**Part A 3 mark**

**1. Discuss primary and secondary energy sources. Describe future of nonconventional energy resources in India.**

- **Primary Energy Sources:** Found in nature and not converted or transformed (e.g., coal, crude oil, natural gas, solar radiation, wind).
- **Secondary Energy Sources:** Derived from the transformation of primary energy sources (e.g., electricity from coal, hydrogen from water).
- **Future of Non-conventional Energy Resources in India:**
    - **Significant Growth:** India is aggressively promoting renewables to meet its growing energy demand and reduce carbon emissions.
    - **Dominant Role:** Solar and wind energy are expected to play a dominant role in India's future energy mix.
    - **Policy Support:** Government policies like production-linked incentives and renewable purchase obligations will drive expansion.
    - **Energy Security:** Increased reliance on non-conventional sources will enhance India's energy security by reducing import dependence.

**2. What are the different types of solar cells? Write about any three types of solar cells.**

- **Different Types of Solar Cells:** Crystalline silicon (monocrystalline, polycrystalline), Thin-film (amorphous silicon, CdTe, CIGS), Perovskite, Dye-sensitized, Organic.
- **Monocrystalline Silicon Solar Cells:**
    - Made from a single crystal of silicon.
    - Highest efficiency (typically 15-22%).
    - Uniform dark appearance.
    - More expensive to produce.
- **Polycrystalline Silicon Solar Cells:**
    - Made from multiple silicon crystals.
    - Lower efficiency than monocrystalline (13-18%).
    - Bluish, speckled appearance.
    - Less expensive to produce.
- **Thin-Film Solar Cells (e.g., Amorphous Silicon - a-Si):**
    - Deposited in thin layers on a substrate.
    - Lower efficiency (6-12%) but flexible and lightweight.

- Perform better in low-light conditions.
- Less material intensive, potentially lower manufacturing cost.

**3. List out the factors influencing the demand of energy.**

- **Population Growth:** More people generally means higher energy consumption.
- **Economic Growth/Industrialization:** Increased industrial activity and a growing economy drive up energy demand.
- **Urbanization:** Urban areas typically have higher energy consumption per capita than rural areas.
- **Lifestyle Changes/Standard of Living:** Increased use of appliances, vehicles, and air conditioning in improving living standards boosts demand.
- **Energy Prices:** Higher prices can discourage consumption, while lower prices can stimulate it.

**4. What are the different components of the tidal power plant? Explain.**

- **Barrage/Dam:** A large wall or barrier constructed across a tidal estuary or bay to create a basin.
- **Sluice Gates:** Openings in the barrage that control the flow of water into and out of the basin.
- **Turbines:** Hydroelectric turbines (e.g., Kaplan turbines) installed within the barrage, driven by the flow of water.
- **Generators:** Connected to the turbines, they convert the mechanical energy of the rotating turbines into electrical energy.
- **Powerhouse:** Houses the turbines, generators, and control equipment.

**5. What do you understand by biomass gasification?**

- **Biomass Gasification:** A thermochemical process that converts solid biomass (e.g., wood chips, agricultural waste) into a combustible gas mixture called "syngas" or "producer gas."
- **Process:** Occurs at high temperatures (typically 700-1200°C) with a limited supply of oxygen or steam, preventing complete combustion.
- **Products:** Primarily carbon monoxide (CO), hydrogen ($H_2$), methane ($CH_4$), and carbon dioxide ($CO_2$).
- **Applications:** Syngas can be used for electricity generation in internal combustion engines or gas turbines, for heating, or as a chemical feedstock.
- **Advantages:** Reduces waste, can be carbon neutral, and provides a versatile fuel.

**6. Compare between the horizontal and vertical axis wind turbines.**

- **Horizontal Axis Wind Turbines (HAWTs):**
  - Most common type, resemble traditional windmills.
  - Rotor axis is parallel to the ground.
  - Require a yaw mechanism to orient towards the wind.
  - Generally more efficient and suitable for large-scale power generation.
  - Higher tower height to capture stronger winds.
- **Vertical Axis Wind Turbines (VAWTs):**
  - Rotor axis is perpendicular to the ground.
  - Omni-directional, do not need to yaw into the wind.
  - Can be installed closer to the ground, potentially less visual impact.
  - Lower efficiency compared to HAWTs for similar rotor swept areas.
  - Better suited for urban environments or distributed generation.

**7. What are the environmental impacts of wind energy?**

- **Wildlife Impact:** Potential for bird and bat collisions with turbine blades.
- **Habitat Disruption:** Construction of wind farms can lead to habitat loss or fragmentation.
- **Noise Pollution:** Mechanical noise from turbines can be an issue for nearby residents.
- **Visual Impact:** Large wind turbines can be considered an aesthetic intrusion on landscapes.
- **Land Use:** Wind farms require significant land area, especially for larger installations.

**8. What are the sources of biogas generation?**

- **Animal Manure:** Feces and urine from livestock (cattle, pigs, poultry).
- **Agricultural Residues:** Crop residues, straw, bagasse, fruit and vegetable waste.
- **Municipal Solid Waste (MSW):** Organic fraction of household and commercial waste.
- **Industrial Wastewater:** Organic wastewater from food processing, breweries, etc.
- **Sewage Sludge:** Sludge from wastewater treatment plants.

**9. What are the properties of hydrogen? Why it is considered as a secondary energy source?**

- **Properties of Hydrogen:**
  - **Lightest Element:** Extremely low density.
  - **High Energy Content (per unit mass):** Releases a significant amount of energy when combusted.
  - **Colorless, Odorless, Tasteless:** Non-toxic in its pure form.
  - **Highly Flammable:** Burns readily with oxygen, producing only water.
  - **Difficult to Store/Transport:** Requires high pressure or cryogenic temperatures.
- **Why it is a Secondary Energy Source:**
  - **Not Naturally Occurring:** Hydrogen does not exist freely in large quantities on Earth.
  - **Requires Energy to Produce:** It must be produced from other primary energy sources (e.g., water, natural gas) through processes like electrolysis or steam reforming.
  - **Energy Carrier:** It acts as an energy carrier, storing energy that was used to produce it, which can then be released when consumed.

**10. What are fuel cells? List out the applications of fuel cells.**

- **Fuel Cells:** Electrochemical devices that convert the chemical energy of a fuel (e.g., hydrogen) and an oxidant (e.g., oxygen) directly into electricity, water, and heat through a non-combustion process.
- **Key Feature:** Unlike batteries, they do not run down or need recharging; they continue to produce electricity as long as fuel and oxidant are supplied.
- **Applications of Fuel Cells:**
  - **Transportation:** Fuel cell electric vehicles (FCEVs), buses, forklifts.
  - **Stationary Power Generation:** Backup power for critical infrastructure, distributed generation, combined heat and power (CHP) systems.
  - **Portable Power:** Powering laptops, mobile phones, and other small electronic devices.
  - **Space Applications:** Used in spacecraft and space shuttles due to their high efficiency and water byproduct.
  - **Military Applications:** Silent power for soldiers in the field, drones, and submarines.

Part B

**11 a) What are solar collectors? Give their classification and compare them based on construction and area of applications. (10)**

- **Solar Collectors:** Devices designed to absorb solar radiation and convert it into thermal energy, which is then transferred to a fluid (like water or air).
- **Classification:**
  1. **Non-concentrating/Flat-plate collectors:** The collector area is the same as the receiver area. They absorb both direct and diffuse radiation.
  2. **Concentrating collectors:** Use reflective surfaces (mirrors or lenses) to focus sunlight onto a smaller receiver area. They primarily use direct radiation.
- **Comparison based on Construction and Applications:**

| Feature | Flat-Plate Collectors | Concentrating Collectors |
|---|---|---|
| **Construction** | Simple, insulated box with a transparent cover and absorber plate. No moving parts. | Complex, use mirrors or lenses to focus sunlight. Often require a tracking mechanism. |
| **Working Fluid** | Water, air, or a glycol mixture. | Often use specialized fluids with high boiling points (e.g., thermal oil, molten salt). |
| **Temperature Range** | Low to medium temperatures (up to 100°C for water, 60-80°C for air). | High temperatures (150°C to over 1000°C). |
| **Efficiency** | Lower efficiency at higher temperatures due to heat loss. | Higher efficiency at high temperatures because of the smaller receiver area and reduced heat loss. |
| **Area of Applications** | **Domestic hot water heating**, space heating, solar drying, swimming pool heating. | **Industrial process heat**, steam generation for power plants (e.g., Concentrated Solar Power - CSP), high-temperature applications. |

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**11 b) Write about any three types of solar cells based on construction materials. (4)**

- **Monocrystalline Silicon Solar Cells:**
  - Made from a single, high-purity silicon crystal ingot.
  - Dark, uniform appearance.

    - Highest efficiency (15-22%), but more expensive to manufacture.
- **Polycrystalline Silicon Solar Cells:**
    - Made from multiple, small silicon crystals melted together.
    - Speckled, bluish appearance.
    - Lower efficiency (13-18%) than monocrystalline, but are cheaper to produce.
- **Thin-Film Solar Cells:**
    - Constructed by depositing one or more thin layers of photovoltaic material onto a substrate.
    - Examples include amorphous silicon (a-Si), Cadmium Telluride (CdTe), and Copper Indium Gallium Selenide (CIGS).
    - Lower efficiency (6-12%), but are flexible, lightweight, and can be cheaper to produce.

**OR**

**12 a) Explain about stand-alone and grid-connected solar photovoltaic systems. (10)**

- **Stand-Alone Solar Photovoltaic (PV) Systems:**
    - **Definition:** These systems operate independently from the utility grid.
    - **Components:** Typically consist of solar panels, a charge controller, a battery bank for energy storage, and an inverter to convert DC power to AC power for appliances.
    - **Working:** The solar panels charge the batteries during the day. The stored energy in the batteries is used to power the loads at night or on cloudy days.
    - **Applications:** Remote homes, cabins, telecommunications towers, water pumps, and other off-grid applications where connecting to the utility grid is unfeasible or too expensive.
    - **Advantages:** Provide energy independence and are suitable for remote locations.
    - **Disadvantages:** Higher initial cost due to batteries, require maintenance of batteries, and are sensitive to weather conditions.
- **Grid-Connected Solar Photovoltaic (PV) Systems:**
    - **Definition:** These systems are tied to the public electricity grid.
    - **Components:** Consist of solar panels, an inverter (grid-tie inverter), and a meter. No batteries are typically required for energy storage.

- **Working:** The solar panels generate DC power, which is converted to AC power by the inverter. This electricity is used by the home or business. Any excess electricity is fed back into the grid, and the owner is credited for it (e.g., through net metering). When solar power is insufficient, electricity is drawn from the grid.
- **Applications:** Residential and commercial buildings in areas with a reliable electricity grid.
- **Advantages:** Lower initial cost as batteries are not needed, provides a reliable source of power, and allows for selling excess power back to the grid.
- **Disadvantages:** Dependent on the utility grid for operation and cannot provide power during a grid outage unless a specific backup system is included.

**12 b) Explain the voltage-current characteristics of a solar cell with neat sketch. (4)**

- **Explanation:**
  - The voltage-current (V-I) characteristic curve of a solar cell plots the relationship between the output current (I) and the output voltage (V) under specific illumination and temperature conditions.
  - **Open-Circuit Voltage (V_oc):** This is the maximum voltage a solar cell can produce. It occurs when no current is flowing (I=0) and the cell is under open-circuit conditions.
  - **Short-Circuit Current (I_sc):** This is the maximum current a solar cell can produce. It occurs when the voltage is zero (V=0) and the cell is under short-circuit conditions.
  - **Maximum Power Point (P_max):** The point on the curve where the product of voltage and current (P=VtimesI) is at its maximum. The ideal operating point of the solar cell is at or near this point.
  - **Fill Factor (FF):** A measure of the "squareness" of the curve, defined as the ratio of the maximum power to the product of V_oc and I_sc (FF=P_max/(V_octimesI_sc)). A higher fill factor indicates a more efficient cell.
- **Neat Sketch:**
  - The y-axis represents the current (I).
  - The x-axis represents the voltage (V).
  - The curve starts at the short-circuit current (I_sc) on the y-axis.
  - It ends at the open-circuit voltage (V_oc) on the x-axis.

- The rectangle formed by the axes and the line from V_oc to I_sc represents the theoretical maximum power.
- The point where a rectangle drawn from the origin to a point on the curve has the largest area is the maximum power point (P_max), with coordinates (V_m, I_m).

**13 a) Discuss the basic principle of OTEC. Describe a closed cycle OTEC with its advantages and disadvantages. (10)**

- **Basic Principle of OTEC:**
  - OTEC stands for Ocean Thermal Energy Conversion.
  - Its basic principle is to exploit the temperature difference between warm surface seawater and cold deep seawater.
  - This temperature gradient is used to drive a heat engine (like a Rankine cycle) to produce electricity.
  - The minimum temperature difference required for viable OTEC operation is typically around 20°C.
- **Closed Cycle OTEC:**
  - **Description:** This system uses a working fluid (like ammonia or a low-boiling-point refrigerant) that is continuously recycled in a closed loop.
  - **Working:**
    1. **Evaporator:** Warm surface seawater is pumped through a heat exchanger (evaporator), where it heats the working fluid, causing it to vaporize into a high-pressure gas.
    2. **Turbine:** The high-pressure vapor expands and drives a turbine connected to a generator, producing electricity.
    3. **Condenser:** After passing through the turbine, the low-pressure vapor enters a second heat exchanger (condenser). Cold seawater from the deep ocean is pumped through the condenser, cooling the vapor and causing it to condense back into a liquid.
    4. **Pump:** The liquid working fluid is then pumped back to the evaporator to repeat the cycle.
  - **Sketch:** *(Please imagine a diagram showing a closed loop with an evaporator on top, a turbine and generator in the middle, a condenser at the bottom, and pumps for both the working fluid and seawater.)*
- **Advantages of Closed Cycle OTEC:**

1. High overall thermal efficiency because the working fluid's properties are optimized for the cycle.
2. Less corrosion and biofouling of the turbine since seawater does not come into direct contact with it.
3. Can use smaller, more efficient turbines because of the high vapor density of the working fluid.
4. The system is not dependent on the seawater's vapor pressure, allowing for greater design flexibility.

- **Disadvantages of Closed Cycle OTEC:**
  1. Requires large heat exchangers, which are expensive and prone to corrosion and biofouling.
  2. The working fluid (e.g., ammonia) can be toxic or hazardous.
  3. The pumping of large volumes of water requires a significant amount of parasitic power, reducing net power output.
  4. The overall efficiency is low due to the small temperature difference, leading to a large physical plant for a given power output.

**13 b) What is biofouling? How it affects efficiency of energy conversion and how can it be minimised? (4)**

- **Biofouling:** The accumulation of microorganisms, algae, plants, and small animals on surfaces submerged in water. In OTEC, this primarily occurs on the surfaces of the heat exchangers.
- **Effect on Efficiency:**
  - Biofouling creates an insulating layer on the heat exchanger surfaces.
  - This layer significantly reduces the rate of heat transfer between the seawater and the working fluid.
  - The reduced heat transfer leads to a smaller temperature difference across the heat engine, thus decreasing its thermal efficiency and the overall power output of the plant.
- **Minimization:**
  - **Mechanical Cleaning:** Using brushes or other devices to physically scrape the surfaces.
  - **Chemical Treatment:** Injecting small amounts of chlorine or other biocides into the seawater to kill the organisms.

- **Special Coatings:** Applying anti-fouling coatings or using materials that are resistant to biological growth.
- **Acoustic or Ultraviolet (UV) Treatment:** Using sound waves or UV light to deter or kill fouling organisms.

**OR**

**14 a) What are the different classifications of tidal power plants. Explain the components and detailed working operation of double basin tidal power plant with neat sketch. (10)**

- **Classifications of Tidal Power Plants:**
    1. **Single Basin:** The most common type, uses a single basin separated from the sea by a barrage. Power is generated during ebb tide (water flowing out) or flood tide (water flowing in), or both.
    2. **Double Basin:** Uses two basins separated from each other and from the sea by barrages. This allows for continuous power generation.
    3. **Tidal Stream/Current:** Uses turbines placed in fast-flowing tidal currents, similar to underwater wind turbines.
- **Double Basin Tidal Power Plant:**
    - **Components:**
        1. **Main Barrage:** Separates the two basins from the sea.
        2. **Basin 1 (High Pool):** A large reservoir that is filled with water from the sea during high tide.
        3. **Basin 2 (Low Pool):** A second large reservoir that is emptied into the sea during low tide.
        4. **Barrage with Turbines and Sluice Gates:** Located between the two basins, housing the turbines and sluice gates.
        5. **Turbines and Generators:** Convert the potential energy of the water into electrical energy.
    - **Working Operation:**
        1. **Filling Basin 1:** During high tide, water is allowed to flow from the sea into Basin 1 (High Pool), raising its water level.
        2. **Emptying Basin 2:** Simultaneously, water from Basin 2 (Low Pool) is released into the sea during low tide, lowering its water level.

**15 a) What is meant by Betz's Limit? Derive the expression for the power extracted by a wind turbine. (8)**

- **Betz's Limit (or Betz's Law):**
  - It is the maximum possible efficiency for a wind turbine.
  - It states that no wind turbine can convert more than 16/27 (or approximately 59.3%) of the kinetic energy of the wind into mechanical energy.
  - This limit is derived from the principles of conservation of mass and momentum of the air passing through the turbine blades.
- **Derivation of Power Extracted by a Wind Turbine:**
  1. **Assumptions:** We assume an ideal, frictionless turbine operating in a steady, uniform wind flow. We consider a stream tube of air flowing through the rotor.
  2. **Mass Flow Rate (m˙):** The mass of air passing through the turbine per second is given by: m˙=ρAv where ρ is the density of air, A is the swept area of the rotor, and v is the wind velocity.
  3. **Kinetic Energy of Wind:** The kinetic energy of the wind is given by: KE=21m˙v2
  4. **Power in the Wind (Pwind):** Power is the rate of energy transfer. The power in the wind is the kinetic energy of the mass of air passing through the swept area per second. Pwind=21ρAv3
  5. **Power Extracted by Turbine (Pturbine):** The turbine extracts power by slowing down the wind. Let v1 be the wind speed before the turbine and v2 be the wind speed after the turbine. The power extracted is the difference in the kinetic energy of the air entering and leaving the rotor. Pturbine=21m˙(v12−v22)
  6. **Mass Flow Rate in Terms of Average Speed (v):** The mass flow rate through the rotor can be expressed using the average wind speed (v) at the rotor plane, which is the average of v1 and v2. v=(v1+v2)/2 m˙=ρAv=ρA2v1+v2
  7. **Substituting for Power:** Pturbine=21(ρA2v1+v2)(v12−v22) Pturbine=41ρA(v1+v2)(v1−v2)(v1+v2) Pturbine=41ρA(v12−v22)(v1+v2)
  8. **Power Coefficient (Cp):** To find the maximum power, we need to maximize this expression. The power coefficient is the ratio of extracted power to the total power in the wind. Cp=PwindPturbine=21ρAv1341ρA(v12−v22)(v1+v2) By maximizing this expression with respect to the ratio of v2/v1, it can be shown that the maximum occurs when v2=v1/3. This gives the maximum value of Cp as 16/27.

**15 b) What are the different types of generators used with wind turbines? (6)**

- **Synchronous Generators:**
  - Operate at a constant speed synchronized with the grid frequency.

- Used in older, fixed-speed wind turbines.
- Requires a gearbox to match the low turbine speed to the high generator speed.
- Can be directly connected to the grid but are not ideal for variable wind speeds.

- **Asynchronous (Induction) Generators:**
  - The most common type for wind turbines.
  - Simple, robust, and relatively inexpensive.
  - Can operate with some slip, allowing for a small variation in speed.
  - Can be doubly-fed induction generators (DFIGs), which allow for a wider speed range and better control of power output.
- **Direct Drive (Gearless) Generators:**
  - Directly connected to the turbine rotor without a gearbox.
  - Used in modern, large-scale wind turbines.
  - Typically multi-pole, synchronous, or permanent magnet generators.
  - Eliminates gearbox maintenance and losses, leading to higher efficiency and reliability.

**OR**

**16 a) Describe the construction of a three-bladed horizontal shaft wind turbine generator unit. Explain the terms yaw control and pitch control. (8)**

- **Construction of a Three-Bladed Horizontal Shaft Wind Turbine:**
  1. **Rotor:** Consists of three blades attached to a hub. The blades are designed aerodynamically to capture the maximum amount of wind energy.
  2. **Nacelle:** The main housing at the top of the tower. It contains the gearbox (if present), the generator, the control equipment, and the braking system.
  3. **Drive Train:** Connects the rotor to the generator. It typically includes a low-speed shaft from the hub, a gearbox to increase rotational speed, and a high-speed shaft connected to the generator.
  4. **Tower:** A tall structure (usually tubular steel or lattice) that supports the nacelle and rotor at a height where the wind is stronger and less turbulent.
  5. **Foundation:** Secures the tower to the ground, designed to withstand the forces of wind and vibration.
- **Yaw Control:**

- **Purpose:** To orient the rotor of the turbine to face the wind directly.
- **Mechanism:** A motor-driven system (yaw drive) is located in the nacelle, which rotates the entire nacelle on top of the tower.
- **Function:** A wind vane on the nacelle senses the wind direction. If the wind direction changes, the yaw control system activates to turn the nacelle so that the rotor is always perpendicular to the wind flow, maximizing power capture.

- **Pitch Control:**
  - **Purpose:** To adjust the angle (pitch) of the turbine blades to control the rotor speed and power output.
  - **Mechanism:** Each blade can be rotated on its axis. A hydraulic or electric motor mechanism is used to change the blade angle.
  - **Function:**
    - **Power Regulation:** At high wind speeds, the blades are pitched out of the wind to prevent the rotor from spinning too fast and to limit the power output to the rated capacity.
    - **Start-up:** At low wind speeds, the blades are pitched at an optimal angle to maximize power capture and help the rotor start spinning.
    - **Braking:** In an emergency or for maintenance, the blades are fully feathered (turned parallel to the wind flow) to stop the rotor completely.

**16 b) What are the advantages and disadvantages of a vertical axis wind turbine system? (6)**

- **Advantages of Vertical Axis Wind Turbine (VAWT) Systems:**
  1. **Omni-directional:** They can accept wind from any direction, so they do not require a yaw control mechanism. This simplifies the design and reduces cost.
  2. **Lower Center of Gravity:** The heavy generator and gearbox can be located at ground level, which simplifies maintenance and reduces the need for a strong tower.
  3. **Better for Urban Environments:** Their design can be less visually intrusive and they are less affected by turbulent winds often found in urban areas.
  4. **Lower Cut-in Speed:** They can often start generating power at lower wind speeds compared to HAWTs.
- **Disadvantages of Vertical Axis Wind Turbine (VAWT) Systems:**
  1. **Lower Efficiency:** Generally have a lower power coefficient (Cp) than HAWTs, making them less efficient at converting wind energy into electricity.

2. **Pulsating Torque:** The torque on the rotor varies during each rotation, which can lead to fatigue and reliability issues.
3. **Difficult to Mount:** The blades are mounted close to the ground where wind speeds are lower, which can limit energy capture.
4. **Self-starting Issues:** Some VAWT designs are not self-starting and require an external power source to begin rotation.

    3. **Power Generation:** A significant head (water level difference) is created between the two basins. Water is then allowed to flow from Basin 1 to Basin 2 through the turbines, generating power.
    4. **Continuous Operation:** This system can maintain a constant head and therefore generate power continuously, unlike single basin systems which are intermittent. The filling and emptying cycles of the two basins are staggered.

- **Sketch:** *(Please imagine a diagram showing the sea on the left, a barrage separating it from two basins. Basin 1 is connected to the sea with sluice gates at high tide. Basin 2 is connected to the sea with sluice gates at low tide. A second barrage with turbines and a generator is placed between Basin 1 and Basin 2.)*

**14 b) What are the limitations of the tidal power production? (4)**

- **High Initial Cost:** Construction of the barrage and other civil works is very expensive.
- **Geographical Constraints:** Only a few locations worldwide have the necessary high tidal ranges (typically >5m) for a viable tidal power plant.
- **Environmental Impact:** Barrages can disrupt the natural ecosystem of the estuary, affecting marine life, sediment flow, and water quality.
- **Intermittency (for Single Basin Plants):** Power generation is intermittent, occurring only during ebb or flood tides, and depends on the lunar cycle, which does not align with peak electricity demand.

**17 a) Describe the construction and working of a biogas plant, its material aspects, and utilization of plant products with a neat diagram. (10)**

- **Construction:** A typical biogas plant consists of the following components:
    1. **Digester:** A large, sealed, airtight tank (usually cylindrical or dome-shaped) where anaerobic digestion takes place. It's constructed from materials like concrete, brick, or steel.

2. **Inlet Chamber:** A small chamber where the feedstock (biomass) is mixed with water to form a slurry before being fed into the digester.
3. **Gas Holder/Dome:** A sealed space on top of the digester to collect the produced biogas. It can be a fixed dome (as part of the digester's concrete structure) or a movable, floating dome (made of steel).
4. **Outlet Chamber (Slurry Outlet):** A chamber where the spent slurry (digestate) overflows from the digester.
5. **Piping:** A network of pipes to connect the inlet, digester, outlet, and to transport the biogas to its point of utilization.

- **Working:**
  1. **Slurry Preparation:** Organic waste materials like cow dung, agricultural waste, and kitchen scraps are mixed with water in the inlet chamber to form a slurry.
  2. **Anaerobic Digestion:** The slurry is fed into the digester, which is a sealed, oxygen-free environment. Anaerobic bacteria (methanogens) present in the slurry break down the organic matter.
  3. **Biogas Production:** The bacteria convert the organic matter into biogas, a mixture of gases primarily composed of methane ($CH_4$) and carbon dioxide ($CO_2$).
  4. **Gas Collection:** The biogas, being lighter than the slurry, rises and collects in the gas holder at the top of the digester.
  5. **Slurry Outlet:** The digested slurry (digestate) overflows from the outlet chamber and is used as a rich organic fertilizer.
- **Material Aspects:**
  - **Digester:** Concrete, brick, or steel for durability and airtightness.
  - **Piping:** PVC or other corrosion-resistant materials for the slurry, and galvanized iron or HDPE pipes for the gas.
  - **Gas Holder:** Steel, fiberglass, or concrete.
  - **Valves and Fittings:** High-quality, corrosion-resistant materials to prevent gas leakage.
- **Utilization of Plant Products:**
  1. **Biogas:** Used as a clean cooking fuel, for lighting, and for running engines to generate electricity.

2. **Digestate (Slurry):** Used as a high-quality organic fertilizer for agricultural fields. It is rich in nitrogen, phosphorus, and potassium and improves soil health.

- **Neat Diagram:** *(Please imagine a diagram showing a cross-section of a biogas plant. It should include the inlet chamber, the digester tank, the gas dome/holder on top, and the outlet chamber for the slurry. Labels should be clear and arrows should indicate the flow of slurry and biogas.)*

**17 b) Explain the advantages and uses of biogas. (4)**

- **Advantages:**
  1. **Clean Fuel:** Biogas is a clean-burning fuel that produces less smoke and soot compared to traditional fuels like firewood or kerosene, improving indoor air quality.
  2. **Waste Management:** It provides an effective way to manage and dispose of organic waste, reducing pollution and the spread of pathogens.
  3. **Reduces Greenhouse Gas Emissions:** It prevents methane, a potent greenhouse gas, from escaping into the atmosphere from decomposing organic waste in landfills.
  4. **Organic Fertilizer:** The byproduct, digestate, is an excellent organic fertilizer, reducing the need for chemical fertilizers and improving soil fertility.
- **Uses:**
  1. **Cooking and Heating:** The primary use in rural and semi-urban areas.
  2. **Electricity Generation:** Can be used to power internal combustion engines connected to generators.
  3. **Lighting:** Used for gas lamps in areas without electricity.
  4. **Vehicle Fuel:** Can be purified and compressed to be used as a fuel for vehicles (Compressed Biogas - CBG).

**OR**

**18 a) What are the different types of biogas plants? Explain the construction, working of a fixed dome type biogas plant and floating dome type biogas plant. (10)**

- **Different Types of Biogas Plants:**
  1. **Fixed Dome Type:** Has a rigid, stationary dome for gas collection. The gas pressure increases as more gas is produced, pushing the slurry level down.
  2. **Floating Dome Type:** Has a movable, floating gas holder that rises and falls with the amount of gas collected, keeping the gas pressure constant.

3. **Bag Type:** Uses a flexible bag made of PVC or other polymer for both the digester and gas holder.

- **Fixed Dome Type Biogas Plant:**
  - **Construction:** The digester and gas holder are integrated into a single, rigid, underground structure, typically made of concrete or brick. The dome is part of the main structure. A separate inlet and outlet are provided.
  - **Working:**
    1. Slurry is fed into the digester.
    2. Biogas is produced and collects in the dome.
    3. As gas accumulates, the pressure inside the dome increases.
    4. This pressure pushes the slurry level down in the digester and up in the outlet chamber.
    5. The increased pressure is used to transport the biogas to the point of consumption.
    6. The slurry overflows from the outlet chamber when new slurry is added.
- **Floating Dome Type Biogas Plant:**
  - **Construction:** It has a separate cylindrical or rectangular digester tank and a movable, floating steel or fiberglass gas holder that sits on top of the slurry inside the digester. Guide pipes prevent the gas holder from tilting.
  - **Working:**
    1. Slurry is fed into the digester.
    2. Biogas is produced and collects inside the floating gas holder.
    3. The holder rises as gas accumulates, maintaining a constant pressure on the gas.
    4. The gas is then piped out from the top of the holder.
    5. The constant pressure ensures a steady supply of gas to the burner.
    6. The digested slurry overflows from a separate outlet.

**18 b) What are the factors affecting the selection of a particular model of a biogas plant? (4)**

- **Initial Investment Cost:** Fixed dome plants are generally cheaper to build than floating dome plants due to simpler construction and material requirements.

- **Available Space:** Fixed dome plants are often built underground, requiring less above-ground space. Floating dome plants require space for the gas holder to move up and down.
- **Maintenance Requirements:** Floating dome plants require more maintenance due to the moving parts (gas holder, guide pipes) and the risk of corrosion of the steel holder. Fixed dome plants are simpler and require less maintenance.
- **Gas Pressure and Stability:** Floating dome plants provide a constant gas pressure, which is beneficial for appliances. Fixed dome plants have a variable gas pressure, which might require a pressure regulator for some applications

**19 a) Explain about the components of a small hydroelectric power generation scheme with the help of a neat diagram. (8)**

- **Components of a Small Hydroelectric Scheme:**
    1. **Water Source:** A river, stream, or canal with a sufficient head (elevation difference) and flow rate.
    2. **Dam/Weir:** A small dam or weir is constructed across the water source to divert water and create a reservoir, ensuring a consistent supply and head.
    3. **Intake/Screen:** Located at the reservoir, the intake directs water into the power generation system. A screen or trash rack is placed at the intake to filter out debris and protect the turbine.
    4. **Penstock:** A pipeline that carries the water from the intake to the turbine. It must be strong enough to withstand the pressure of the water.
    5. **Turbine:** The heart of the system. The high-pressure water from the penstock strikes the turbine blades, causing them to rotate. Common types for small hydro include Francis, Pelton, and Turgo turbines.
    6. **Generator:** Connected to the turbine shaft, it converts the rotational mechanical energy into electrical energy.
    7. **Draft Tube:** A pipe that carries the water from the turbine outlet to the tailrace. It helps to recover some of the kinetic energy of the water, increasing efficiency.
    8. **Tailrace:** A channel that carries the water from the draft tube back to the river downstream.
    9. **Powerhouse:** The building that houses the turbine, generator, and control equipment.
- **Neat Diagram:** *(Please imagine a diagram showing a cross-section of a small hydro plant. It should include a small dam, an intake with a screen, a penstock sloping down*

*to a powerhouse, a turbine connected to a generator, and a tailrace leading back to the river. The head and flow of water should be indicated.)*

**19 b) Explain about any two methods of hydrogen production. (6)**

- **1. Steam Methane Reforming (SMR):**
  - **Description:** The most common and cost-effective method for producing hydrogen commercially. It uses natural gas (methane, $CH_4$) as the feedstock.
  - **Process:** High-temperature steam (700-1100°C) is reacted with methane in the presence of a catalyst to produce synthesis gas, a mixture of hydrogen ($H_2$), carbon monoxide (CO), and a small amount of carbon dioxide ($CO_2$).
  - **Chemical Reaction:** $CH_4 + H_2O$ (+ heat) $\rightarrow CO + 3H_2$
  - **Purification:** The CO is then reacted with more steam in a water-gas shift reaction to produce more hydrogen and carbon dioxide. The hydrogen is then purified for use.
  - **Drawback:** This process produces significant amounts of carbon dioxide, making it a "gray hydrogen" method.
- **2. Electrolysis:**
  - **Description:** A clean method for producing hydrogen from water, especially when powered by renewable electricity.
  - **Process:** An electric current is passed through water ($H_2O$), splitting it into its constituent elements, hydrogen ($H_2$) and oxygen ($O_2$).
  - **Chemical Reaction:** $2H_2O$ (+ electricity) $\rightarrow 2H_2 + O_2$
  - **Components:** The system consists of an electrolyzer with two electrodes (an anode and a cathode) separated by an electrolyte. Hydrogen is produced at the cathode, and oxygen is produced at the anode.
  - **Advantage:** If the electricity comes from renewable sources like solar or wind, this process is carbon-free, producing "green hydrogen."
  - **Disadvantage:** It is currently a more expensive method compared to SMR.

**OR**

**20 a) Explain the working of a $H_2-O_2$ fuel cell and also write the advantages and disadvantages of a fuel cell. (8)**

- **Working of a $H_2-O_2$ Fuel Cell:**
  1. **Anode:** Hydrogen gas ($H_2$) is supplied to the anode, which is a porous electrode coated with a catalyst (usually platinum). The catalyst splits the hydrogen molecules into protons ($H^+$) and electrons ($e^-$).

- **Reaction:** $H_2 \rightarrow 2H^+ + 2e^-$

2. **Electrolyte:** The protons pass through the electrolyte (a proton-exchange membrane or PEM) to the cathode. The electrolyte is an ion-conductor but an electrical insulator, preventing the electrons from passing through.
3. **External Circuit:** The electrons are forced to travel through an external circuit, creating an electric current that can power a load.
4. **Cathode:** Oxygen gas ($O_2$) is supplied to the cathode. Here, the electrons from the external circuit and the protons from the anode combine with the oxygen to form water ($H_2O$) and heat.
   - **Reaction:** $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
5. **Overall Reaction:** The net reaction is the combination of hydrogen and oxygen to produce water, with electricity and heat as byproducts.
   - **Reaction:** $2H_2 + O_2 \rightarrow 2H_2O$

- **Advantages of Fuel Cells:**
  1. **High Efficiency:** They convert chemical energy directly into electrical energy, bypassing the Carnot cycle limitations of heat engines, leading to higher efficiency.
  2. **Environmentally Friendly:** When using hydrogen as a fuel, the only byproduct is water, making them a zero-emission technology at the point of use.
  3. **Scalable and Modular:** They can be built in various sizes to meet different power needs, from small portable devices to large power plants.
  4. **Quiet Operation:** They have no moving parts (apart from pumps and fans), resulting in silent operation.
  5. **No Recharge Time:** They can be refueled instantly, unlike batteries that require hours to recharge.
- **Disadvantages of Fuel Cells:**
  1. **High Cost:** The catalysts (e.g., platinum) and construction materials are expensive.
  2. **Hydrogen Storage:** Storing and transporting hydrogen safely and efficiently is a major challenge due to its low density.
  3. **Fuel Source:** The production of hydrogen is often reliant on fossil fuels (SMR), which offsets the environmental benefits.
  4. **Durability:** The lifespan and reliability of fuel cells are still a concern for widespread adoption.

**20 b) What are the advantages and applications of hydrogen energy? (6)**

- **Advantages of Hydrogen Energy:**
    1. **Clean Combustion:** When hydrogen is burned, it produces only water, with no carbon dioxide or other greenhouse gases.
    2. **High Energy Density (by mass):** Hydrogen has the highest energy content per unit of mass of any fuel.
    3. **Versatility:** It can be used as a fuel in fuel cells to generate electricity, burned directly for heat, or used as a chemical feedstock in industrial processes.
    4. **Storage of Renewable Energy:** Hydrogen can be produced via electrolysis using excess renewable electricity (e.g., from solar or wind farms), effectively storing this energy for later use.
    5. **Reduces Dependence on Fossil Fuels:** Widespread adoption could decrease reliance on traditional fossil fuels.
- **Applications of Hydrogen Energy:**
    1. **Transportation:** Fueling hydrogen fuel cell vehicles (FCEVs), buses, trains, and even ships and aircraft.
    2. **Stationary Power:** Used in fuel cells to provide backup power for critical facilities, or for combined heat and power (CHP) systems in buildings.
    3. **Industrial Feedstock:** A crucial component in the production of ammonia for fertilizers and in various chemical processes.
    4. **Space Technology:** Used as a rocket fuel due to its high energy density.
    5. **Energy Storage:** As a medium to store excess electricity from renewable sources, enabling the grid to become more stable.