GUJARAT TECHNOLOGICAL UNIVERSITY

BE-4 SEMESTER – S22 TO W25 – QUESTION BANK SOLUTION

Subject Name & Code:

ENVIRONMENTAL SCIENCE, SUSTAINABILITY AND RENEWABLE ENERGY- BE04000101

Note on Question Sources: This question bank is compiled from old GTU subjects (3110007 Environmental Sciences & 3161914 Renewable Energy Engineering) and the ESSRE list. Since the new syllabus (BE04000101) started in 2024-25, no direct previous papers exist. These questions are the **best available match** to the new syllabus topics and sub-topics.

Unit 4 – Renewable Energy

Q. Explain the need for renewable energy. (3 marks – appeared W25, W22)
Ans:

- **Fossil fuel depletion:** Coal, oil, gas are finite → will exhaust within 50-200 years.
- **Climate change:** Fossil fuels emit CO_2, CH_4, N_2O → global warming.
- **Energy security:** Reduces import dependence (India imports ~85% oil, ~50% gas).
- **Environmental pollution:** No air/water pollution from RE (except some lifecycle impacts).
- **Sustainability:** RE is inexhaustible & available everywhere.

Example: India targets 500 GW non-fossil capacity by 2030.

Q. Explain advantages and limitations of renewable energy. (4 marks – appeared W25, S24, S25)
Ans:

Advantages	Limitations
Inexhaustible & free after installation	Intermittent (solar: night, wind: calm days)
No fuel cost, low operating cost	High initial capital cost
Low to zero operational emissions	Land requirement large for solar/wind farms
Decentralized – can be installed at remote sites	Energy storage needed (batteries)
Creates local jobs	Low energy density (needs large area per MW)

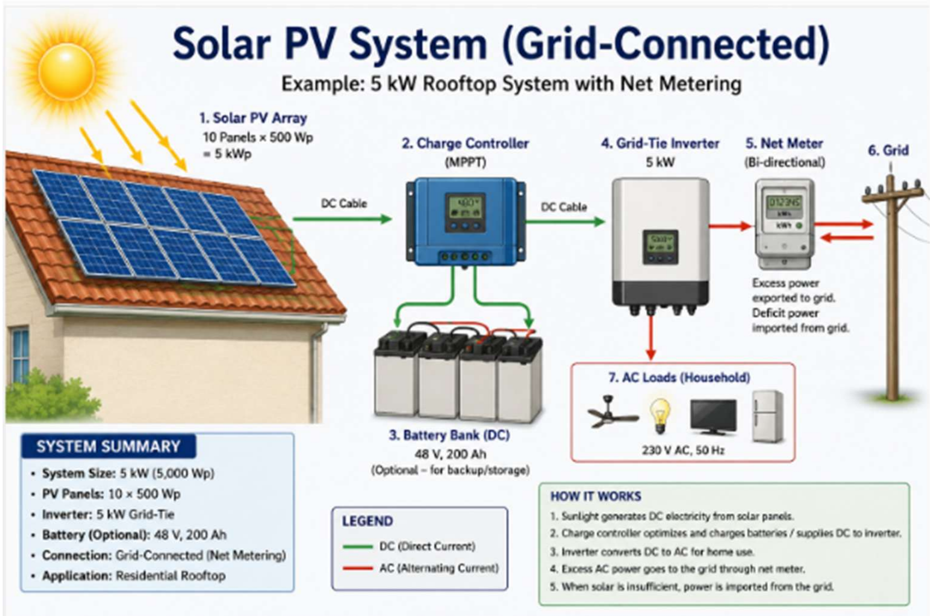
Example: A solar plant generates no pollution but produces only during daytime; batteries add 30% cost.

Q. Explain photovoltaic system / solar cell working / types. (7 marks – appeared W25, W23, S24, S25, S22)
Ans:
Working principle:

- Solar cell is a p-n junction diode (typically silicon).
- Photons with energy > bandgap excite electrons from valence to conduction band.

- Built-in electric field separates electrons (to n-side) and holes (to p-side) → generates voltage & current.

Diagram:



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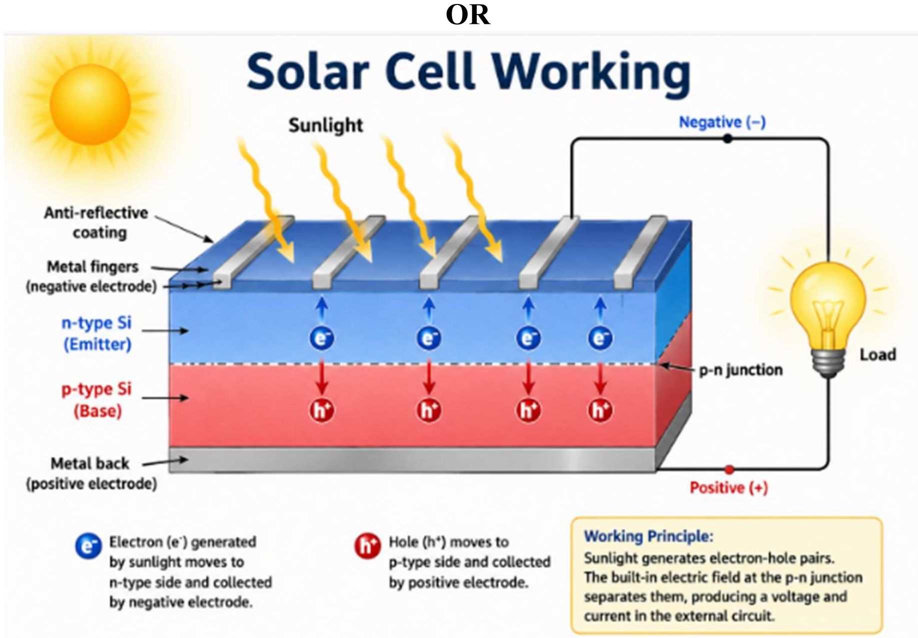


Types of solar cells:

Type	Efficiency	Cost	Applications
Monocrystalline Si	18-22%	High	Rooftops, space
Polycrystalline Si	15-18%	Medium	Utility solar farms
Thin-film (CdTe, CIGS)	10-13%	Low	Building-integrated, portable

Type	Efficiency	Cost	Applications
Perovskite (emerging)	25%+ (lab)	Very low	Future tech

Real-world: India's Bhadla Solar Park uses polycrystalline panels – 2,245 MW.

Q. Explain solar cooker and methods to improve performance. (7 marks – appeared W25, S25, W22) ***BUT syllabus says "principles" – optional, still provided***
Ans:
Working principle: Box-type solar cooker:

- Black absorbing tray inside double-glazed box with reflectors.
- Sunlight enters, gets trapped (greenhouse effect), temperature reaches 100-140°C.

Methods to improve performance:

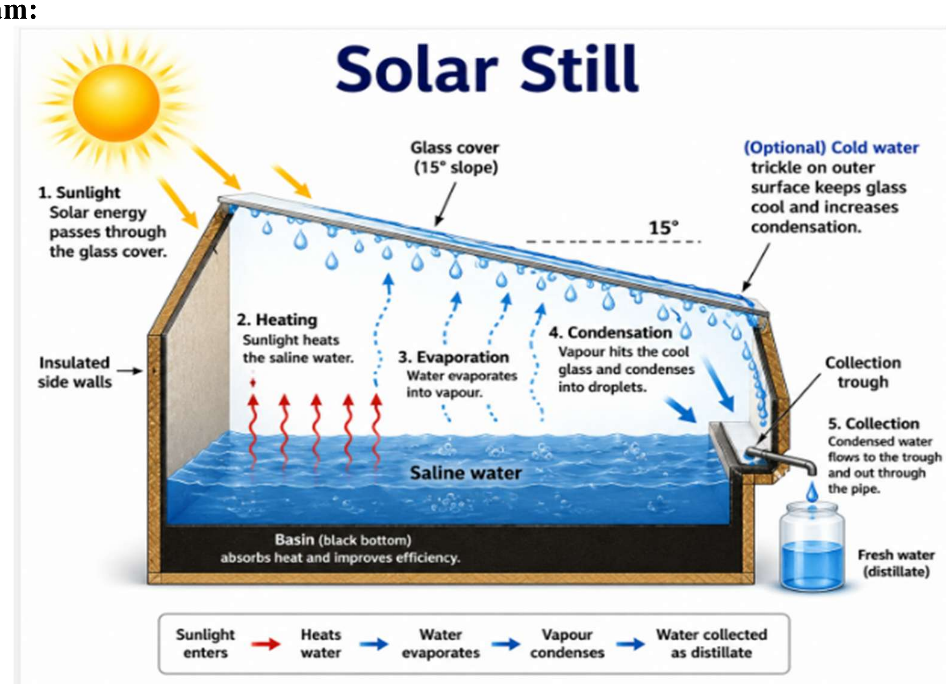
1. Use reflectors (mirror/aluminium foil) to concentrate more sunlight.
2. Double glass cover reduces heat loss.
3. Black paint with high absorptivity.
4. Insulation (glass wool) around sides and bottom.
5. Cook during 10 am – 2 pm.
6. Use pressure cooker inside to achieve higher temperature.

Example: A solar cooker can save 3-4 LPG cylinders per household per year.

Q. Explain solar still with sketch. (4 marks – appeared W25, W24, S23)
Ans:
Working principle:

- Basin with saline water, covered by transparent sloping glass.
- Solar radiation heats water → evaporation.
- Water vapour condenses on cool glass surface → droplets slide down into collection trough.
- Fresh water collected, brine remains in basin.

Diagram:



Application: Remote coastal/villages for drinking water.

Q. Explain basics of lift and drag in wind turbines. (4 marks – appeared W23, S23, S22)
Ans:

- **Lift:** Perpendicular force to the wind direction, caused by pressure difference over aerofoil (longer curved upper surface → lower pressure). Used by modern horizontal-axis turbines to spin blades.
- **Drag:** Force parallel to wind direction, opposes motion. Older windmills used drag (cup anemometers).

Formula: Lift = ½ ρ V^2 A C_L, Drag = ½ ρ V^2 A C_D
Example: Modern turbine blades are aerofoils – high lift-to-drag ratio (CL/CD ≈ 50-100).

Q. Explain horizontal axis vs vertical axis wind turbines. (4 marks – appeared W24, S23)
Ans:

Feature	Horizontal Axis (HAWT)	Vertical Axis (VAWT)
Orientation	Axis parallel to ground	Axis perpendicular to ground
Blades	3-blade most common (upwind)	Darrieus (eggbeater) or Savonius (S-shaped)
Efficiency	40-50%	30-40%
Yaw mechanism	Required	Not required (any wind direction)
Location of generator	On top of tower	At ground level (easy maintenance)
Self-starting	No (needs starter)	Savonius yes, Darrieus no
Typical use	Utility-scale farms	Urban, rooftop, small-scale

Q. What is biomass energy? (3 marks – appeared W25)
Ans:

- Biomass energy is energy derived from organic matter (plants, animal waste, agricultural residue, wood, municipal solid waste).
- Converted via combustion, gasification, anaerobic digestion, or pyrolysis.
- **Example:** Burning rice husk in a boiler to produce steam → electricity.
- **Note:** Carbon-neutral if biomass regrown.

Q. Explain types of biogas plants / floating drum biogas plant. (7 marks – appeared W24, W23, S22, W25)
Ans:
Floating drum type (KVIC model):

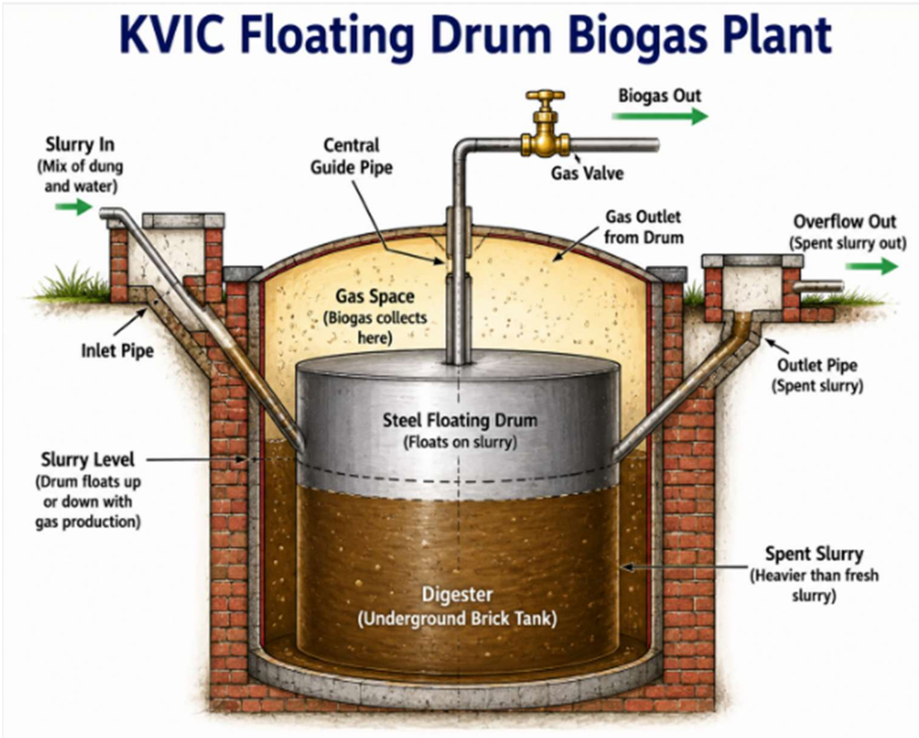
- **Construction:**
  - Underground brick masonry digester (dome-shaped bottom).
  - Inlet pipe for slurry (cow dung + water) and outlet pipe for spent slurry.

- Mild steel drum (gas holder) inverted & floating in digester.
- **Working:**
  - Slurry ferments anaerobically (20-55°C) → biogas (60% CH_4, 40% CO_2) rises.
  - Gas collects in drum, drum rises. As gas is used, drum sinks.
  - Gas pipe from drum to kitchen.

Other types:

- Fixed dome (Deenbandhu) – cheaper, no moving parts.
- Bag type – for small households.

Diagram:



Example: India has 5 million+ family-size biogas plants.

Q. Explain factors affecting biogas generation. (7 marks – appeared W25, S24, S23)
Ans:

Factor	Effect	Optimum range
Temperature	Higher temp → faster microbial activity	35-55°C (mesophilic/thermophilic)
pH	Acidic inhibits methanogens	6.5-7.5
C/N ratio	Too high C → slow, too low N → ammonia toxicity	20-30:1
Retention time	Time for digestion	30-50 days
Loading rate	Too high → acid accumulation	2-4 kg VS/m³/day

Factor	Effect	Optimum range
Mixing	Uniform temperature & substrate	Intermittent stirring
Inhibitors	Antibiotics, detergents, heavy metals	Zero

Example: In cold Himalayan regions, biogas production drops 50% in winter without heating.

Q. Explain vapor dominated vs liquid dominated geothermal plants. (4 marks – appeared W24, S24)
Ans:

Feature	Vapor dominated	Liquid dominated
Resource	Dry steam (superheated)	Hot water + steam mix
Temperature	>200°C	150-300°C
Plant type	Direct steam to turbine	Flash steam / binary cycle
Efficiency	High (~80% of thermal)	Moderate (15-25%)
Example	Geysers, California	Most plants worldwide, e.g., Philippines

Working (vapor dominated): Steam directly from well → removes impurities → turbine → generator → condenser → reinjection.
Example (liquid dominated): Hot water under pressure flashed to steam in low-pressure tank → steam drives turbine.

Q. Explain advantages and applications of geothermal energy. (7 marks – appeared W23, S23)
Ans:
Advantages:

- Baseload power – operates 24/7, not intermittent.
- Very low emissions (only trace gases).
- Small land footprint (1-2 acres per MW).
- High capacity factor (>90%).

Limitations:

- Only available at tectonic plate boundaries (e.g., Himalayas, Andaman in India).
- Drilling cost high, risk of induced seismicity.
- H_2S gas release possible.

Applications:

1. Electricity generation (binary, flash, dry steam).
2. Direct use: space heating, greenhouse heating, fish farming (aquaculture), food dehydration.
3. Geothermal heat pumps (GHP) for buildings – any location.

Example: Puga Valley (Ladakh) – India's first geothermal power plant under development (1 MWe pilot).

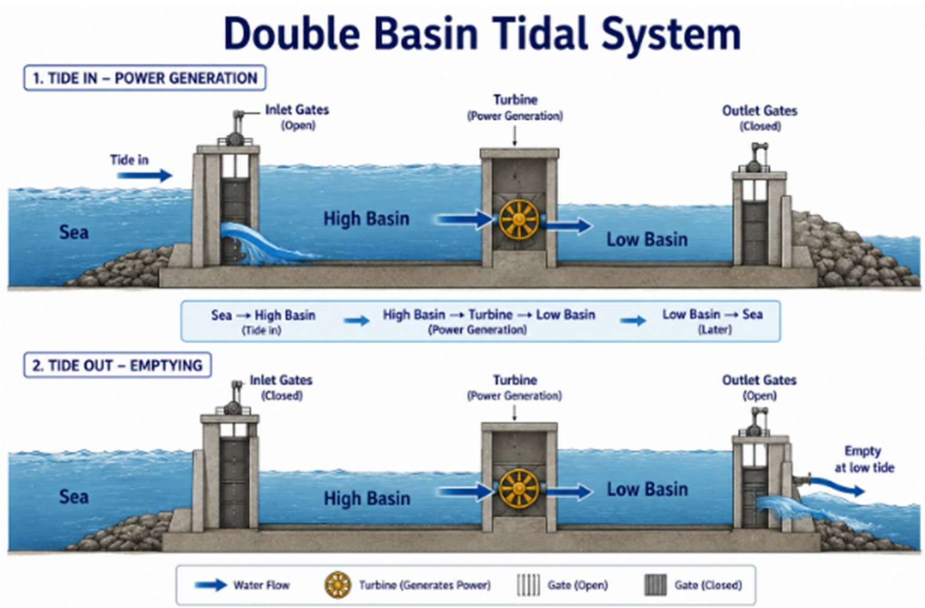
Q. Explain tidal power generation methods – single/double basin systems. (7 marks – appeared W23, S22, S25, W24)
Ans:
Tidal barrage principle: Store water during high tide, release through turbine during low tide (or vice versa).
Single basin system:

- **Ebb generation (most common):** Basin fills at high tide (sluices open), close gates, water held until low tide, then released through turbines.
- **Flood generation:** Fill basin at low tide via pumps, then release at high tide – less efficient.

Double basin system:

- Two basins – one high, one low.
- Turbine connects both basins. High basin always kept higher than low basin.
- Power generated continuously (unlike single basin which produces intermittently).

Diagram:



Example: La Rance (France) – single basin, 240 MW.

Excel File Questions – Unit 4
Q. List different types of renewable energy sources. (3 marks)
Ans:

1. Solar energy
2. Wind energy
3. Hydropower (including small hydro)
4. Biomass & Bioenergy (biogas, bioethanol, biodiesel)
5. Geothermal energy
6. Tidal & Wave energy
7. Green hydrogen (from renewable electricity)

Q. Define green hydrogen. (3 marks)
Ans:
Green hydrogen is hydrogen gas produced by **electrolysis of water** using electricity from **renewable sources** (solar, wind, hydro). No CO_2 emissions during production.

Comparison:

- Grey H_2: from natural gas (steam methane reforming) – emits CO_2.
- Blue H_2: grey + carbon capture & storage.
- Green H_2: zero emission.

Example: India's National Green Hydrogen Mission targets 5 MMT production by 2030.

Q. Describe the limitations of conventional energy sources. (3 marks)
Ans:

- **Finite reserves** (coal, oil, gas will deplete).
- **Environmental pollution** (air, water, land from mining & combustion).
- **Climate change** (CO_2 emissions).
- **Geopolitical dependence** (imported oil/gas).
- **Health impacts** (miners' silicosis, respiratory diseases from smog).

Example: Coal power plants emit SO_2 causing acid rain & PM2.5 causing asthma.

Q. Explain the need for renewable energy in sustainable development. (3 marks)
Ans:

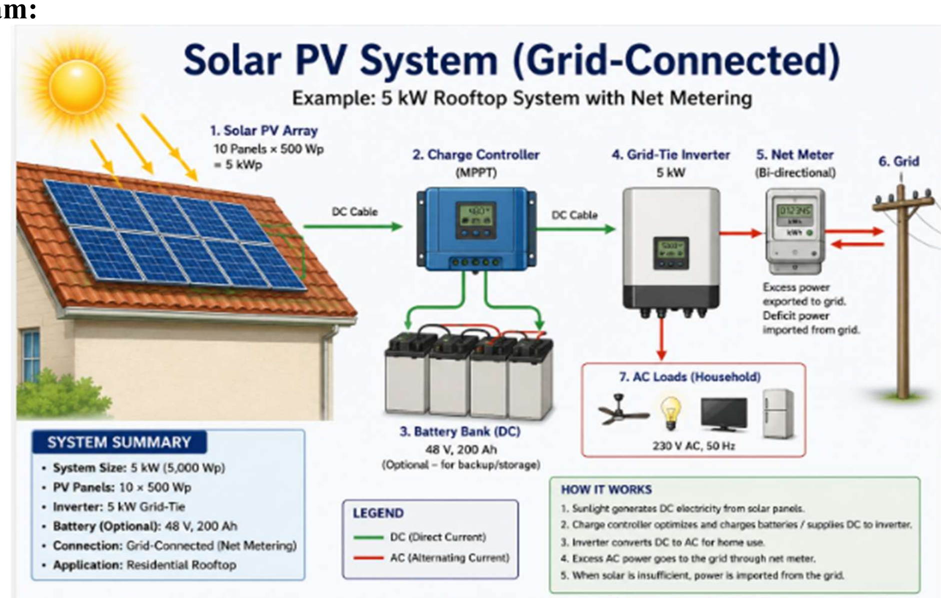
- Sustainable development balances **economic growth, social equity, environmental protection**.
- Renewable energy:
  - Decouples growth from fossil fuel depletion (economic).
  - Provides energy access to remote villages (social).
  - Eliminates air/water pollution & CO_2 (environmental).

Example: Solar microgrids in Odisha tribal areas – replaced kerosene, improved health & education.

Q. Demonstrate the working principle of solar photovoltaic systems. (4 marks)
Ans:

- Solar PV modules → produce DC electricity.
- Inverter converts DC to AC.
- AC powers loads or feeds grid.
- Optional battery storage for night use.

Diagram:

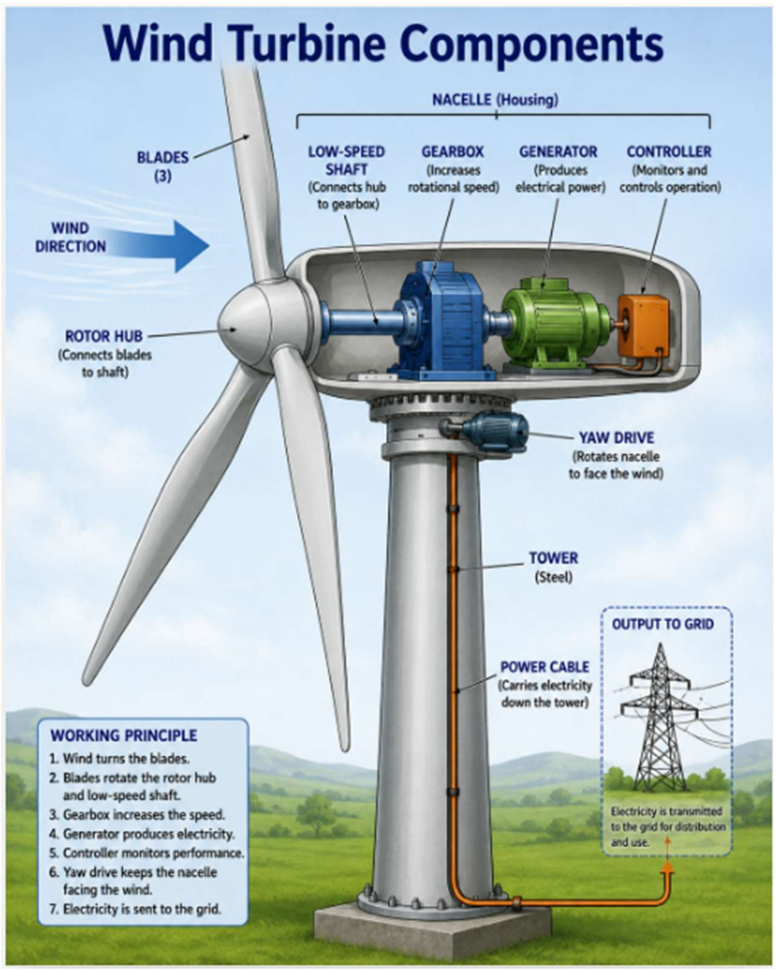


Example: A 5 kW rooftop system with 10 panels, inverter, net metering.

Q. Explain the process of wind energy generation with a diagram. (4 marks)
Ans:

- Wind turns rotor blades (aerofoil lift principle).
- Rotor connected to low-speed shaft → gearbox → high-speed shaft → generator → electricity.
- Tower holds rotor at height (higher wind speed).
- Yaw motor turns nacelle to face wind.

Diagram:



Example: Suzlon S144 – 3 MW, rotor diameter 144 m, hub height 140 m.

Q. Compare conventional energy sources with renewable energy sources in terms of efficiency and environmental impact. (4 marks)
Ans:

Parameter	Conventional (coal, diesel)	Renewable (solar, wind)
Efficiency (plant)	30-45% (coal), 35-45% (gas)	Solar PV 15-22%, Wind 40-50%, Hydro 90%
Environmental	High – air/water pollution,	Low – land use, manufacturing

Parameter	Conventional (coal, diesel)	Renewable (solar, wind)
impact	mining, CO_2	footprint only
Waste	Fly ash, toxic sludge	Panels/turbines recyclable (emerging)
Water use	Very high (cooling)	Negligible (except CSP)

Conclusion: RE has lower environmental impact but lower efficiency (except hydro).

Q. Analyze the environmental impacts of geothermal energy. (4 marks)
Ans:
Positive impacts:

- Minimal land footprint, no fuel transport, very low emissions (1/50th of coal).

Negative impacts:

- **H_2S release** – toxic, rotten egg smell.
- **Induced seismicity** – micro-earthquakes from fluid injection (e.g., Pohang, South Korea).
- **Ground subsidence** – if fluid not reinjected.
- **Noise** during drilling.
- **Thermal pollution** in discharge water (if not treated).

Example: The Geysers (USA) – H_2S scrubbers installed to reduce emissions.

Q. Compare hydropower and biomass energy in terms of efficiency. (4 marks – Analyze)
Ans:

Parameter	Hydropower	Biomass Energy
Electrical efficiency (large scale)	85–95% (modern turbines)	20–40% (direct combustion), 35–45% (gasification), 40–55% (co-firing with coal)
Overall energy conversion efficiency	Very high – water's potential energy → mechanical → electrical with minimal losses	Lower – chemical energy (biomass) → heat → steam → mechanical → electrical
Capacity factor	35–50% (depends on water availability)	60–85% (can run 24/7 if fuel supplied)
Losses	Friction in penstock, turbine, generator	Drying losses, combustion losses, heat losses
Example efficiency value	90% for a well-designed Francis turbine	30% for a typical rice husk-fired power plant

Conclusion: Hydropower is far more efficient in converting available energy to electricity. Biomass has lower efficiency but provides dispatchable power (not intermittent).
Real-world example: Bhakra Dam (hydropower, 90% efficient) vs. a 10 MW biomass plant in Punjab using paddy straw (≈32% efficient).

Q. Justify the role of wind and hydropower in India's energy mix. (7 marks – Evaluate)
Ans:
1. Current contribution (as of 2024):
- Wind power: ~45 GW (≈10% of total installed capacity)
- Hydropower: ~47 GW (≈11% of total capacity) + ~5 GW small hydro

2. Justification for wind power:
- **Seasonal complementarity:** Wind speeds high during monsoon (June–Sept) and summer – different from solar.
- **Mature technology:** LCOE ₹2.5–3.0/kWh – cheaper than new coal.
- **Large potential:** India has 700 GW potential at 100 m hub height (onshore).
- **States leading:** Tamil Nadu, Gujarat, Karnataka – coastal & plateau regions.

3. Justification for hydropower:
- **Grid stability:** Hydro plants can ramp up/down quickly (black start capability, frequency regulation).
- **Storage:** Pumped hydro storage (PHS) – essential for integrating solar/wind (e.g., Tehri PHS 1 GW).
- **Multi-purpose:** Irrigation, flood control, drinking water.
- **Low emissions:** 40× less CO_2 than coal per kWh.

4. Synergy in India's energy mix:
- Solar peaks during day; wind peaks evening/night in some regions; hydro acts as a battery.
- **Example (real-world):** In Karnataka, wind (5 GW) + hydro (3.5 GW) + solar (7 GW) together meet 70% of daytime demand during monsoon.

5. Limitations acknowledged:
- Wind: variable, land acquisition issues, bird/bat impact.
- Hydro: displacement, seismic concerns, siltation (e.g., dams in Himalayas).

Justification statement: Without wind and hydropower, India's renewable target of 500 GW by 2030 would be impossible – hydro provides storage & flexibility, wind provides low-cost evening generation complementing solar.

Q. Justify the role of renewable energy in India's energy security. (7 marks – Evaluate)
Ans:
1. Definition of energy security: Reliable, affordable, and uninterrupted availability of energy at reasonable prices.
2. India's current vulnerability:
- Imports 85% of crude oil, 50% of natural gas, 30% of coal.
- Forex outflow > $150 billion annually.
- Geopolitical risks (Russia-Ukraine war → oil price spikes).

3. How renewable energy enhances security:

Aspect	Role of RE
Reduces import dependence	Solar, wind, hydro use indigenous resources. Every 1 GW solar saves ₹500 crore of coal imports/year.
Decentralized generation	Remote villages can have microgrids – reduces transmission losses & vulnerability.
Fuel diversity	Solar (day), wind (evening/seasonal), hydro (dispatchable), biomass (rural)

Aspect	Role of RE
	– not a single point of failure.
Price stability	RE has zero fuel cost – once installed, price is fixed for 25 years. Immune to global price shocks.
Strategic advantage	During conflicts, fossil fuel supply lines can be disrupted; RE plants are distributed and harder to target.

4. Real-world evidence:

- **2022 coal crisis:** India faced power cuts due to coal shortage; states with high RE (Gujarat, Karnataka) managed better.
- **Solar pumps for agriculture:** Over 2.5 lakh solar pumps installed – reduce diesel dependence and grid load.

5. Future potential:

- Green hydrogen can replace imported ammonia (fertilizers) and natural gas.
- Offshore wind (Gujarat, Tamil Nadu) – 70 GW potential.

Justification statement: RE is not just an environmental choice – it is a strategic necessity for India's energy security, reducing import bills, stabilizing prices, and providing resilient infrastructure.

Q. Assess the potential of tidal energy in coastal regions of India. (7 marks – Evaluate)
Ans:
1. What is tidal energy? – Energy from rising/falling sea levels (tidal range) or tidal currents.
2. India's coastline & tidal range:

- Total coastline ≈ 7,500 km.
- Average tidal range: West coast (Gujarat, Maharashtra) – 3–6 m; East coast (Tamil Nadu, Odisha) – 1–3 m. Minimal in Kerala/Goa.

3. Identified potential sites (India):

Location	Tidal range	Estimated potential	Feasibility
Gulf of Kutch (Gujarat)	5–7 m	~300 MW	High – narrow gulf, can be barraged
Gulf of Khambhat (Gujarat)	6–8 m	~1,200 MW	Medium – high siltation
Sunderbans (WB)	3–5 m	~100 MW	Low – ecologically sensitive (mangroves)
Palk Bay (TN)	2–3 m	<50 MW	Low range – not economical

4. Technical & economic challenges:

- **High capital cost:** ₹25–30 crore/MW – 3× more than solar/wind.
- **Siltation:** Gulf of Khambhat has high sediment load – maintenance difficult.
- **Environmental impact:** Tidal barrage alters estuary ecology, affects fish migration.

- **Transmission:** Potential sites are far from load centers (except near Jamnagar, Gujarat).

5. Comparison with global success:

- La Rance (France, 240 MW) – built 1966, still working.
- Sihwa Lake (S. Korea, 254 MW) – successful.
- India's only pilot: 3.75 MW at Kachchh (GoG) – shelved due to cost.

6. Assessment:

- **Technically feasible** in Gulf of Kutch only (≈300 MW).
- **Economically not viable** under current costs – solar/wind cheaper (₹3-4 crore/MW).
- **Future scope:** Tidal current turbines (without barrage) are less environmentally damaging; India can test pilot in Gulf of Kutch.

Conclusion: Tidal energy potential in India is limited (<2 GW), high cost, and site-specific. It should not be a priority but can be developed as a niche baseload source in Gujarat.

Q. Develop a case study on the potential of green hydrogen as a future energy carrier in India. (7 marks – Create)

Ans:

Case Study Title: *Green Hydrogen Adoption for Fertilizer & Steel Sectors in India – A 2030 Roadmap*

1. Background:

India's National Green Hydrogen Mission (2023) targets **5 million metric tonnes (MMT) green hydrogen production by 2030**, with ₹19,744 crore investment. Current hydrogen demand (grey) ≈ 6 MMT, mainly for **fertilizers (ammonia) + refineries + steel**.

2. Why green hydrogen?

- Replace imported ammonia (currently 30% imported).
- Decarbonize hard-to-abate sectors: steel, heavy transport, shipping.
- Use India's abundant cheap solar & wind (LCOE ₹2.5-3.0/kWh) for electrolysis.

3. Proposed location & resource:

- **Region:** Gujarat (Kutch, Jamnagar) – high solar radiation + strong wind + port access.
- **Electrolyzer:** 1 GW alkaline/PEM electrolyzer (800 MW for hydrogen).
- **Renewable power:** 2.5 GW dedicated solar+wind farm (capacity factor 35%).

4. Production estimate:

- 1 GW electrolyzer → 4.5 tonnes H_2/hour at full load → ≈ 40,000 tonnes/year (assuming 4000 hours operation).
- For 5 MMT national target: need ~125 GW electrolysis capacity + 350 GW RE.

5. Cost analysis (current vs 2030 target):

Parameter	2024	2030 (target)
Electrolyzer capex	₹5-6 crore/MW	₹2-2.5 crore/MW
RE electricity cost	₹2.5-3.0/kWh	₹1.5-2.0/kWh
Green H_2 cost	₹350-400/kg	₹160-200/kg
Grey H_2 cost	₹150-180/kg (but rising)	Same (plus carbon tax)

6. Applications:

- **Fertilizers:** RIL's Jamnagar complex to use green ammonia by 2027.
- **Steel:** ArcelorMittal & Nippon Steel to use hydrogen in direct reduced iron (DRI)

plant.

- **Transport:** Hydrogen trucks for heavy freight (Delhi-Mumbai corridor).

7. Infrastructure needs:

- Hydrogen pipelines (limited), ammonia cracking, hydrogen refueling stations.
- Storage: underground salt caverns (likely in Gujarat's Cambay basin).

8. Real-world steps already taken:

- GAIL's 10 MW electrolyzer at Vijaipur (MP).
- NTPC's 5 MW pilot at Kawas (Gujarat).
- India-Germany green hydrogen alliance.

9. Challenges & mitigation:

Challenge	Mitigation
High cost → Viability gap funding (VGF)	Govt offers ₹130/kg incentive under SIGHT scheme
Water scarcity in Gujarat (electrolysis uses 9 kg H_2O/kg H_2)	Use treated wastewater / desalination
Transportation	Convert to green ammonia (easier to ship)

10. Conclusion: Green hydrogen is feasible in India by 2030 with **targeted subsidy + RE cost reduction + demand aggregation**. Gujarat can become the green hydrogen hub of Asia.

Expected outcome by 2030:

- 5 MMT green H_2 → saves ₹1 lakh crore annually in import bills.
- Reduces CO_2 by 50 million tonnes/year.
- Creates 6 lakh jobs.

Q. Propose a hybrid renewable energy system for a rural community. (7 marks – Create)

Ans:

Scenario: A remote village in Odisha (off-grid, 200 households, 1 primary school, 1 health clinic). Existing energy: kerosene lamps, diesel gen (2 hours/day).

Proposed Hybrid System: Solar PV (65%) + Biogas (25%) + Small Wind (10%) + Battery storage + Diesel backup (emergency only)

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1. Load assessment (estimated):

Component	Peak load (kW)	Daily energy (kWh)
Households (200 × 4 LED bulbs + 1 fan + mobile charger)	40	240
School (lights, 5 fans, projector)	3	15
Clinic (lights, refrigerator for vaccines, sterilization)	2	12
Water pumping (1 HP pump, 2 hrs)	0.75	1.5

Component	Peak load (kW)	Daily energy (kWh)
Total	**45.75 kW**	**268.5 kWh/day**

2. System design:

Component	Specification	Justification
Solar PV	50 kWp (polycrystalline) – 200 panels of 250 Wp	Covers daytime load + charges battery
Wind turbine	5 kW (horizontal axis, 8 m rotor diameter, 15 m mast)	Provides night-time generation (coastal Odisha wind speed 5 m/s)
Biogas plant	50 m³ floating drum type – uses cattle dung (50 cows in village)	6 kW gas engine generator – runs 6 hours evening
Battery storage	200 kWh ($LiFePO_4$, 48 V system) – equivalent to 1 day autonomy	Stores solar for morning peak
Diesel gen (backup)	15 kVA – only for 2 days of monsoon/low RE	Emergency; run less than 5% of year

3. Working principle (daily cycle):

- 6 am – 4 pm: Solar PV powers loads + charges battery + runs water pump.
- 4 pm – 8 pm: Battery discharges for evening peak.
- 8 pm – 10 pm: Biogas genset runs (cooking waste heat used for community kitchen).
- 10 pm – 6 am: Wind turbine (if present) trickle-charges battery.
- Battery management system (BMS) ensures depth of discharge <70%.

4. Cost estimate (₹):

Item	Cost
Solar PV (50 kW) – installed	₹22,00,000 (₹44,000/kW)
Wind turbine (5 kW)	₹6,00,000
Biogas plant + engine	₹4,50,000
Battery (200 kWh $LiFePO_4$)	₹12,00,000
Diesel gen + control panel	₹1,50,000
Installation, wiring, protection	₹2,00,000

Item	Cost
Total ≈ ₹48 lakh (~$58,000)	

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5. Financial viability (subsidy assumed 50% from MNRE):

- User pay: ₹200-250/household/month + school/clinic free.
- Payback period ≈ 5 years (vs diesel gen running 4 hours/day).
- Diesel saved: 15,000 litres/year (₹12 lakh/year).

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6. Social impact:

- Elimination of kerosene (indoor air pollution).
- Vaccine refrigerator in clinic (life-saving).
- Children can study after dark.
- Women's safety – street lighting.

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7. Maintenance & local ownership:

- Train two village youth as mini-grid operators.
- Annual maintenance contract with local NGO/startup.
- Spare parts (inverter, battery, bi-directional meter) available at nearest block.

Conclusion: The hybrid system is technically feasible, financially viable with subsidy, and socially transformative. It provides **24×7 reliable power** with >90% renewable fraction.

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