected back underground, forming a closed-loop system.

Magma lies beneath the Earth’s crust and continuously releases enormous amounts of heat. In magma-based geothermal systems, this heat is transferred to surrounding rocks and fluids. Instead of directly tapping molten magma (which is extremely difficult), wells are drilled near magma bodies or into magma-heated rocks to extract thermal energy safely.

Merits, Demerits & Applications:

Magma source geothermal plants can generate very high energy because magma provides extremely high temperatures and continuous heat with very low emissions. However, they are difficult and costly due to deep drilling, extreme heat, and safety risks. At present, they are mainly used for research, with future potential for large-scale power generation and high-temperature industrial applications**.**

Note: Same above fig may be used.

3.15 Geothermal Power Plants in the World:

Geothermal power plants are used in many countries where underground heat resources are naturally available, especially in volcanic and tectonically active regions. The United States is the world’s largest producer of geothermal electricity, with major plants in California. Other leading countries include Indonesia, Philippines, Turkey, New Zealand, Iceland, Kenya, Italy, Japan, and Mexico. Iceland is well known for using geothermal energy not only for electricity but also for district heating. Most geothermal plants worldwide operate using hydrothermal systems, while HDR/EGS and magma-based systems are still under development. Overall, geothermal power provides reliable base-load renewable energy and plays an important role in reducing dependence on fossil fuels globally.

3.16 Problems Associated With Geothermal Conversion:

Geothermal energy conversion is a reliable and clean source of power, but it also faces several technical, environmental, and economic challenges. The major problems associated with geothermal conversion are explained below.

1. Location-Specific Resources

Geothermal energy is highly dependent on geographical conditions. Suitable geothermal resources are mainly found in volcanic regions, tectonic plate boundaries, or areas with high geothermal gradients. This limits the widespread application of geothermal power plants.

2. High Initial Cost

Drilling deep wells (often 3–6 km or more) requires advanced technology and involves high capital investment. Exploration, drilling, and plant construction costs are much higher compared to other renewable energy systems.

3. Corrosion and Scaling

Geothermal fluids often contain dissolved minerals and gases such as silica, sulfur, and salts. These substances can cause scaling and corrosion in pipes, turbines, and heat exchangers, reducing efficiency and increasing maintenance costs.

4. Environmental Issues

Although geothermal energy is clean, it can release small amounts of gases like hydrogen sulfide (H_2S) and carbon dioxide. Improper disposal of geothermal fluids can contaminate groundwater, and land subsidence may occur if fluids are not reinjected properly.

5. Induced Seismicity

Injection and extraction of geothermal fluids can alter underground stress conditions, sometimes causing small earthquakes. This issue is more significant in HDR/EGS systems where artificial fracturing is used.

6. Decline in Reservoir Performance

Over time, geothermal reservoirs may cool or lose pressure if heat extraction exceeds natural heat replenishment. This can reduce plant efficiency and shorten the operational life of the resource.

7. Technical Challenges

Operating at high temperatures and pressures requires specialized materials and equipment. Extreme conditions can cause equipment failure and reduce system reliability.

8. Disposal of Waste Fluids

Geothermal brines are often highly saline and contain toxic elements. Safe handling, treatment, and reinjection of these fluids are essential to avoid environmental damage.

Summary:

Problem	Brief Explanation
Location specific	Geothermal resources are available only in certain regions with suitable geology.
High initial cost	Deep drilling, exploration, and plant construction require high investment.
Corrosion and scaling	Minerals in geothermal fluids damage pipes and equipment.
Environmental issues	Release of gases and improper fluid disposal can affect the environment.
Induced seismicity	Fluid injection may cause small earthquakes, especially in EGS systems.
Reservoir depletion	Overuse can reduce temperature and pressure over time.
Technical challenges	Equipment must withstand high temperature and pressure.
Waste fluid disposal	Saline and toxic fluids require safe treatment and reinjection.

3.17 Scope of Geothermal Energy

The scope of geothermal energy is wide and promising because it provides a clean, reliable, and continuous source of renewable power.The scope of geothermal energy can be clearly understood by examining its applications under major functional parameters such as electricity generation, heating, cooling, and energy storage.

Electricity Generation:

Geothermal energy has strong scope in electricity generation because it provides continuous, base-load power independent of weather conditions. Geothermal power plants such as hydrothermal, hot-water, HDR/EGS, and future magma-based systems can supply reliable electricity with very low emissions.

Heating Applications:

Geothermal energy is widely used for direct heating purposes. It is suitable for district heating, space heating of buildings, greenhouse heating, aquaculture, and industrial process heating. This application is highly efficient and cost-effective, especially in cold regions.

Cooling Applications:

Geothermal energy is also used for cooling through geothermal heat pump systems. These systems transfer heat from buildings to the ground during summer, providing efficient and eco-friendly air conditioning for residential and commercial buildings.

Energy Storage:

Geothermal reservoirs can act as natural thermal energy storage systems. Heat stored underground can be extracted when required, and reinjection helps maintain reservoir temperature, making geothermal energy suitable for long-term energy storage and continuous supply.

Hybrid and Integrated Energy Systems:

Geothermal energy can be combined with solar and wind power in hybrid systems to improve reliability and grid stability. It also supports combined heat and power (CHP) systems, increasing overall energy efficiency.

Future Expansion (EGS):

With the development of Enhanced Geothermal Systems (EGS), the scope of geothermal energy extends to non-volcanic regions, significantly increasing its global potential.

Summary:

Parameter	Scope / Application
Electricity generation	Provides continuous base-load power with low emissions using geothermal power plants.
Heating	Used for district heating, space heating, greenhouse heating, aquaculture, and industrial processes.
Cooling	Geothermal heat pumps offer efficient and eco-friendly building cooling systems.
Energy storage	Underground reservoirs store thermal energy for long-term and continuous use.
Hybrid energy systems	Can be integrated with solar and wind systems to improve reliability and grid stability.
Combined heat and power (CHP)	Simultaneous production of electricity and useful heat improves efficiency.
Future expansion (EGS)	Enhanced Geothermal Systems enable use in non-volcanic regions.

QUESTION BANK (Wind Power Plant)

5-Mark Questions (Short / Medium Answer Type)

1. Define wind energy and explain the basic principle of wind power generation.
2. Explain the working principle of a wind turbine.
3. List the main components of a horizontal axis wind turbine and state their functions.
4. Define a Horizontal Axis Wind Turbine (HAWT) and mention its applications.
5. Explain the construction of a Vertical Axis Wind Turbine (VAWT).
6. Compare Horizontal Axis and Vertical Axis wind turbines (any four points).
7. Write short notes on Savonius rotor.
8. Explain the working principle of a Darrieus wind turbine.
9. What is wind resource assessment? State its importance.
10. Explain the significance of wind speed in wind resource assessment.
11. What is wind speed distribution? Mention its importance.
12. Define wind power density and explain its role in site selection.
13. What is turbulence intensity? Why should it be low for wind farms?
14. Explain the effect of terrain and surface roughness on wind flow.
15. What is annual energy production (AEP)? Why is it important?
16. Explain the preliminary wind energy site assessment procedure with reference to wind speed.
17. List the major site selection parameters for wind power plants.
18. What are wake effects in wind farms?
19. Explain the impact of wake effects on power generation.
20. What is wind farm layout optimization? Why is it required?
21. Explain the role of turbine spacing in reducing wake losses.
22. Write short notes on yaw control and wake steering.
23. What are grid codes in wind power plants?
24. Explain voltage regulation issues in wind power grid integration.
25. Define fault ride-through capability of wind turbines.

10-Mark Questions (Long / Descriptive Answer Type)

1. Explain the basics of wind energy and wind turbine technology with neat sketches.
2. Describe the construction, working principle, merits, demerits, and applications of a Horizontal Axis Wind Turbine.
3. Explain Vertical Axis Wind Turbines with construction, working, merits, demerits, and applications.
4. Explain the different types of vertical axis wind turbines (Savonius, Darrieus, H-Darrieus, Helical) with comparison.
5. Describe wind resource assessment in detail. Explain all the key parameters involved.
6. Explain wind speed viability classification and its importance in wind energy projects.
7. Explain site selection parameters for wind power plants under climatic, natural, geological, environmental, and socio-economic factors.
8. Explain wake effects in wind farms with formation, characteristics, impact on power generation, and wake recovery.
9. Describe wind farm layout optimization techniques with reference to wake effects.
10. Explain grid integration and power system considerations for wind power plants, covering voltage control, frequency control, power quality, and grid codes.

QUESTION BANK (Geothermal Power Plant):

5-MARK QUESTIONS (Short / Medium Answer Type)

1. Define wind power and explain why wind energy is considered a renewable source.
2. What is meant by variability of wind power? How does it affect grid operation?
3. Explain voltage regulation and frequency control in wind power plants.
4. What is fault ride-through capability in wind turbines? Why is it important?
5. Define wind power forecasting and state its significance for grid operators.
6. What is geothermal energy conversion? Mention its advantages.
7. Explain the working principle of a geothermal power plant in brief.
8. List the types of geothermal stations and mention one feature of each.
9. Write a short note on hydrothermal geothermal systems (steam type).
10. Write a short note on hydrothermal geothermal systems (water type).
11. What is a geopressurized geothermal system? State its special features.
12. Define Hot Dry Rock (HDR) or Enhanced Geothermal System (EGS).
13. Write a short note on magma source geothermal power plants.
14. Mention any five problems associated with geothermal energy conversion.
15. Write a short note on geothermal power plants in the world.
16. Explain the role of reinjection wells in geothermal power plants.
17. What is meant by induced seismicity in geothermal systems?
18. List the applications of geothermal energy.
19. Explain cooling applications of geothermal energy.
20. What is the scope of geothermal energy in the future?

10-MARK QUESTIONS (Long / Descriptive Type)

1. Explain grid integration and power system considerations for wind power plants, covering variability, voltage regulation, frequency control, power quality, grid codes, and energy storage.
2. Describe in detail the working principle of a geothermal power plant with a neat diagram.
3. Explain hydrothermal geothermal systems (steam type) with construction, working principle, merits, demerits, and applications.
4. Explain hydrothermal geothermal systems (water type) with construction, working principle, merits, demerits, and applications.
5. Describe geopressurized geothermal systems, explaining construction, working principle, advantages, limitations, and applications.
6. Explain Hot Dry Rock (HDR) or Enhanced Geothermal System (EGS) with neat sketch and working.
7. Explain the magma source geothermal power plant, its working principle, and challenges.
8. Discuss the problems associated with geothermal energy conversion in detail.
9. Write an essay on geothermal power plants in the world, highlighting leading countries and applications.
10. Explain the scope of geothermal energy with respect to electricity generation, heating, cooling, energy storage, hybrid systems, and future expansion.

MODULE-04 TIDAL POWER & OCEAN THERMAL ENERGY CONVERSION

Syllabus: Tidal Power: ***Tides and waves as energy suppliers and their mechanics; fundamental characteristics of tidal power, harnessing tidal energy, advantages and limitations.*** **Ocean Thermal Energy Conversion:** ***Principle of working, OTEC power stations in the world, problems associated with OTEC.***

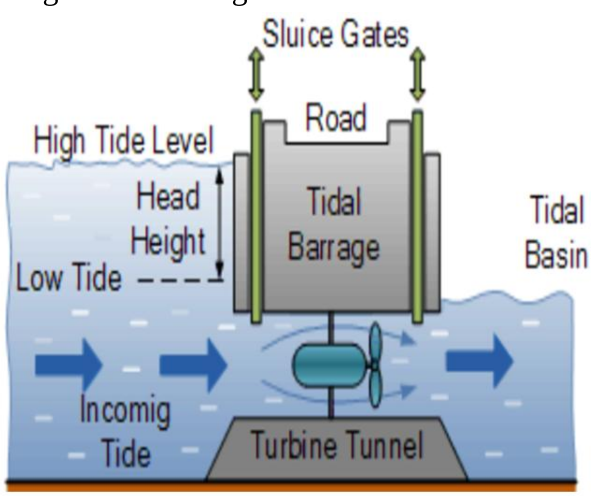
4.0 Introduction:

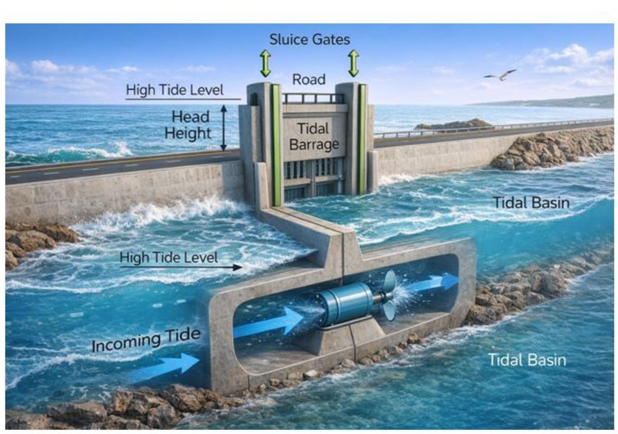
Tidal energy is a renewable source of energy that is generated from the periodic rise and fall of sea water levels, known as tides. These tides are mainly caused by the gravitational pull of the Moon, with the Sun also contributing to a lesser extent, along with the rotation of the Earth. As the Earth rotates, different coastal regions experience high tides and low tides at regular intervals, resulting in continuous and predictable movement of large volumes of sea water. This moving water contains both potential energy, due to differences in water levels, and kinetic energy, due to the flow of water. By capturing this energy using tidal power devices such as turbines or barrages, it can be converted into electrical energy. Because tidal patterns are highly predictable and occur regularly, tidal energy is considered a reliable and sustainable source of renewable power.

In addition to tides, ocean waves also play a supporting role in coastal energy systems. Waves are generated by wind blowing over the sea surface and carry energy through the up-and-down motion of water (potential energy) and the forward movement of water particles (kinetic energy). Near tidal power plants, especially around barrages and turbine inlets, wave motion can increase local water movement and contribute additional kinetic energy to the flowing water. By capturing the combined effect of tidal currents and wave-induced motion using turbines or hybrid wave–tidal devices, this energy can be converted into electrical energy. Since tides are highly predictable and waves are abundant in coastal regions, tidal energy—supported by wave energy—is considered a reliable and sustainable source of renewable power.

4.1 Tidal Power Plant:

A tidal power plant generates electricity by using the energy of rising and falling sea water levels caused by tides. It converts the kinetic and potential energy of tidal water into electrical energy using turbines and generators.





Construction Details:

Component	Description
Tidal barrage	Dam-like structure built across a bay or estuary
Tidal basin	Area where sea water is stored during high tide
Sluice gates	Control the flow of water into and out of the basin
Turbine tunnel	Passage through which water flows to rotate turbines
Turbine	Converts water energy into mechanical energy
Generator	Converts mechanical energy into electrical energy
Power house	Houses turbine and generator
Transmission system	Delivers electricity to the grid

Operating Principle:

In a tidal power plant, a barrage is constructed across a bay or estuary. During high tide, sea water flows into the tidal basin through sluice gates and acts as temporary storage device. When the tide falls, the stored water is released back to the sea through turbine tunnels. As the water flows through the turbines, it causes them to rotate and drive generators, producing electricity. In some plants, power is generated during both incoming and outgoing tides.

Merits, Demerits and Applications:

Tidal power plants use a clean and renewable energy source and produce no air pollution during operation. Tides are highly predictable, making power generation reliable. However, tidal plants have high construction costs and are suitable only at specific coastal locations. They may also affect marine life and navigation. Tidal power plants are mainly used for electricity generation in coastal regions and can support remote coastal communities and hybrid renewable energy systems.

4.2 Waves as Energy Suppliers:

Ocean waves are formed mainly due to the action of wind blowing over the sea surface. When wind transfers its energy to the water, waves are created. These waves travel long distances and carry a large amount of energy in the form of up-and-down motion and forward movement of water.

In a tidal power plant, electricity is mainly generated using tidal energy, which comes from the regular rise and fall of sea levels caused by the gravitational pull of the Moon and the Sun. This creates a predictable flow of water through turbines during high tide and low tide, allowing reliable power generation.

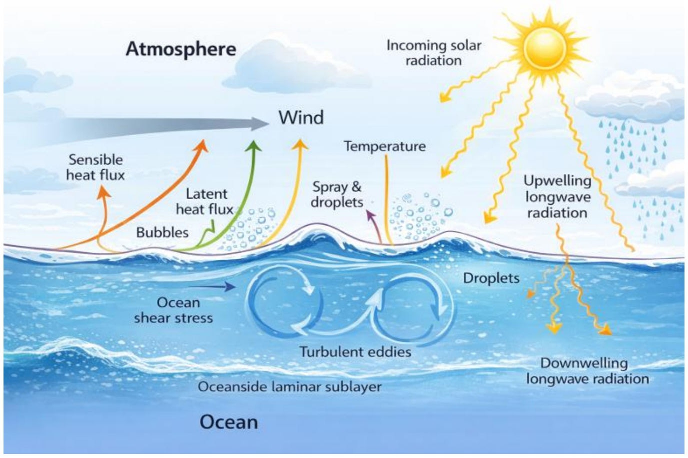
Waves, which are caused by wind, also contain energy in the form of potential energy (vertical rise and fall of water) and kinetic energy (horizontal motion of water particles). Near tidal power plant structures such as barrages, channels, or turbine inlets, wave motion can increase local water movement and add extra kinetic energy to the flowing water.

While tides provide the main, predictable energy source for tidal power plants, waves can enhance water motion and can be used in hybrid wave–tidal systems. In such systems, both tidal currents and wave motion are captured to improve overall energy extraction.

Both tidal and wave energy are clean, renewable, and pollution-free sources of energy. Tidal energy is more predictable because tides occur at fixed times, while wave energy is less predictable since it depends on wind conditions. Together, tides and waves have great potential to supply energy to coastal regions and help reduce dependence on fossil fuels.

4.3 Mechanics of Tides and Waves:

Wind energy generates waves by producing surface ripples, turbulence, and circular water motion, which store both kinetic and potential energy in ocean waves.



Step 1: Solar heating of the Earth and atmosphere

Incoming solar radiation heats the Earth unevenly. Land, sea, and air warm at different rates, creating temperature differences in the atmosphere. These temperature differences are the starting point for wind formation.

Step 2: Wind generation due to pressure differences

Uneven heating causes pressure differences in the atmosphere. Air moves from high-pressure regions to low-pressure regions, producing wind. Wind speed and direction depend on temperature gradients and weather conditions.

Step 3: Transfer of wind energy to the ocean surface

When wind blows over the ocean, friction between air and water transfers energy from the atmosphere to the ocean surface. This transfer of momentum is called wind stress and is the main mechanism responsible for wave generation.

Step 4: Formation and growth of ocean waves

Initial small ripples form on the water surface. Continued wind action increases wave height and wavelength. Stronger winds blowing over longer distances produce larger and more powerful waves.

Step 5: Heat exchange between ocean and atmosphere

During wind–ocean interaction, sensible heat flux (direct heat transfer) and latent heat flux (heat carried during evaporation) occur. Spray droplets and bubbles further enhance the exchange of heat and momentum, supporting wave growth.

Step 6: Ocean surface disturbance and turbulence

Wind stress creates ocean shear at the surface, disturbing upper water layers. This results in turbulent eddies that mix surface water with deeper layers, helping distribute wave energy and influence ocean circulation.

Step 7: Radiation balance and atmospheric feedback

The ocean absorbs solar energy and later releases it as longwave radiation. Upwelling and downwelling radiation affect atmospheric temperature and pressure patterns, indirectly influencing wind strength and wave behavior.

Step 8: Tides generation by gravitational forces

Unlike waves, tides are generated by the gravitational pull of the Moon and the Sun on the Earth's oceans. This pull causes periodic rise and fall of sea levels known as tides.

Step 9: Influence of atmosphere on tides

Although tides are mainly gravitational, wind, atmospheric pressure, and ocean mixing can modify tidal heights and currents, especially near coastlines.

Step 10: Combined ocean–atmosphere interaction

Overall, waves are produced by wind energy transferred to the ocean surface, while tides result from gravitational forces. The processes shown in the diagram explain how heat, wind, radiation, and ocean motion work together to control tides and waves.

Summary:

Step	Process	Simple Explanation
1	Solar heating	Sun heats Earth unevenly, creating temperature differences in air and ocean
2	Wind formation	Temperature differences cause pressure changes, producing wind
3	Wind–ocean interaction	Wind transfers energy to ocean surface through friction (wind stress)
4	Wave initiation	Small ripples form on water surface due to wind action
5	Wave growth	Stronger wind and longer duration increase wave height and size
6	Heat exchange	Sensible and latent heat transfer occurs between ocean and atmosphere
7	Turbulence & mixing	Wind causes surface shear and turbulent eddies in ocean water
8	Radiation balance	Ocean absorbs solar radiation and releases longwave radiation
9	Tide generation	Moon and Sun gravitational pull causes rise and fall of sea level
10	Atmospheric influence on tides	Wind and pressure can increase or reduce tidal height locally
11	Combined effect	Waves are wind-driven, tides are gravity-driven, both interact with atmosphere

4.4 Fundamental Characteristics of Tidal Power:

Characteristic	Explanation
Predictability	Tides occur regularly and can be accurately predicted because they depend on the Moon and Sun's gravity.
Cyclical nature	Power generation happens during high and low tides, so energy is produced in regular cycles.
High energy density	Sea water is very dense, allowing turbines to produce good power even at low water speeds.
Two forms of energy	Tidal power uses both potential energy (water level difference) and kinetic energy (moving water).
Location specific	Tidal plants work best only in coastal areas with large tidal ranges or strong currents.
Environmental impact	Tidal energy produces very low pollution, but construction may affect marine life locally.
Strong infrastructure	Equipment must be strong to survive seawater, waves, and corrosion, increasing initial cost.

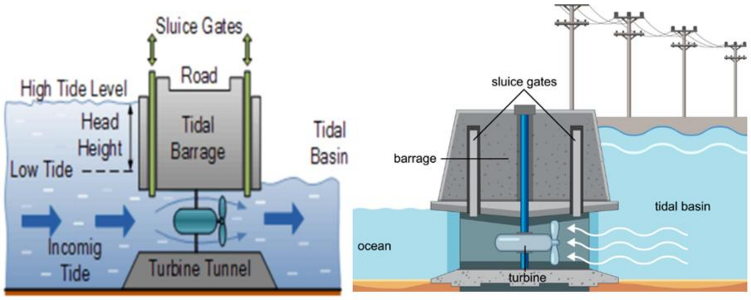
Harnessing Tidal Energy:

4.5 Different ways to extract energy through tides:

Energy from tides can be extracted in several practical ways depending on tidal range, water flow speed, and site conditions. The main methods are explained below.

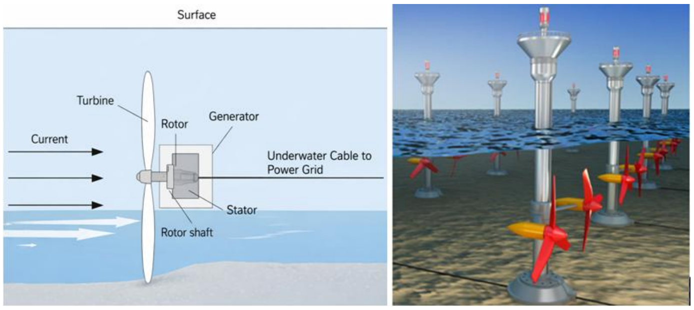
1. Tidal Barrage System

In this method, a dam-like structure called a barrage is constructed across a bay or estuary. During high tide, seawater flows into a tidal basin through sluice gates. When the tide falls, the stored water is released back to the sea through turbines, which rotate and generate electricity. Power can be generated during incoming tide, outgoing tide, or both. This method uses mainly potential energy due to water level difference.



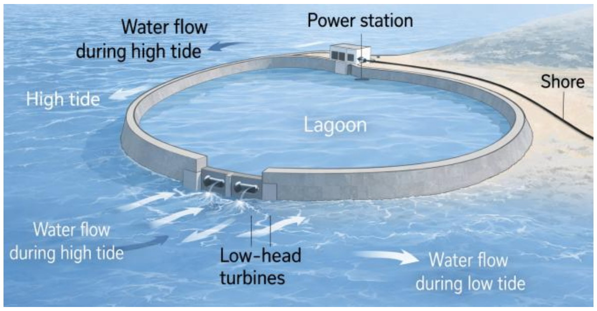
2. Tidal Stream (Current) Turbines

Tidal stream systems use underwater turbines placed in fast-moving tidal currents, similar to underwater wind turbines. As tidal water flows past the turbine blades, they rotate and drive a generator to produce electricity. This method extracts kinetic energy from moving water and does not require large dams.



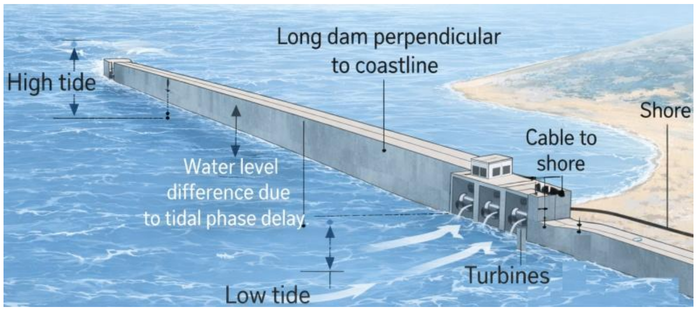
3. Tidal Lagoon System

A tidal lagoon is an enclosed water body created along the coastline using a circular or semi-circular wall. Water enters and leaves the lagoon through turbines during high and low tides. Like barrages, lagoons use the potential energy of tidal height difference but usually have less environmental impact.



4. Dynamic Tidal Power (Conceptual Method)

This is an advanced and experimental method where long dams are built perpendicular to the coastline. These structures create a water level difference due to tidal phase delay along the coast. Turbines installed in the dam extract energy from the resulting water flow.

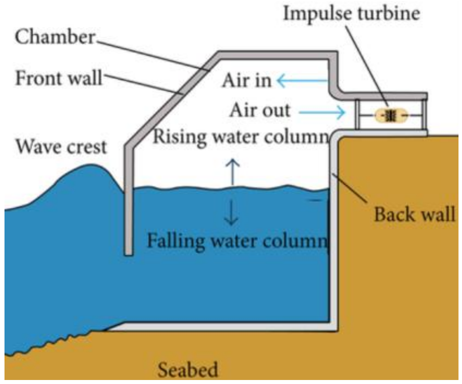


Summary:

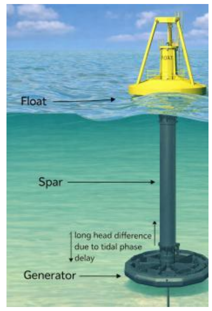
Method	Basic Principle	Type of Energy Used	Key Feature
Tidal barrage system	Water stored during high tide is released through turbines during low tide	Potential energy	Dam built across bay or estuary
Tidal stream turbines	Fast-moving tidal currents rotate underwater turbines	Kinetic energy	No large dam required
Tidal lagoon system	Enclosed coastal basin uses water level difference during tides	Potential energy	Lower environmental impact than barrage
Dynamic tidal power	Long coastal dam creates water level difference due to tidal phase delay	Potential + kinetic energy	Conceptual and experimental method

4.6 Different ways to extract energy through Waves:

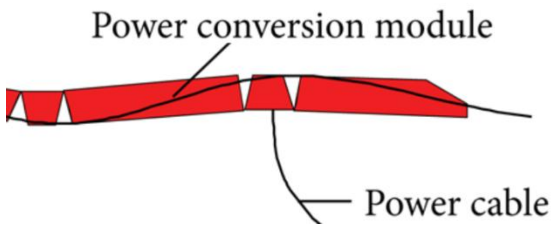
1. Oscillating Water Column (OWC): An oscillating water column is a wave energy device where waves enter a partially enclosed chamber. As waves rise and fall, the water level inside the chamber moves up and down, compressing and decompressing the air above it. This moving air flows through a turbine connected to a generator, producing electricity. The turbine is usually placed above water, which makes maintenance easier.



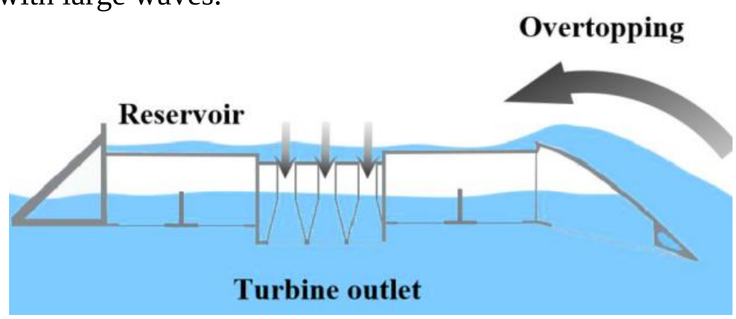
2. Point Absorber: A point absorber is a small floating device that moves up and down with wave motion. This vertical movement is converted into mechanical energy and then into electrical energy using a generator. Point absorbers can capture energy from waves coming in any direction and are often used in deep water.



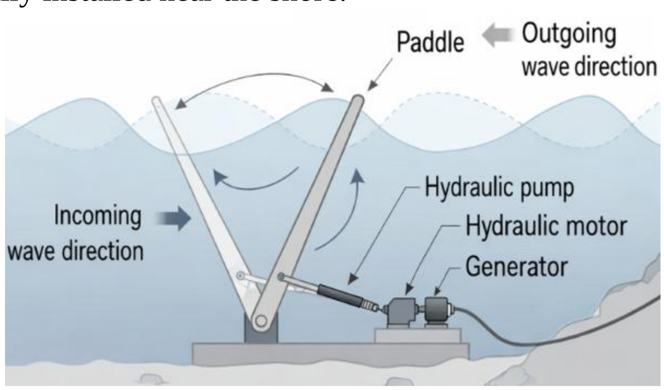
3.Attenuator: An attenuator is a long, floating structure placed parallel to the direction of wave travel. As waves pass along its length, the structure bends at its joints. This bending motion drives hydraulic systems or generators that produce electricity. Attenuators are suitable for offshore locations with strong waves.



4. Overtopping Device: In an overtopping device, waves flow over a ramp into a raised reservoir above sea level. The stored water is then released back to the sea through low-head turbines, generating electricity. This method mainly uses the potential energy of waves and works best in areas with large waves.



5. Oscillating Wave Surge Converter: An oscillating wave surge converter consists of a large flap or plate fixed to the seabed in shallow water. Incoming waves push the flap back and forth. This horizontal movement is converted into mechanical energy and then into electrical energy. These devices are usually installed near the shore.



Summary:

Method	Working Principle	Type of Energy Used	Key Feature
Oscillating Water Column (OWC)	Rising and falling waves compress and decompress air to drive a turbine	Kinetic + potential energy	Turbine is placed above water
Point absorber	Floating device moves up and down with waves and drives a generator	Potential energy	Compact and flexible design
Attenuator	Long floating structure bends with wave motion to produce power	Kinetic energy	Installed parallel to wave direction
Overtopping device	Waves overtop a ramp into a reservoir and flow through turbines	Potential energy	Uses stored elevated water
Oscillating wave surge converter	Horizontal wave motion pushes a hinged flap to generate power	Kinetic energy	Fixed near shore or seabed

Ocean Thermal Energy Conversion:

Ocean Thermal Energy Conversion (OTEC) is a renewable energy technology that generates electricity by utilizing the natural temperature difference between warm surface seawater and cold deep seawater. Typically, the surface water temperature in tropical oceans is about 25–30 °C, while deep seawater (at depths of 800–1000 m) is around 4–5 °C. This temperature difference, known as the thermal gradient, is the driving force for OTEC systems.

OTEC is especially suitable for tropical and subtropical regions, where this temperature difference is consistently available throughout the year, making it a reliable source of base-load renewable power, unlike solar or wind energy which are intermittent.

4.7 Working Principle:

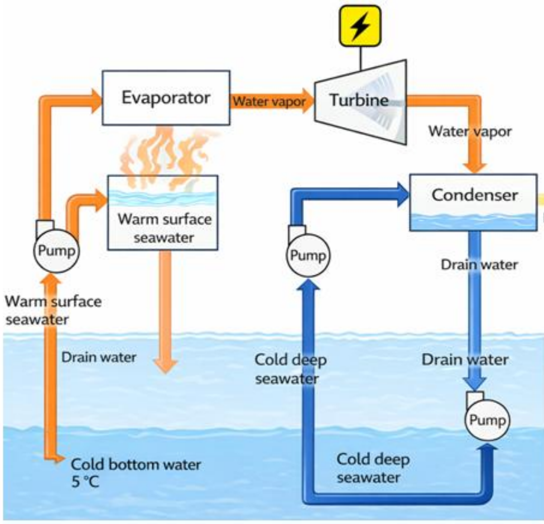
Ocean Thermal Energy Conversion (OTEC) works on the heat engine principle by using warm surface seawater as the heat source and cold deep seawater as the heat sink. Warm seawater transfers heat to a working fluid, causing it to vaporize. The vapor expands and drives a turbine connected to a generator to produce electricity. The vapor is then cooled and condensed back into liquid form using cold deep seawater, and the fluid is recycled to repeat the process continuously.

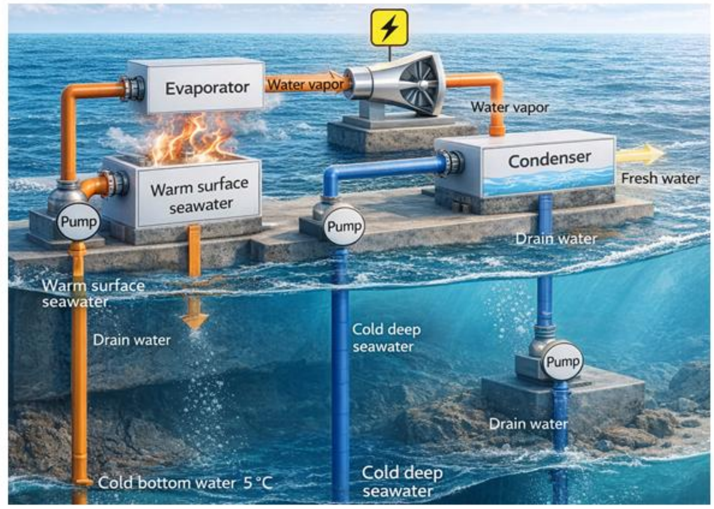
Classification:

Ocean Thermal Energy Conversion (OTEC) systems are classified based on the type of working fluid used and the method of energy conversion. Since OTEC operates using the temperature difference between warm surface seawater and cold deep seawater, different system configurations have been developed to improve efficiency and meet specific needs such as power generation and freshwater production. Accordingly, OTEC systems are mainly classified into open cycle, closed cycle, and hybrid cycle systems, each having distinct operating principles, advantages, and applications.

4.8 Open Cycle OTEC:

Open Cycle Ocean Thermal Energy Conversion (OTEC) is a system in which warm seawater itself is used as the working fluid. Electricity is generated by flashing warm seawater into steam and condensing it using cold deep seawater, producing freshwater as a by-product.





Construction Details:

Component	Description
Warm surface seawater intake	Draws warm seawater from the ocean surface
Pump	Circulates warm and cold seawater through the system
Evaporator (flash chamber)	Warm seawater is flash-evaporated under low pressure
Low-pressure turbine	Steam drives the turbine to produce power
Generator	Converts mechanical energy into electrical energy
Condenser	Steam is condensed using cold deep seawater
Cold deep seawater intake pipe	Supplies cold seawater from deep ocean
Freshwater outlet	Collects desalinated freshwater
Drain water outlet	Returns used seawater back to the ocean

Operating Principle:

In an open cycle OTEC system, warm surface seawater is pumped into a low-pressure evaporator where it rapidly flashes into steam due to the reduced pressure. This steam expands and flows through a low-pressure turbine, causing it to rotate and generate electricity. After leaving the turbine, the steam enters a condenser where cold deep seawater removes heat from it, converting the steam back into liquid water. This condensed water is fresh and desalinated, while the used seawater is discharged back into the ocean. The process continues as long as the temperature difference between surface and deep seawater is available.

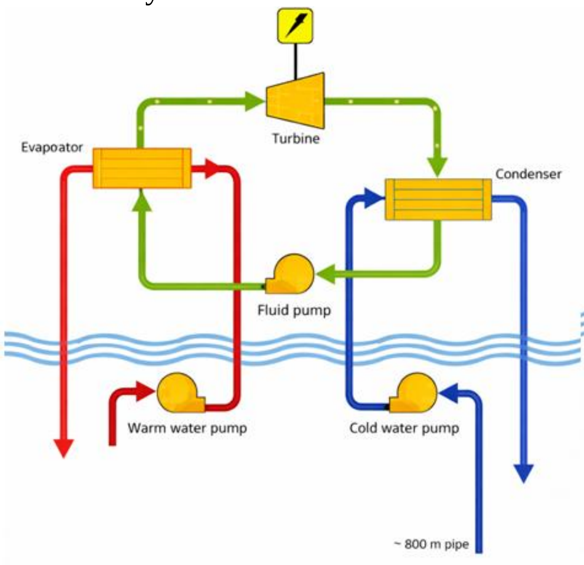
Merits, Demerits and Applications:

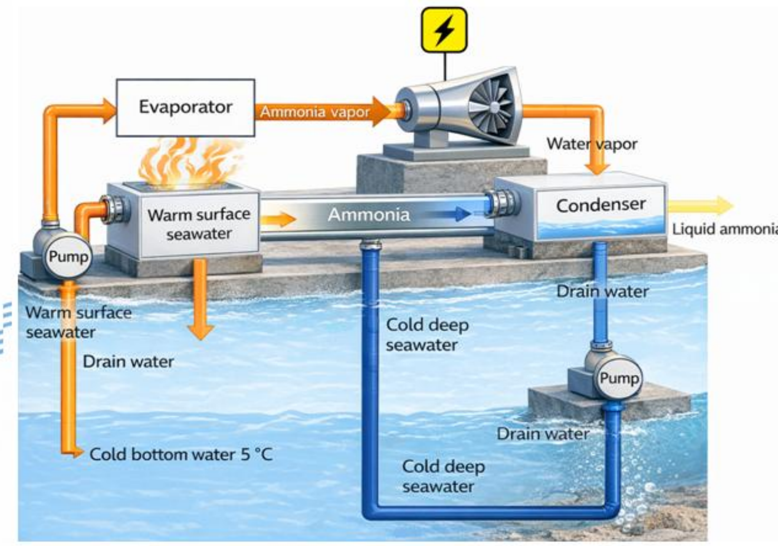
Open cycle OTEC uses renewable ocean thermal energy and does not require any chemical working fluid. It produces electricity continuously and also generates freshwater as a valuable by-product. The system is environmentally friendly with very low pollution.The system has low efficiency due to the small temperature difference between warm and cold seawater. It requires large seawater flow rates and high initial installation cost. It is suitable only in tropical regions where sufficient temperature difference exists.Open cycle OTEC is used for electricity generation in island and coastal regions. It is especially useful for freshwater production through desalination. It can also support cooling systems and aquaculture activities.

Note: *To explain working principle open cycle may be used.*

4.9 Closed Cycle OTEC :

Closed Cycle Ocean Thermal Energy Conversion (OTEC) is a system in which a low-boiling working fluid such as ammonia circulates in a closed loop to produce power. Warm surface seawater vaporizes the working fluid, and cold deep seawater condenses it, generating electricity continuously.





Construction Details :

Component	Description
Warm surface seawater intake	Draws warm seawater from the ocean surface
Warm water pump	Circulates warm seawater through the evaporator
Evaporator (heat exchanger)	Transfers heat from warm seawater to working fluid
Working fluid (ammonia)	Low boiling point fluid used in closed loop
Turbine	Driven by ammonia vapor to produce mechanical energy
Generator	Converts mechanical energy into electrical power
Condenser (heat exchanger)	Condenses ammonia vapor using cold seawater
Cold deep seawater intake pipe	Supplies cold seawater from deep ocean (~800–1000 m)
Cold water pump	Circulates cold seawater through the condenser
Working fluid pump	Returns liquid ammonia back to the evaporator
Drain water outlet	Discharges used seawater back to the ocean

Operating Principle:

In a closed cycle OTEC system, warm surface seawater is pumped through an evaporator where it transfers heat to a low-boiling working fluid such as ammonia. Due to this heat, the ammonia vaporizes and expands, flowing through a turbine that drives a generator to produce electricity. After passing through the turbine, the ammonia vapor enters a condenser where cold deep seawater removes heat and condenses it back into liquid form. The liquid ammonia is then pumped back to the evaporator, forming a closed loop, while the warm and cold seawater are discharged back into the ocean.

Merits, Demerits and Applications:

Closed cycle OTEC provides continuous renewable power and does not mix seawater with the working fluid. It has better efficiency than open cycle systems and uses proven heat exchanger technology. The system produces electricity without pollution or fuel cost.The efficiency is still low due to small temperature difference in the ocean. High initial cost and large heat exchangers are required. Handling of working fluids like ammonia requires safety precautions.Closed cycle OTEC is used for electricity generation in tropical coastal and island regions. It can supply base-load power to remote areas. It is also suitable for offshore power plants and future large-scale ocean energy projects.

Summary of Open Cycle and Closed Cycle OTEC:

Aspect	Open Cycle OTEC	Closed Cycle OTEC
Working fluid	Seawater itself	Low-boiling fluid (usually ammonia)
Cycle type	Open loop	Closed loop
Evaporation process	Warm seawater is flash-evaporated under low pressure	Working fluid vaporizes in a heat exchanger
Turbine fluid	Low-pressure steam from seawater	Ammonia vapor
Condensation	Steam condensed by cold deep seawater	Ammonia vapor condensed by cold deep seawater
Freshwater production	Yes, freshwater obtained as by-product	No freshwater production
Mixing with seawater	Seawater directly enters the system	No mixing of seawater with working fluid
Efficiency	Lower efficiency	Slightly higher efficiency
System complexity	Simpler in concept	More complex due to working fluid loop
Environmental impact	Very low, no chemical fluid	Low, but working fluid handling needed
Capital cost	High	High
Suitable regions	Tropical and subtropical regions	Tropical and subtropical regions
Major application	Power + desalination	Continuous power generation

4.10 OTEC Power Stations in the World:

Ocean Thermal Energy Conversion (OTEC) power stations are mostly experimental and pilot-scale plants established to test the technical feasibility of generating electricity using ocean temperature differences. Since OTEC requires a minimum temperature difference of about 20 °C between surface and deep seawater, most installations are located in tropical and subtropical regions, especially near islands and deep oceans.

Major OTEC Power Stations in the World

- **Hawaii, USA**
  The world's most well-known OTEC research facilities are located in Hawaii. The Natural Energy Laboratory of Hawaii Authority (NELHA) has successfully demonstrated open-cycle and closed-cycle OTEC systems, including the first open-cycle plant to produce electricity and freshwater. Hawaii is ideal due to its steep ocean floor and consistent temperature gradient.
- **Okinawa, Japan**
  Japan has developed small-scale OTEC plants in Okinawa. These plants mainly focus on demonstration and research, supplying power to local facilities and supporting desalination and air-conditioning systems. Japan continues to invest in OTEC for island energy security.
- **India (Lakshadweep Islands)**
  India has carried out OTEC experiments through the National Institute of Ocean Technology (NIOT). A floating OTEC pilot plant was tested near Lakshadweep to study feasibility for island power generation, though large-scale commercialization is still under development.

- **Nauru Island**
  One of the earliest OTEC demonstrations was conducted near Nauru Island in the Pacific Ocean during the 1980s. It proved the technical concept but faced economic and engineering challenges.
- **Other Countries**
  Countries such as France, South Korea, and China are actively involved in OTEC research and pilot projects, mainly targeting island communities and coastal regions.
  At present, no large commercial OTEC power station is operating at full scale. Most existing plants are pilot or demonstration units, producing power in the kilowatt to small megawatt range. High capital cost, low efficiency, and engineering challenges related to deep-sea pipelines have limited commercialization.

Summary:

Location / Country	Nature of Plant	Type of OTEC	Capacity / Status	Remarks
Hawaii (USA)	Research & demonstration	Open and Closed cycle	kW-scale pilot plants	World's most successful OTEC experiments; electricity and freshwater demonstrated
Okinawa (Japan)	Demonstration plant	Closed cycle	Small-scale	Supplies power to local facilities; focus on island energy needs
Lakshadweep (India)	Pilot floating plant	Closed cycle	Experimental	Developed by NIOT to study feasibility for island power
Nauru	Early experimental plant	Closed cycle	Pilot-scale	One of the earliest OTEC demonstrations in the 1980s
France	Research projects	Hybrid / Closed cycle	Pilot stage	Focus on overseas tropical territories
South Korea	Research & development	Closed cycle	Pilot stage	Research for island and coastal applications
China	Experimental plants	Closed cycle	Pilot stage	Research-oriented OTEC development

4.11 Problems Associated With OTEC:

1. Efficiency:

OTEC systems have low thermal efficiency because the temperature difference between warm surface seawater and cold deep seawater is small, usually about 20 °C. Since the available thermal energy is limited, large quantities of seawater must be circulated to generate even a small amount of power, which reduces the overall efficiency of the system.

2. Capital Cost:

The capital cost of OTEC plants is very high due to the requirement of large heat exchangers, long deep-sea cold water pipes, offshore platforms, and corrosion-resistant materials. These specialized components significantly increase the initial investment, making OTEC economically challenging compared to other renewable energy technologies.

3. Pumping Power Requirement:

OTEC systems require continuous pumping of huge volumes of warm and cold seawater. A significant portion of the generated electricity is consumed by these pumps, which reduces the net power output and lowers the overall performance of the plant.

4. Location Constraints:

OTEC plants can operate effectively only in tropical and subtropical regions where a sufficient and consistent temperature difference exists throughout the year. This geographical limitation restricts the application of OTEC to specific regions of the world.

5. Technical and Engineering Challenges:

The design and installation of long cold water intake pipes from deep ocean depths involve complex engineering challenges. These pipes must withstand ocean pressure, currents, and waves, making construction, operation, and maintenance difficult and costly.

6. Environmental Impact:

Large-scale intake and discharge of seawater can disturb marine ecosystems. The mixing of cold, nutrient-rich deep seawater with warmer surface water may alter local temperature distribution and affect marine life and ecological balance.

7. Working Fluid Safety:

In closed cycle OTEC systems, working fluids such as ammonia are used because of their low boiling point. However, these fluids require careful handling and strict safety measures to prevent leakage and environmental or health hazards, increasing operational complexity.

8. Maintenance and Reliability:

The marine environment causes corrosion, biofouling, and material degradation of OTEC components. Regular maintenance is necessary to ensure reliable operation, which increases operating costs and affects long-term reliability.

9. Commercial Maturity:

OTEC technology is still in the pilot and demonstration stage, with limited large-scale operational experience. The lack of proven commercial plants and economic uncertainty delays its widespread adoption and commercialization.

Summary:

Parameter	Problem Description
Thermal efficiency	Very low efficiency due to small temperature difference between warm and cold seawater
Capital cost	High initial investment for heat exchangers, deep-sea pipes, and offshore structures
Pumping power	Large power consumption for pumping huge volumes of seawater
Location limitation	Suitable only for tropical and subtropical regions
Engineering complexity	Difficulty in designing and installing long deep-water intake pipes
Environmental impact	Possible disturbance to marine ecosystems due to seawater intake and discharge
Working fluid safety	Risk associated with handling and leakage of fluids like ammonia
Maintenance	Corrosion and biofouling increase maintenance effort and cost
Commercial viability	Technology still in pilot stage with limited large-scale experience

Question Bank:

Five-Mark Questions :

1. Explain the working principle of a tidal power plant with a neat diagram.
2. Describe the construction details of a tidal power plant.
3. Explain tides and waves as energy suppliers.
4. Discuss the mechanics of tides and waves.
5. Explain the fundamental characteristics of tidal power.
6. Describe the tidal barrage system for power generation.
7. Explain tidal stream (current) turbines with advantages.
8. Write a short note on tidal lagoon system.
9. Explain dynamic tidal power as a conceptual method.

10. Explain the working principle of Ocean Thermal Energy Conversion (OTEC).
11. Describe the open cycle OTEC system with construction and operation.
12. Explain the closed cycle OTEC system and list its components.
13. Compare open cycle and closed cycle OTEC (any three points).
14. Write a short note on OTEC power stations in the world.
15. Explain the problems associated with OTEC (any five).

Ten-Mark Questions :

1. Explain tidal energy as a renewable source and describe the construction and working of a tidal power plant with neat diagram.
2. Discuss tides and waves as energy suppliers and explain the mechanics of tides and waves.
3. Explain the fundamental characteristics of tidal power and different methods of harnessing tidal energy.
4. Describe the tidal barrage system, tidal stream turbines, and tidal lagoon system with neat diagrams.
5. Explain dynamic tidal power and compare it with conventional tidal power methods.
6. Explain Ocean Thermal Energy Conversion (OTEC) in detail, including working principle and classification.
7. Describe the open cycle OTEC system with neat diagram, construction, operating principle, merits, demerits, and applications.
8. Explain the closed cycle OTEC system with neat diagram, construction details, operating principle, merits, demerits, and applications.
9. Compare open cycle and closed cycle OTEC in detail with a neat comparison table.
10. Discuss the OTEC power stations in the world and explain the problems associated with OTEC.

MODULE-05 BIOMASS POWER PLANTS & HYDROGEN ENERGY

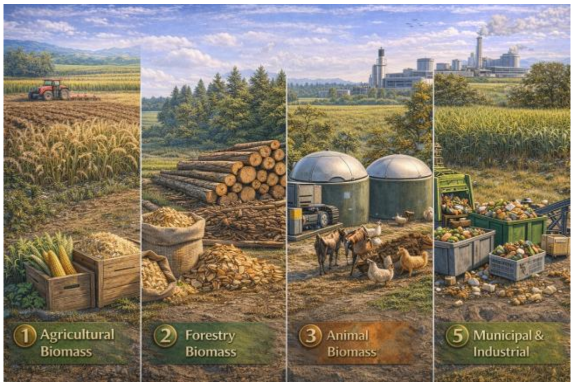
Syllabus: Biomass Power Plants: *Biomass as a renewable energy source: types and characteristics, Conversion technologies: combustion, gasification, and anaerobic digestion, biomass feedstock selection and availability, Environmental impacts and sustainability of biomass power plants, Integration of biomass power plants with other energy systems.*
Hydrogen Energy: *Properties of Hydrogen with respected to its utilization as a renewable form of energy, sources of hydrogen, production of hydrogen, electrolysis of water, thermal decomposition of water, thermos Chemical production biochemical production.*

5.0 Introduction:

Biomass is defined as organic material of biological origin, such as plants, agricultural residues, animal waste, and organic wastes, that is used as a renewable source of energy by converting its stored chemical energy into heat, electricity, or fuels.

Biomass as a renewable energy source refers to the use of organic materials such as agricultural residues, wood, animal waste, and organic municipal waste to produce energy. Biomass stores solar energy through photosynthesis, and when it is used for energy generation, the carbon dioxide released is approximately equal to the amount absorbed during plant growth, making it nearly carbon neutral. Biomass energy can be produced through direct combustion for heat and electricity, gasification to generate producer gas, anaerobic digestion to produce biogas, and pyrolysis to obtain biofuels. It is widely used for electricity generation, cooking, heating, and combined heat and power applications. Biomass helps in waste management, reduces dependence on fossil fuels, and supports rural development. However, it requires a continuous supply of raw material, proper emission control, and efficient management to be sustainable.

5.1 Types and Characteristics of Biomass:



1. Agricultural Biomass

Agricultural biomass consists of crop residues such as rice husk, wheat straw, sugarcane bagasse, and corn stalks obtained after harvesting. It is widely available in rural areas and is renewable in nature. This type of biomass has moderate calorific value and relatively high moisture content, which can affect combustion efficiency. Agricultural biomass is mainly used for direct combustion, gasification, and power generation in biomass plants, and it also helps in reducing agricultural waste burning.

2. Forestry Biomass

Forestry biomass includes wood, wood chips, sawdust, bark, and residues from forest operations. It has a higher calorific value and lower ash content compared to agricultural biomass, making it suitable for combustion and pellet production. Forestry biomass is relatively uniform in composition and easier to handle and store. Sustainable forest management is essential to ensure its renewability and environmental benefits.

3. Animal Biomass

Animal biomass mainly consists of cattle dung, poultry litter, and other animal wastes. It has high moisture content and is best suited for anaerobic digestion rather than direct combustion. The major characteristic of animal biomass is its ability to produce biogas rich in methane. It is commonly used in biogas plants for cooking, heating, and electricity generation while also producing nutrient-rich slurry as fertilizer.

4. Municipal and Industrial Biomass

Municipal and industrial biomass includes organic solid waste, food waste, sewage sludge, and biodegradable industrial waste. This biomass helps in effective waste management and reduces landfill problems. Its composition is highly variable, and it may require segregation and preprocessing. Municipal biomass can be used for biogas production, refuse-derived fuel, and waste-to-energy power plants.

5. Energy Crops

Energy crops are specially grown plants such as sugarcane, switchgrass, miscanthus, and fast-growing trees for energy production. They have predictable yield, uniform quality, and good calorific value. Energy crops ensure a continuous and reliable biomass supply but require land, water, and proper cultivation practices. They are mainly used for biofuel production, biomass power plants, and co-firing applications.

Summary:

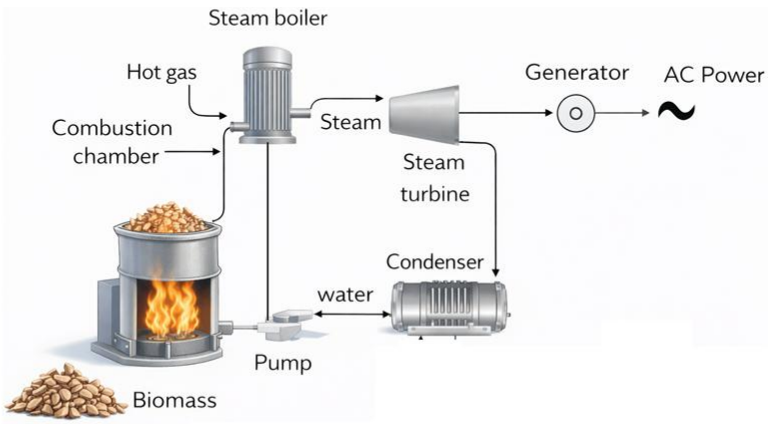
Sl. No.	Type of Biomass	Sources / Examples	Main Characteristics	Typical Applications
1	Agricultural Biomass	Rice husk, straw, bagasse, corn stalks	Renewable, widely available, moderate calorific value, high moisture content	Biomass power plants, gasification, direct combustion
2	Forestry Biomass	Wood, wood chips, sawdust, bark	High calorific value, low ash content, easy handling and storage	Combustion, pellets, CHP plants
3	Animal Biomass	Cattle dung, poultry litter	High moisture content, suitable for anaerobic digestion, biogas production	Biogas plants, cooking, electricity
4	Municipal & Industrial Biomass	Food waste, sewage sludge, organic solid waste	Variable composition, requires segregation, supports waste management	Waste-to-energy, biogas, RDF
5	Energy Crops	Sugarcane, switchgrass, fast-growing trees	Uniform quality, predictable yield, renewable but land-intensive	Biofuels, biomass power plants

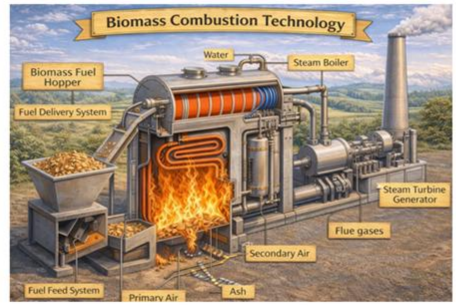
Conversion Technologies:

Conversion technologies such as combustion, gasification, and anaerobic digestion are commonly used to convert biomass into useful energy. In combustion, biomass is directly burned in the presence of excess air to produce heat, which is used for space heating or to generate steam and electricity. Gasification converts biomass into a combustible producer gas by heating it with a limited supply of oxygen or air; this gas can be used in engines or turbines for power generation. Anaerobic digestion is a biological process in which microorganisms break down wet organic biomass in the absence of oxygen to produce biogas, mainly methane, which is used for cooking, heating, and electricity generation.

5.2 Combustion Biomass Power Plant:

A combustion biomass power plant is a renewable energy system in which biomass fuel is directly burned in the presence of excess air to produce heat. The heat is used to generate steam, which drives a turbine to produce electricity.





Construction Details:

Sl. No.	Part / Component	Explanation
1	Biomass	Organic fuel such as wood chips, agricultural waste, or pellets used for combustion.
2	Combustion Chamber	Enclosed chamber where biomass is burned in the presence of air to produce heat and hot gases.
3	Hot Gas	High-temperature gases produced during combustion that transfer heat to the boiler.
4	Steam Boiler	Heat exchanger where hot gases convert water into high-pressure steam.
5	Steam	High-pressure vapor produced in the boiler used to drive the turbine.
6	Steam Turbine	Converts thermal energy of steam into mechanical rotational energy.
7	Generator	Converts mechanical energy from the turbine into electrical energy.
8	AC Power	Electrical output supplied to the grid or loads in alternating current form.
9	Condenser	Cools exhaust steam from the turbine and converts it back into water.
10	Water	Condensed steam reused in the system to maintain a closed cycle.
11	Pump	Circulates water from the condenser back to the boiler under pressure.
12	Cooling Water	Removes heat from the condenser to aid steam condensation.
13	Hot Water (for heating)	Useful thermal energy recovered for space heating or industrial use (CHP application).

Operating Principle:

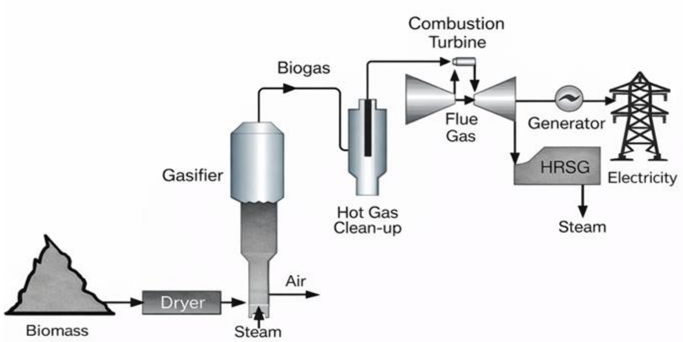
In a combustion biomass power plant, biomass fuel is fed into the combustion chamber through a fuel feed system. The fuel is burned in the presence of excess air supplied as primary and secondary air, producing high-temperature heat. This heat is transferred to water in the boiler, converting it into high-pressure steam. The steam drives a steam turbine connected to a generator, producing electricity. The combustion gases exit through the chimney, while ash is collected at the bottom and removed.

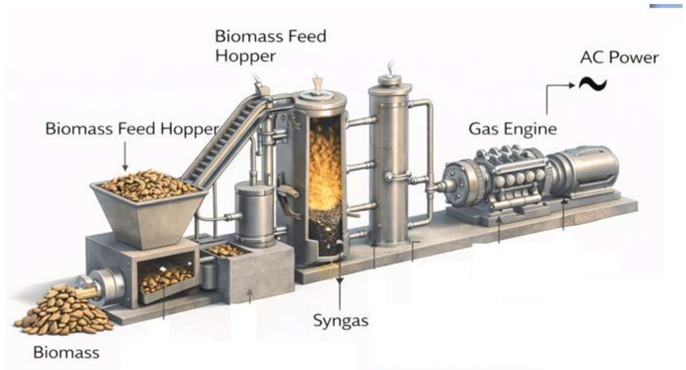
Merits, Demerits, and Applications:

Combustion biomass power plants use renewable fuel, reduce dependence on fossil fuels, and help in effective waste management. They provide continuous and reliable power and support rural employment.These plants require a continuous supply of biomass fuel, large storage areas, and proper emission control systems. They also have lower efficiency compared to fossil fuel power plants and involve higher maintenance.Combustion biomass power plants are used for electricity generation in rural and agricultural areas, industrial power supply, combined heat and power systems, and waste-to-energy projects.

5.3 Gasification Biomass Power Plant:

A gasification biomass power plant converts solid biomass into a combustible gas (producer gas or biogas) by reacting it with limited air or steam. This gas is then used to generate electricity using a gas turbine or engine.





Construction Details:

SN	Component	Construction Details
1	Biomass Storage	Stores raw biomass such as wood chips or agricultural waste.
2	Dryer	Reduces moisture content of biomass before gasification.
3	Gasifier	Vertical reactor where biomass is converted into combustible gas using limited air/steam.
4	Air Supply System	Supplies controlled air to support gasification reactions.
5	Steam Injection System	Supplies steam to enhance gasification and gas quality.
6	Hot Gas Clean-up Unit	Removes dust, tar, and impurities from producer gas.
7	Combustion Turbine	Burns cleaned gas to produce mechanical energy.
8	Generator	Converts mechanical energy into electrical energy.
9	HRSG (Heat Recovery Steam Generator)	Uses turbine exhaust heat to produce steam.
10	Steam System	Utilizes steam for heating or additional power generation.

Operating Principle:

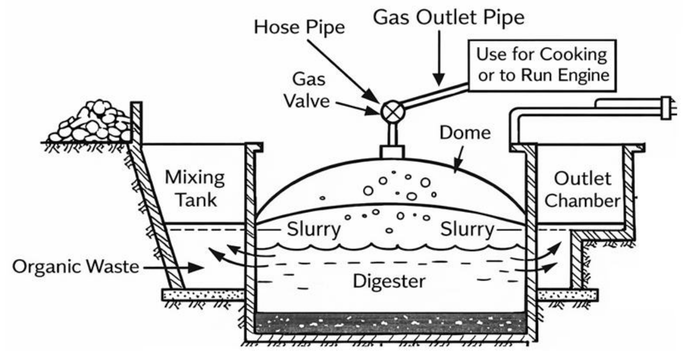
In a gasification biomass power plant, biomass is first dried and fed into the gasifier. Inside the gasifier, biomass reacts with a limited supply of air and steam at high temperature, producing combustible producer gas. This gas is cleaned in the hot gas clean-up unit to remove dust and tar. The clean gas is then burned in a combustion turbine or gas engine, which drives a generator to produce electricity. The hot exhaust gases are used in the HRSG to generate steam for heating or additional power.

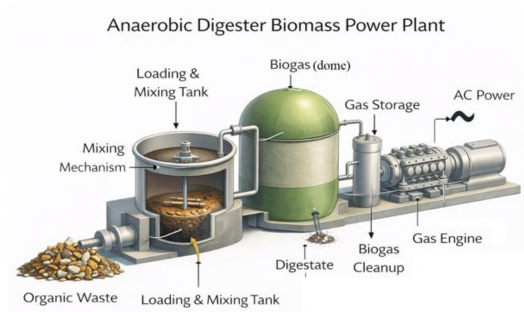
Merits, Demerits, and Applications:

Gasification offers higher efficiency than direct combustion, produces cleaner fuel gas, and allows better control of emissions. It efficiently uses biomass and enables combined heat and power generation.The system is complex and costly, requires skilled operation, and gas cleaning units need regular maintenance. Tar formation can cause operational issues.Gasification biomass power plants are used for decentralized electricity generation, rural electrification, industrial power supply, combined heat and power systems, and waste-to-energy applications.

5.4 Anaerobic Digestion Biomass Plant (Dome Type):

An anaerobic digestion biomass plant is a renewable energy system in which organic waste is decomposed by microorganisms in the absence of oxygen to produce biogas. The biogas is used for cooking, heating, or electricity generation.





Construction Details:

Sl. No.	Component	Construction Details
1	Mixing Tank	Open tank where organic waste is mixed with water to form slurry.
2	Inlet Pipe / Chamber	Transfers slurry from mixing tank to the digester.
3	Digester	Airtight underground chamber where anaerobic digestion takes place.
4	Dome	Curved top of digester that collects and stores biogas.
5	Gas Outlet Pipe	Pipe that carries biogas from the digester to the point of use.
6	Gas Valve	Controls the flow of biogas to appliances or engines.
7	Outlet Chamber	Collects digested slurry after gas production.
8	Digestate Pit	Stores spent slurry which can be used as manure.
9	Foundation	Provides structural support to the entire plant.

Operating Principle:

In an anaerobic digestion biomass plant, organic waste is mixed with water in the mixing tank to form slurry. This slurry flows into the airtight digester, where anaerobic bacteria break down the organic matter in the absence of oxygen. During digestion, biogas consisting mainly of methane is produced and collected in the dome. The gas is drawn through a gas outlet pipe and controlled by a valve for use in cooking, heating, or running engines. The digested slurry flows into the outlet chamber and is used as organic fertilizer.

Merits, Demerits, and Applications:

Anaerobic digestion produces clean and renewable energy, reduces organic waste, and provides useful manure as a by-product. It is environmentally friendly and suitable for rural areas. Initial construction cost is high, gas production is slow, and plant performance depends on temperature and waste quality. Regular maintenance is required. Anaerobic digestion plants are used for household biogas systems, rural electrification, cooking fuel supply, wastewater treatment, organic waste management, and small-scale power generation.

5.5 Biomass feedstock selection and availability:

Biomass feedstock selection and availability refer to choosing suitable biomass materials and ensuring their continuous supply for energy generation. Proper feedstock selection is important because the performance, efficiency, and cost of a biomass power plant largely depend on the type and quality of biomass used. Common biomass feedstocks include agricultural residues (rice husk, straw, bagasse), forestry residues (wood chips, sawdust), animal waste, and organic municipal waste. Selection of biomass feedstock depends on factors such as

1. Local Availability

Local availability refers to how easily biomass feedstock can be obtained near the power plant site. Biomass that is locally available reduces transportation cost and ensures continuous fuel supply. Using locally available agricultural or forestry residues also supports rural development.

2. Moisture Content

Moisture content indicates the amount of water present in biomass. High moisture content reduces calorific value and lowers combustion or gasification efficiency. Therefore, biomass with low moisture content is preferred, or drying is required before use.

3. Calorific Value

Calorific value is the amount of energy released when biomass is burned. Biomass with higher calorific value produces more energy per unit mass, improving overall plant efficiency. Wood and energy crops generally have higher calorific value than wet biomass.

4. Ash Content

Ash content represents the non-combustible residue left after biomass conversion. High ash content causes slagging, fouling, and maintenance problems in boilers and gasifiers. Hence, biomass with low ash content is preferred for efficient operation.

5. Ease of Collection and Transportation

Biomass should be easy to collect, handle, and transport. Bulky or scattered biomass increases logistics cost and operational complexity. Densified biomass such as pellets is easier to transport and store.

6. Seasonal Availability

Many biomass sources, especially agricultural residues, are available only during certain seasons. Seasonal variation can affect continuous plant operation. Proper storage systems or alternative feedstocks are needed to manage this issue.

7. Sustainability and Environmental Impact

Feedstock selection must be sustainable to avoid deforestation and soil degradation. Biomass should be sourced without disturbing food supply or ecological balance. Sustainable practices ensure long-term availability and environmental protection.

Summary:

SN	Factor	Brief Explanation
1	Local Availability	Biomass should be easily available near the plant to reduce transportation cost and ensure continuous supply.
2	Moisture Content	Low moisture content is preferred as high moisture reduces efficiency and calorific value.
3	Calorific Value	Higher calorific value biomass produces more energy and improves plant efficiency.
4	Ash Content	Low ash content is desirable to avoid slagging, fouling, and maintenance issues.
5	Ease of Collection & Transport	Biomass should be easy to collect, handle, store, and transport to reduce logistics problems.
6	Seasonal Availability	Continuous year-round availability is important; seasonal biomass requires proper storage.
7	Sustainability & Environment	Biomass sourcing should be sustainable without causing deforestation or ecological damage.

5.6 Environmental Impacts of Biomass Power Plants:

Environmental impacts of biomass power plants refer to the effects of generating energy from biomass on air, land, water, and ecosystems. These impacts include both benefits such as reduced fossil fuel use and challenges like air emissions, land use, and waste disposal.The following are the parameters to be considered.

1. Greenhouse Gas Emissions

Biomass power plants release carbon dioxide during energy conversion, but this is largely offset by the carbon absorbed by plants during growth. Hence, biomass is considered nearly carbon neutral when sustainably managed.

2. Air Pollution

Combustion and gasification of biomass can emit particulate matter, nitrogen oxides, and carbon monoxide. Proper emission control systems such as filters and scrubbers are required to minimize air pollution.

3. Land Use and Deforestation

Large-scale biomass extraction may cause deforestation if energy crops or wood are not managed sustainably. This can lead to loss of biodiversity and ecological imbalance.

4. Soil and Water Impact

Improper disposal of ash and digestate may contaminate soil and water. Excessive removal of agricultural residues can reduce soil fertility and increase erosion.

5. Waste Management

Biomass plants help reduce agricultural waste burning and landfill use by converting waste into energy. This reduces methane emissions from organic waste decomposition.

6. Noise and Transport Impact

Transportation and handling of biomass can cause noise, dust, and local air pollution, especially when biomass is transported over long distances.

5.7 Sustainability of Biomass Power Plants:

Sustainability of biomass power plants refers to the ability of these plants to produce energy continuously without depleting natural resources or causing environmental harm. It depends on the use of renewable biomass feedstock, efficient energy conversion technologies, and environmentally responsible management practices. The main parameters influencing sustainability are explained below.

1. ***Greenhouse Gas Balance:***
   Biomass power plants are sustainable because the carbon dioxide released during energy generation is balanced by the carbon absorbed by plants during growth. This near carbon-neutral cycle helps reduce long-term greenhouse gas emissions.
2. ***Air Quality Management:***
   The use of modern emission control systems such as filters and scrubbers reduces particulate matter and harmful gases, improving air quality and environmental compliance.
3. ***Land Use Management:***
   Sustainability is achieved by avoiding deforestation and using agricultural residues, energy crops, and waste biomass. Planned harvesting protects biodiversity and maintains ecological balance.
4. ***Soil and Water Protection:***
   Proper handling of ash and digestate prevents soil and water pollution. Using treated residues as manure helps maintain soil fertility.
5. ***Waste Management and Circular Economy:***
   Biomass power plants convert organic waste into energy and useful by-products, reducing landfill use and supporting a circular economy.

6. ***Renewable Resource Availability:***
   Sustainable operation depends on a continuous and renewable biomass supply. Feedstock planning and storage ensure year-round availability.
7. ***Transport and Logistics Optimization:***
   Local sourcing of biomass reduces transportation emissions, noise, and fuel consumption, improving environmental sustainability.
8. ***Energy Efficiency Improvement:***
   Advanced conversion technologies and combined heat and power systems increase efficiency, making better use of biomass resources.
9. ***Socio-Economic Sustainability:***
   Biomass power plants create rural employment, support farmers, and promote decentralized power generation, contributing to long-term sustainable development.

Summary:

SN	Parameter	Environmental Impacts	Sustainability Aspect
1	Greenhouse Gas Emissions	Nearly carbon neutral but emits CO_2 during operation	Balanced by carbon absorption through biomass regrowth
2	Air Quality	Emits particulates, NO_x, and CO if not controlled	Emission control systems reduce pollution
3	Land Use	Risk of deforestation and biodiversity loss	Sustainable harvesting and use of residues prevent damage
4	Soil & Water	Ash and waste may affect soil and water quality	Proper ash handling and soil conservation improve sustainability
5	Waste Management	Reduces open burning and landfill waste	Supports circular economy by converting waste to energy
6	Resource Availability	Biomass supply may be seasonal	Renewable feedstock planning ensures continuity
7	Transport Impact	Dust, noise, and emissions from transport	Local sourcing reduces environmental impact
8	Energy Efficiency	Lower efficiency if poorly designed	Advanced technologies improve efficiency
9	Social Impact	Can affect local environment if unmanaged	Creates rural employment and supports local economy

5.8 Integration of Biomass Power Plants with Other Energy Systems

Integration of biomass power plants with other energy systems refers to the coordinated operation of biomass-based generation with other conventional or renewable energy technologies to improve reliability, efficiency, and sustainability of the overall energy system. Because biomass power plants can provide controllable and dispatchable power, they are well suited for integration with variable energy sources such as solar and wind.

Integration with solar energy systems:Biomass power plants are often integrated with solar power plants to overcome the intermittency of solar energy. During daytime, solar plants supply electricity, while biomass plants operate during night or cloudy periods to ensure continuous power supply. For example, in hybrid solar–biomass plants, solar energy reduces biomass fuel consumption during peak sunshine hours, improving overall efficiency and reducing operating costs.

Integration with wind energy systems: Wind energy is highly variable and depends on wind availability. Biomass power plants can act as a backup or base-load source in wind–biomass hybrid systems. When wind generation is low, biomass plants compensate by supplying steady power, thereby stabilizing the grid. This integration improves grid reliability and reduces dependence on fossil fuel-based backup plants.

Integration with energy storage systems: Biomass plants can be integrated with thermal energy storage or electrical energy storage systems. Excess heat produced during low-demand periods can be stored and used later, while batteries can help manage short-term load variations. This integration enhances system flexibility and efficiency.

Integration with conventional power systems and grids**:** Biomass power plants can be integrated into existing power grids as distributed generation units. They help support grid stability by providing firm power, voltage control, and frequency regulation. In rural or remote areas, biomass plants integrated with diesel generators reduce fuel consumption and operating costs.

Summary:

SN	Integration System	Description / Role	Key Benefits	Example
1	Solar Energy Systems	Biomass plants operate during night or cloudy periods when solar power is unavailable	Ensures continuous power supply, reduces biomass fuel use	Hybrid solar–biomass power plant
2	Wind Energy Systems	Biomass acts as backup or base-load when wind generation is low	Improves grid stability, reduces fossil fuel backup	Wind–biomass hybrid system
3	Energy Storage Systems	Integrated with thermal storage or batteries to store excess heat or power	Improves flexibility, manages load variations	Biomass plant with thermal storage
4	Conventional Power Grids	Biomass plants operate as distributed generation units in the grid	Provides firm power, voltage and frequency control	Grid-connected biomass plant
5	Rural / Remote Power Systems	Biomass integrated with diesel generators for remote areas	Reduces diesel consumption and operating cost	Biomass–diesel hybrid system

Hydrogen Energy:

Hydrogen energy refers to the use of hydrogen as a clean and sustainable fuel for producing electricity, heat, and power. Hydrogen is the most abundant element in the universe and can be used as an energy carrier in various applications. It can be produced from different sources such as water, natural gas, biomass, and renewable energy through processes like electrolysis, reforming, and gasification.

When hydrogen is used as a fuel, especially in fuel cells, it produces electricity with water as the only by-product, making it environmentally friendly. Hydrogen has a high energy content per unit mass and can be stored and transported for later use. It can be used in power generation, transportation, industrial processes, and energy storage systems. Hydrogen energy is also important for integrating renewable energy sources such as solar and wind by storing excess energy in the form of hydrogen.

However, challenges such as high production cost, storage difficulties, and infrastructure development need to be addressed. With advancements in technology, hydrogen energy is expected to play a significant role in future clean energy systems and help reduce greenhouse gas emissions.

5.9 Properties of Hydrogen with Respected to its Utilization as a Renewable Form of Energy (Advantages of Hydrogen Energy) :

1. High Energy Content

Hydrogen has a very high energy content per unit mass compared to many conventional fuels. It releases a large amount of energy during combustion or when used in fuel cells. This property makes hydrogen an efficient fuel for power generation, transportation, and energy storage applications.

2. Clean Combustion

Hydrogen is considered a clean fuel because when it reacts with oxygen, the main product formed is water vapor. Unlike fossil fuels, it does not produce carbon dioxide, sulfur oxides, or particulate matter during combustion. This characteristic makes hydrogen an environmentally friendly energy source.

3. Abundant Availability

Hydrogen is the most abundant element in the universe and is widely available in compounds such as water and hydrocarbons. Although it does not exist freely in large quantities on Earth, it can be produced from renewable resources such as water through electrolysis using solar or wind energy.

4. High Combustion Efficiency

Hydrogen burns efficiently with a wide range of air–fuel mixtures. It has a high flame speed and can ignite easily, which improves combustion efficiency in engines and turbines. This allows hydrogen to be used effectively in energy conversion systems.

5. Energy Storage Capability

Hydrogen can be stored and transported for later use, making it useful for energy storage. Renewable electricity from solar and wind can be converted into hydrogen and stored for long periods, helping balance energy supply and demand.

6. Lightweight Gas

Hydrogen is the lightest element and has a very low density. Because of its low molecular weight, it rises and disperses quickly in the atmosphere if leaked. However, its low density requires larger storage volumes compared to other fuels.

7. High Diffusivity and Flammability

Hydrogen has very high diffusivity, meaning it spreads quickly through air. It also has a wide flammability range and a low ignition energy, which allows it to ignite easily. While these properties make hydrogen an efficient fuel, they also require careful handling and safety measures during storage and transportation.

8. Environmental Impact

Hydrogen energy has a very low environmental impact when produced from renewable sources. Its use in fuel cells or combustion mainly produces water as a by-product, reducing greenhouse gas emissions and air pollution. Therefore, hydrogen is considered a promising clean energy carrier for sustainable energy systems.

9. Versatile Applications

Hydrogen can be used in different energy systems such as fuel cells, internal combustion engines, and industrial processes. It can generate electricity, heat, or mechanical power, making it a versatile energy carrier for future renewable energy technologies.

Summary:

SN	Property	Brief Explanation
1	High Energy Content	Hydrogen has very high energy per unit mass, making it an efficient fuel for power generation and transportation.
2	Clean Combustion	Hydrogen reacts with oxygen to produce mainly water vapor, resulting in very low emissions and reduced pollution.
3	Abundant Availability	Hydrogen is the most abundant element and can be produced from water, biomass, and other renewable resources.
4	High Combustion Efficiency	It burns efficiently with a wide air–fuel mixture range and has a high flame speed, improving energy conversion efficiency.
5	Energy Storage Capability	Hydrogen can store excess energy from renewable sources and supply power when needed.
6	Lightweight Gas	Hydrogen has very low density and disperses quickly in the atmosphere, though it requires larger storage volume.
7	High Diffusivity and Flammability	Hydrogen spreads rapidly in air and ignites easily, requiring careful handling and safety measures.
8	Environmental Impact	When produced from renewable sources, hydrogen energy reduces greenhouse gas emissions and air pollution.
9	Versatile Applications	Hydrogen can be used in fuel cells, internal combustion engines, power generation, and industrial processes.

5.10 Sources of Hydrogen:

1. Water (Electrolysis)

Water is one of the most important renewable sources of hydrogen. Hydrogen can be produced by electrolysis of water, where an electric current splits water into hydrogen and oxygen. When the electricity used for electrolysis comes from renewable sources such as solar or wind energy, the hydrogen produced is known as green hydrogen and is considered environmentally friendly.

2. Natural Gas (Steam Methane Reforming)

Natural gas is the most widely used source for hydrogen production. In steam methane reforming (SMR), methane from natural gas reacts with high-temperature steam to produce hydrogen and carbon dioxide. This process is highly efficient and widely used in industry, but it produces greenhouse gas emissions.

3. Biomass

Biomass such as agricultural residues, wood waste, and organic matter can also be used to produce hydrogen. Biomass undergoes processes such as gasification, pyrolysis, or biological fermentation to produce hydrogen-rich gases. Since biomass is renewable, this method is considered more sustainable compared to fossil fuel-based hydrogen production.

4. Coal

Coal can produce hydrogen through coal gasification. In this process, coal reacts with steam and oxygen at high temperatures to produce synthesis gas (syngas), which contains hydrogen and carbon monoxide. Hydrogen is then separated from this gas mixture. However, this method produces high carbon emissions.

5. Industrial By-products

Hydrogen is often produced as a by-product in several industrial processes such as petroleum refining, chlor-alkali production, and chemical manufacturing. This hydrogen can be captured and utilized for energy or industrial purposes instead of being released into the atmosphere.

6. Renewable Energy Sources

Renewable energy sources such as solar, wind, and hydropower can be used to generate electricity for water electrolysis. This method produces hydrogen without carbon emissions and is considered a key technology for sustainable hydrogen production.

7. Nuclear Power Sources

Nuclear energy can also be used to produce hydrogen. Nuclear reactors generate large amounts of heat and electricity, which can be used for high-temperature electrolysis or thermochemical water-splitting processes. Hydrogen produced using nuclear energy can provide a stable and continuous supply with low carbon emissions.

Summary:

SN	Source	Method of Hydrogen Production	Brief Explanation
1	Water	Electrolysis	Electricity splits water into hydrogen and oxygen; renewable electricity produces green hydrogen.
2	Natural Gas	Steam Methane Reforming (SMR)	Methane reacts with steam at high temperature to produce hydrogen and carbon dioxide; widely used industrial method.
3	Biomass	Gasification / Pyrolysis / Fermentation	Organic materials such as agricultural waste and wood are converted into hydrogen-rich gases.
4	Coal	Coal Gasification	Coal reacts with steam and oxygen to produce synthesis gas from which hydrogen is extracted.
5	Industrial By-products	Chemical and Refining Processes	Hydrogen produced as a by-product in industries like petroleum refining and chlor-alkali plants.
6	Renewable Energy Sources	Electrolysis using Solar/Wind Power	Renewable electricity is used to split water, producing clean and sustainable hydrogen.
7	Nuclear Power Sources	High-temperature Electrolysis / Thermochemical Processes	Heat and electricity from nuclear reactors are used to split water and produce hydrogen with low carbon emissions.

5.11 Hydrogen Production:

Hydrogen can be produced by several methods depending on the energy source and technology used. The following represent some of major methods.

Electrolysis of Water:

In this method, hydrogen is produced by passing an electric current through water. The electric current splits water molecules into hydrogen and oxygen gases. Hydrogen is collected at the cathode and oxygen at the anode. When renewable electricity such as solar or wind power is used, the hydrogen produced is considered clean and environmentally friendly.

Thermal Decomposition of Water:

Thermal decomposition involves breaking water molecules into hydrogen and oxygen using very high temperatures, usually above 2000 °C. At such high temperatures, water molecules separate naturally into their components. This method requires advanced materials and high-temperature heat sources such as solar thermal or nuclear energy.

Thermochemical Production:

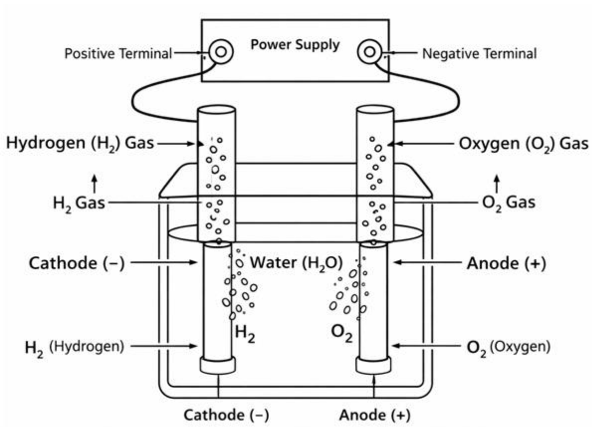
Thermochemical hydrogen production uses a series of chemical reactions driven by heat to split water into hydrogen and oxygen. These reactions usually involve intermediate chemicals such as sulfur or iodine. The process requires high temperatures and is often linked with nuclear or concentrated solar power systems.

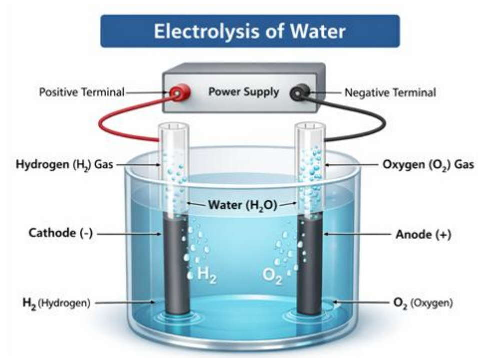
Biochemical Production:

Biochemical methods use microorganisms such as bacteria or algae to produce hydrogen. In these processes, organic materials or water are broken down through biological reactions like fermentation or photosynthesis. This method is considered environmentally friendly and uses renewable biological resources.

5.12 Electrolysis of Water:

Water electrolysis is the process of splitting water (H_2O) into hydrogen (H_2) and oxygen (O_2) using an electric current. It is an important method for producing clean hydrogen fuel, especially when powered by renewable energy.





Construction Details:

Sl. No.	Component	Construction Details
1	Power Supply	Provides direct current (DC) electricity to drive the electrolysis reaction.
2	Electrolyte (Water with electrolyte)	Conducting liquid medium that allows electric current to pass through water.
3	Cathode (–)	Negative electrode where hydrogen gas is produced.
4	Anode (+)	Positive electrode where oxygen gas is produced.
5	Electrolysis Container	Vessel that holds the electrolyte and electrodes.
6	Gas Collection Tubes	Collect hydrogen and oxygen gases produced during electrolysis.
7	Connecting Wires	Connect the electrodes to the power supply.

Operating Principle:

In water electrolysis, two electrodes called the anode and cathode are placed in water containing a small amount of electrolyte to improve conductivity. When a direct electric current is passed through the water, chemical reactions occur at the electrodes. Hydrogen ions move toward the cathode where they gain electrons and form hydrogen gas, while oxygen is produced at the anode as water molecules lose electrons. The hydrogen and oxygen gases are collected separately, with hydrogen produced in double the volume of oxygen.

Electrochemical Reactions:

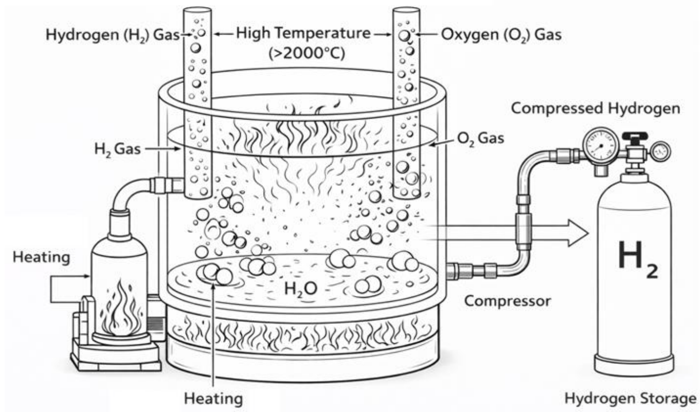
Cathode (Reduction):
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Anode (Oxidation):
$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$
Overall Reaction:
$2H_2O \rightarrow 2H_2 + O_2$

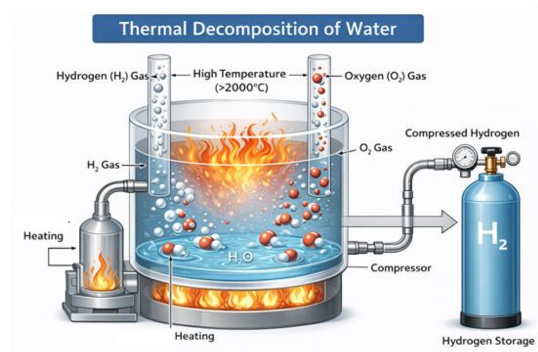
Merits, Demerits & Applications:

Water electrolysis produces clean hydrogen without harmful emissions when renewable electricity is used. It is a simple and reliable process and allows hydrogen production directly from water. The produced hydrogen can be stored and used as a clean energy source.The process requires a large amount of electrical energy, which can make hydrogen production expensive. Special materials and equipment are required for efficient electrolysis. Hydrogen storage and transportation also require careful safety measures.Hydrogen produced by electrolysis is used in fuel cells for electricity generation, as a fuel for vehicles, and in industrial processes such as ammonia production and petroleum refining. It is also used for energy storage in renewable energy systems.

5.13 Thermal Decomposition of Water (thermolysis or water splitting):

Thermolysis is the process of decomposing a chemical compound into simpler substances using very high temperature. In hydrogen production, thermolysis splits water (H_2O) into hydrogen (H_2) and oxygen (O_2) at temperatures above about 2000 °C.





Construction Details:

Sl. No.	Component	Construction Details
1	Heating Device	High-temperature furnace or burner used to supply heat required for water decomposition.
2	Reaction Chamber	Container where water is heated and decomposed at very high temperature.
3	Water (H_2O)	Raw material placed in the chamber for decomposition.
4	Gas Collection Tubes	Tubes used to collect hydrogen and oxygen gases separately.
5	Compressor	Compresses the produced hydrogen gas for storage or transportation.
6	Hydrogen Storage Tank	Stores compressed hydrogen safely for later use.
7	Gas Outlet Pipes	Pipes that transfer produced gases from the reactor to compressor and storage systems.

Operating Principle:

In thermolysis of water, water is heated to extremely high temperatures, typically above 2000 °C, using a heating device such as a furnace or solar thermal system. At this high temperature, water molecules break down into hydrogen and oxygen gases. The hydrogen and oxygen gases rise through the chamber and are collected through gas outlet tubes. The hydrogen gas is then passed through a compressor to increase its pressure and stored in hydrogen storage tanks for later use.

Chemical Reaction:

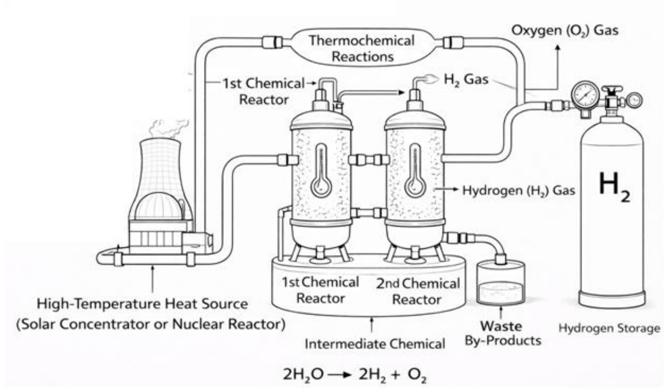
$2H_2O \rightarrow 2H_2 + O_2$

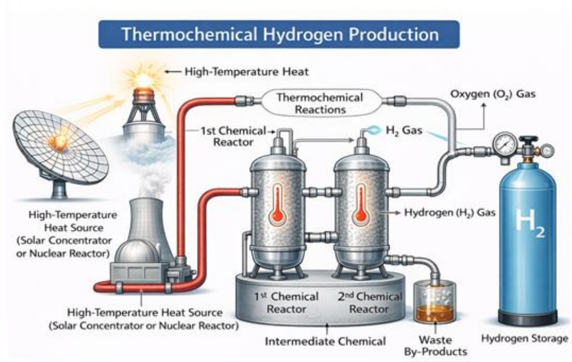
Merits, Demerits & Applications:

Thermolysis can produce hydrogen without using electricity and can utilize high-temperature heat sources such as solar thermal or nuclear energy. The process produces clean hydrogen with oxygen as the only by-product.The process requires extremely high temperatures, which makes the system technically complex and expensive. Special materials are needed to withstand the high temperature and ensure safe operation. Hydrogen produced through thermolysis can be used in fuel cells for electricity generation, as a fuel for vehicles, in industrial processes such as ammonia production, and for energy storage in renewable energy systems.

5.14 Thermochemical Hydrogen Production:

Thermochemical hydrogen production is the process of producing hydrogen from water using a series of chemical reactions driven by high temperature. These reactions use heat from sources such as solar concentrators or nuclear reactors to split water into hydrogen and oxygen.





Construction Details:

SN	Component	Construction Details
1	High-Temperature Heat Source	Solar concentrator or nuclear reactor used to provide the high heat required for the reactions.
2	Heat Transfer Pipes	Pipes that transfer high-temperature heat to the chemical reactors.
3	First Chemical Reactor	Reactor where the first thermochemical reaction takes place using intermediate chemicals.
4	Second Chemical Reactor	Reactor where the next reaction occurs to produce hydrogen gas.
5	Intermediate Chemical Tank	Stores intermediate chemicals used in the reaction cycle.
6	Gas Outlet Pipes	Pipes used to carry produced hydrogen and oxygen gases from reactors.
7	Hydrogen Storage Tank	Stores produced hydrogen gas safely for later use.
8	Waste By-product Container	Collects by-products formed during thermochemical reactions.

Operating Principle:

In thermochemical hydrogen production, water is decomposed into hydrogen and oxygen through a series of chemical reactions that occur at high temperatures. Heat from a high-temperature source such as a solar concentrator or nuclear reactor is supplied to the chemical reactors. Intermediate chemicals are used to carry out different reactions in stages. These reactions release hydrogen gas, which is separated and collected. Oxygen and other by-products are also produced during the process. The hydrogen gas is then transferred through pipes and stored in hydrogen storage tanks for future use.

Overall Reaction:

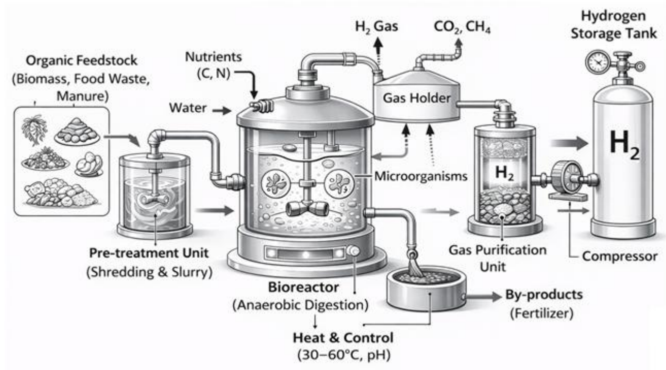
$2H_2O \rightarrow 2H_2 + O_2$

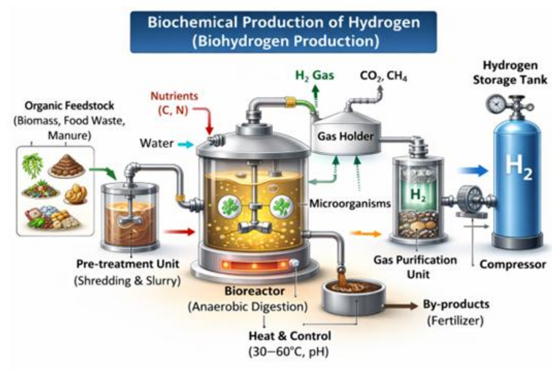
Merits, Demerits & Applications:

Thermochemical hydrogen production uses heat instead of electricity, which can improve efficiency. It can utilize renewable heat sources such as solar thermal energy or nuclear power. The process produces clean hydrogen with minimal environmental pollution. The process requires very high temperatures and complex chemical systems. The equipment and materials must withstand high temperature and corrosion, which increases cost and technical difficulty. Hydrogen produced by thermochemical methods is used in fuel cells for electricity generation, transportation fuels, industrial chemical production, and energy storage systems for renewable energy.

5.15 Biochemical Production:

Biochemical production of hydrogen is the process of producing hydrogen gas using microorganisms such as bacteria or algae through biological reactions. These microorganisms break down organic materials or water in the absence of oxygen to generate hydrogen gas.





Construction Details:

SN	Component	Construction Details
1	Organic Feedstock	Biomass, food waste, or manure used as raw material for hydrogen production.
2	Pre-treatment Unit	Shreds and mixes the biomass with water to form slurry for easier microbial digestion.
3	Bioreactor (Anaerobic Digester)	Main chamber where microorganisms break down organic matter in the absence of oxygen.
4	Nutrient Supply	Nutrients such as carbon and nitrogen added to support microbial growth.
5	Gas Holder	Collects the gas mixture produced during digestion.
6	Gas Purification Unit	Separates hydrogen gas from other gases like CO_2 and CH_4.
7	Compressor	Compresses hydrogen gas for storage and transportation.
8	Hydrogen Storage Tank	Stores the purified hydrogen gas safely.
9	By-product Tank	Collects digestate or slurry residue that can be used as fertilizer.

Operating Principle:

In biochemical hydrogen production, organic materials such as biomass or food waste are first processed in a pre-treatment unit to form slurry. This slurry is fed into a bioreactor where microorganisms decompose the organic matter under anaerobic (oxygen-free) conditions. During this biological process, gases such as hydrogen, carbon dioxide, and methane are produced. The gas mixture is collected in a gas holder and then passed through a gas purification unit where hydrogen is separated. The purified hydrogen is compressed using a compressor and stored in hydrogen storage tanks, while the remaining residue is collected as fertilizer.

Merits, Demerits & Applications:

Biochemical hydrogen production uses renewable organic waste materials and produces clean energy. The process also helps in waste management and generates useful by-products such as organic fertilizer. The rate of hydrogen production is relatively slow and depends on microbial activity. The process requires controlled environmental conditions such as temperature and pH for efficient operation.Hydrogen produced by biochemical methods can be used in fuel cells for electricity generation, as a clean fuel for transportation, and for energy storage. The by-products can also be used as biofertilizers in agriculture.

QUESTION BANK:

5 Marks Questions (Short Answer)

Biomass Power Plants

1. Define biomass and explain its importance as a renewable energy source.
2. List the different types of biomass with examples.
3. Explain the characteristics of agricultural biomass.
4. Explain the conversion technologies used for biomass energy.
5. Write short notes on combustion biomass power plant.
6. Explain the working principle of a gasification biomass power plant.
7. Write short notes on anaerobic digestion biomass plant.
8. List the factors affecting biomass feedstock selection.
9. Explain the environmental impacts of biomass power plants.
10. Write short notes on sustainability of biomass power plants.
11. Explain the integration of biomass power plants with solar energy systems.
12. Write short notes on biomass integration with wind energy systems.

Hydrogen Energy

13. Define hydrogen energy and state its importance.
14. Explain the properties of hydrogen as an energy source.
15. Write short notes on clean combustion and high energy content of hydrogen.
16. List the different sources of hydrogen.
17. Explain the electrolysis of water for hydrogen production.
18. Write short notes on thermal decomposition of water.
19. Explain the thermochemical method of hydrogen production.
20. Write short notes on biochemical production of hydrogen.

10 Marks Questions (Long Answer)

Biomass Power Plants

1. Explain types and characteristics of biomass with suitable examples.
2. Explain the construction and working of a combustion biomass power plant with a neat diagram.
3. Explain the gasification biomass power plant with construction, working principle, merits, and applications.
4. Explain the anaerobic digestion biomass plant with construction and working principle.
5. Discuss the factors affecting biomass feedstock selection and availability.
6. Explain the environmental impacts of biomass power plants with suitable parameters.
7. Discuss the sustainability of biomass power plants in detail.
8. Explain the integration of biomass power plants with other energy systems with examples.

Hydrogen Energy

9. Explain hydrogen energy and its properties as a renewable energy source.
10. Discuss the various sources of hydrogen production with examples.
11. Explain the different methods of hydrogen production.
12. Explain the electrolysis of water for hydrogen production with construction, working principle, reactions, merits, and applications.
13. Explain thermal decomposition of water (thermolysis) for hydrogen production.
14. Explain thermochemical hydrogen production with construction and working principle.
15. Explain biochemical production of hydrogen with construction and working principle.
16. Discuss the advantages of hydrogen energy as a clean fuel.

CBCS SCHEME

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BME654B

Sixth Semester B.E./B.Tech. Degree Examination, June/July 2025
Renewable Energy Power Plants

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.

		Module – 1	M	L	C
Q.1	a.	Explain briefly different renewable and non-renewable energy sources.	10	L2	CO1
	b.	Explain environmental benefits and challenges of renewable energy sources.	10	L2	CO1
		OR			
Q.2	a.	Explain extra-terrestrial radiation and special distribution of extra terrestrial radiation.	10	L2	CO1
	b.	Explain solar radiation at the earth's surface.	10	L2	CO1
		Module – 2			
Q.3	a.	Explain pyranometer with neat sketch.	10	L2	CO2
	b.	Explain pyrheliometer with neat sketch.	10	L2	CO2
		OR			
Q.4	a.	Explain PV system components and their functionalities.	10	L2	CO2
	b.	What are the design considerations for solar power plants.	10	L2	CO2
		Module – 3			
Q.5	a.	Explain horizontal wind energy power plant with diagram.	10	L3	CO3
	b.	Explain the parameters effecting the energy extraction through wind.	10	L2	CO1
		OR			
Q.6	a.	Explain with schematic diagram the working of a dry steam geothermal power plant.	10	L3	CO3
	b.	What are the problems associated with geothermal conversion.	10	L2	CO3
		Module – 4			
Q.7	a.	Explain different ways to extract energy through tides with neat diagram.	10	L3	CO4
	b.	Explain different ways to extract energy through waves with neat diagram.	10	L2	CO4
		OR			
Q.8	a.	Describe OTEC and working principle with neat sketch.	10	L2	CO4
	b.	What are the problems associated with OTEC.	10	L2	CO4
		Module – 5			
Q.9	a.	Explain fixed dome biogas power plant with diagram.	10	L2	CO5
	b.	Explain gasification with diagram.	10	L2	CO5
		OR			
Q.10	a.	Explain Hydrogen Production Technology (Electrolysis method).	10	L2	CO5
	b.	Describe advantages of hydrogen energy.	10	L2	CO5

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