Unit 3: Renewable Energy Technologies

Environmental Sustainability — DI02000051

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Unit 3 — Syllabus Coverage

Topics (Weightage: 25% | Hours: 7)

3.1	Introduction: Renewable vs Non-renewable, advantages, India status
3.2	Solar energy: photovoltaic (solar cell), solar thermal, water heater, cooker
3.3	Wind energy: turbine types, working, HAWT vs VAWT
3.4	Biomass energy: biogas (fixed dome, floating drum), biofuels
3.5	Hydropower, tidal, wave, OTEC
3.6	Geothermal energy, hydrogen energy, fuel cells
3.7	Energy conservation, efficiency, BEE, green buildings

GTU PYQ: Su'25, W'25 — Solar cell, biogas plant, wind turbine (25% weightage)

3.1 Introduction to Renewable Energy

Classification · Advantages · India Status

Energy — Classification (Exam Guide — 3M)

Type	Characteristic	Examples
Conventional (Non-renewable)	Finite, exhaustible Formed over millions of years	Coal, oil, natural gas, nuclear Form 80% of global energy supp
Renewable	Naturally replenished Inexhaustible; low pollution	Solar, wind, hydropower Biomass, tidal, geothermal
Non-conventional	Newer renewable sources Alternative to fossil fuels	Solar PV, wind, ocean energy Hydrogen, fuel cells

India's energy: 58% from fossil fuels; but renewable capacity growing rapidly (target: 500 GW by 2030). India = 4th largest renewable energy producer globally (2023).

Advantages & Limitations of Renewable Energy (Exam — 4M)

Advantages

- ➨ Inexhaustible / perpetually available
- ➨ Zero / low direct GHG emissions
- ➨ Reduces dependence on fossil fuel imports
- ➨ Decentralised — rural electrification
- ➨ Low operating cost (free fuel: sun, wind)
- ➨ Creates local employment
- ➨ Reduces air pollution and health costs
- ➨ Energy security for nations

Limitations

- ➨ Intermittent (sun/wind not always available)
- ➨ High initial capital cost
- ➨ Low energy density
- ➨ Requires large land area
- ➨ Storage challenge (batteries costly)
- ➨ Geographic dependent (solar in tropics, wind in coastal areas)
- ➨ Grid integration challenges

India — Renewable Energy Status (Exam Guide — 3M)

India's Installed Capacity (2023–24)

Source	Capacity (GW)	Notes
Solar	≈73 GW	World's 4th largest; Rajasthan, Gujarat, Ta
Wind	≈44 GW	World's 4th; Tamil Nadu, Gujarat, Rajastha
Hydropower (large)	≈47 GW	Sikkim, HP, Uttarakhand, Karnataka
Biomass / bioenergy	≈10 GW	Sugarcane states; NE India
Total Renewable	≈180 GW	Target: 500 GW by 2030

Key policies: National Solar Mission (2010); National Wind Policy; PM-KUSUM (solar for farmers); MNRE = Ministry of New and Renewable Energy. India pledged Net Zero by **2070** at COP26.

3.2 Solar Energy

Photovoltaic · Solar Thermal · Water Heater · Cooker

Solar Radiation — Basics (Exam Guide — 3M)

Key Terms

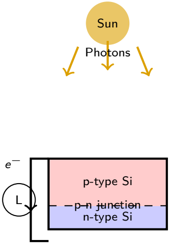
Solar constant: 1361 W/m^2 (energy from sun at top of atmosphere)

Insolation: Solar radiation received per unit area on Earth's surface. India receives: 4–7 kWh/m^2/day

Peak Sun Hours (PSH): Hours/day when average irradiance = 1 kW/m^2

India Solar Resource

➥ 300+ sunny days/year (most of India)
➥ Best regions: Rajasthan, Gujarat, Punjab
➥ Thar Desert = best solar irradiation
➥ India's total solar potential estimated at **750 GW**
➥ Jawaharlal Nehru National Solar Mission: target 100 GW (2022) $\rightarrow$ achieved!



Working

1. **Photons** from sunlight strike the solar cell
2. Silicon (p-n junction): photons knock out electrons (photoelectric effect)
3. **Electric field** at junction drives electrons → current flows through external circuit
4. **DC electricity** produced

Efficiency: 15–22% (commercial)

Cell → **Module** → **Array** → **System**

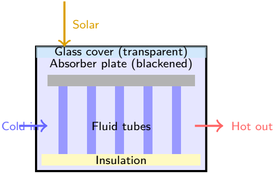
Photovoltaic — Types & Applications (Exam Guide — 3M)

PV Cell Types

Monocrystalline Si: Efficiency 18–22%; long life; costly
Polycrystalline Si: Efficiency 15–18%; cheaper; common
Thin Film (a-Si, CdTe): Efficiency 10–12%; flexible; light; low cost
Perovskite: >25% lab efficiency; next-generation
Bifacial: Absorbs light from both sides

Applications

- ➥ Rooftop solar (homes, factories)
- ➥ Solar street lights
- ➥ Solar water pumps (PM-KUSUM)
- ➥ Grid-scale solar farms
- ➥ Off-grid rural electrification
- ➥ Satellites and spacecraft
- ➥ Solar EV charging
- ➥ Solar lanterns (BIS standard)



Working

Glass cover: Allows solar radiation in; traps infrared (greenhouse effect)

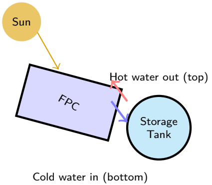
Absorber plate: Black-painted to absorb max solar heat

Fluid tubes: Water/fluid heated as it flows through

Insulation: Prevents heat loss from back and sides

Temperature achieved: 60–90°C
Used for: domestic water heating

Solar Water Heater — System (Exam Guide — 3M)



Key Details

Working: Cold water enters FPC from bottom; heated by solar energy; hot water rises by natural convection (thermosiphon) to storage tank at top.

Temperature: 60–80°C
Saves: 1500–2000 units electricity/year for 100 LPD system

Types: Thermosiphon (no pump) / Forced circulation (pump)
India: BIS IS 12933; subsidised by MNRE

Box-type Solar Cooker

Components:
➥ Outer box + inner black tray
➥ Double glass lid (traps heat)
➥ Plane mirror reflector (boosts heat)

Working: Sunlight reflected + directly enters; inner box heats to **150°C**; suitable for boiling, baking, steaming.

Advantages:
No fuel cost; no smoke/pollution; nutritional value retained; simple.

Limitations:
Not for frying/fast cooking; needs direct sunlight; slow.

Other Solar Thermal Devices

Solar dryer: Dries fish, fruits, crops using solar heat

Solar still: Distils brackish/salty water using solar evaporation

Concentrated Solar Power (CSP):
Parabolic trough / Tower concentrates sunlight to generate steam → turbine → electricity. Temperatures: 200–1000°C.

Scheffler Reflector: Fixed-focus community cooker used in India

Solar Energy — Summary & India Status (Exam Guide — 3M)

Advantages

- Abundant; India gets avg 5–6 $kWh/m^2/day$
- Zero fuel cost after installation
- Zero GHG during operation
- Modular — from 1W to GW scale
- Low maintenance; 25-year panel life
- Dual use — agrivoltaics

Limitations

- Intermittent (night, cloud) $\Rightarrow$ needs storage
- Land intensive: 1 GW $\approx$ 3000–5000 acres
- Panel manufacturing has some carbon footprint
- Panel waste by 2050 (10 million tonnes)
- High upfront cost (though falling fast: 2/unit)

Ladakh's Hanle has India's first Dark Sky Reserve. **World's largest solar park:** Bhadla, Rajasthan (2.7 GW). **Kochi Metro:** First metro powered 100% by solar.

Wind Energy — Basics & Resource (Exam Guide — 3M)

Wind Energy Basics

Wind energy converts kinetic energy of wind into electrical energy using wind turbines. Wind is solar energy in another form (sun heating causes pressure differences → wind).

Wind Power Formula

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

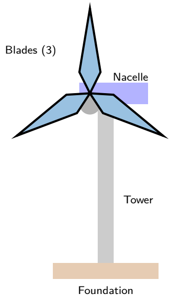
Where: ρ = air density, A = swept area, v = wind speed.

Power $\propto v^3$ — small increase in wind speed gives large power gain!

India Wind Resource

- ➥ Potential: ≈800 GW (at 100 m hub height)
- ➥ Best states: Tamil Nadu, Gujarat, Rajasthan, Karnataka
- ➥ Coastal and inland plains best
- ➥ Offshore: Gujarat, Tamil Nadu coasts
- ➥ Min useful wind speed: 3–4 m/s

Wind Turbine — Components (Exam Guide — 4M)



Key Components

Rotor blades: Capture wind kinetic energy; aerofoil shape
Hub: Connects blades; transfers rotation to shaft
Nacelle: Houses gearbox, generator, brake system
Gearbox: Steps up RPM (slow blade to fast generator)
Generator: Converts mechanical to electrical energy
Tower: Raises rotor to height with stronger winds
Foundation: Anchors turbine to ground

HAWT vs VAWT (Exam Guide — 4M)

Feature	**HAWT** (Horizontal Axis)	**VAWT** (Vertical Axis)
Orientation	Axis horizontal; faces wind	Axis vertical; omnidirectional
Efficiency	Higher (35–45%)	Lower (25–35%)
Wind direction	Must face wind (yaw mechanism)	Accepts wind from all direction
Installation	Tall tower needed	Low to ground; easy access
Noise	More	Less
Maintenance	Difficult (nacelle at height)	Easier (equipment at ground)
Examples	Most commercial turbines	Darrieus, Savonius types
Applications	Grid-scale, offshore	Urban, small scale, rooftop

➥ **Most commercial wind turbines are HAWT** with 3 blades, hub height 80–120 m, rated power 1–5 MW.

Wind Turbine — Working (Exam Guide — 4M)

Step-by-step working

Step 1: Wind strikes aerofoil-shaped rotor blades; lift force causes rotation (like aircraft wing)

Step 2: Blades rotate the main shaft (low RPM: 10–25 RPM)

Step 3: Gearbox increases shaft speed to 1000–1800 RPM for generator

Step 4: Generator converts rotational energy to AC electricity

Step 5: Yaw mechanism rotates nacelle to face wind (HAWT only)

Step 6: Pitch control adjusts blade angle (feathers blades if wind too strong)

Step 7: Transformer steps up voltage; connected to grid

➥ **Cut-in speed:** $\approx$3 m/s (starts generating). **Rated speed:** $\approx$12 m/s (full power). **Cut-out speed:** $\approx$25 m/s (turbine shut down for safety).

Wind Energy — Advantages & Challenges (Exam — 3M)

Advantages

- ➥ Renewable; zero fuel cost; zero GHG (operation)
- ➥ Land dual-use: farming + wind turbines
- ➥ Low water usage (unlike thermal)
- ➥ Fast installation
- ➥ Offshore wind = high speed, consistent
- ➥ Lowest cost electricity in many regions
- ➥ India's wind cost: 2.5–3/unit

Challenges

- ➥ Intermittent (no wind = no power)
- ➥ Bird and bat mortality
- ➥ Noise pollution near residential areas
- ➥ Visual impact (aesthetic objections)
- ➥ Land required for wind farms
- ➥ Best areas often far from demand centres
- ➥ Gearbox maintenance complex

3.4 Biomass Energy

Biogas · Biofuels · Biomass Power

Biomass

Biomass = organic material from plants and animals used as fuel. It stores solar energy through photosynthesis.

Types of Biomass

- ➥ **Wood:** Firewood, charcoal, pellets
- ➥ **Agricultural residue:** Paddy straw, bagasse, cotton stalks
- ➥ **Animal dung:** Cow dung for biogas
- ➥ **Municipal solid waste:** Organic fraction
- ➥ **Energy crops:** Jatropha, switchgrass, sugarcane
- ➥ **Aquatic biomass:** Algae

Conversion Pathways

Thermochemical: Combustion, gasification, pyrolysis

Biochemical: Anaerobic digestion (biogas), fermentation (ethanol)

Chemical: Transesterification (biodiesel from vegetable oil)

➥ India's biomass potential: **500 million tonnes/year**

Biogas — Composition & Benefits (Exam Guide — 4M)

Biogas

Biogas is produced by **anaerobic digestion** of organic matter by methanogenic bacteria. Also called **gobar gas** in rural India.

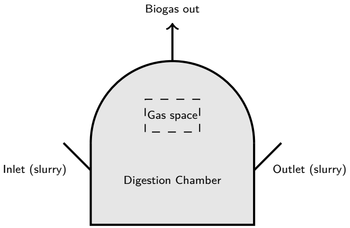
Composition

Gas	% by volume
Methane (CH_4)	55–65%
Carbon dioxide (CO_2)	30–40%
Hydrogen (H_2)	1–5%
Nitrogen, H_2S	traces

Benefits

- Cooking + electricity from cow dung
- Slurry = excellent organic fertiliser
- Reduces indoor air pollution (vs wood fire)
- Reduces GHG (captures CH_4 from dung)
- Decentralised energy for rural homes
- Carbon-neutral energy cycle

Fixed Dome Biogas Plant (PYQ — 4M)



Fixed Dome

Also called: Deenbandhu model (India); Janta model; Chinese model

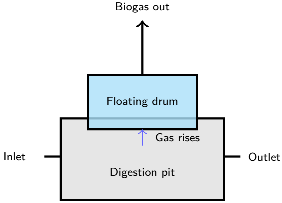
Construction: Permanent brick/concrete fixed dome underground

Gas storage: Gas stored in fixed gas space above slurry; creates gas pressure

Slurry: Displaced to expansion chamber when gas pressure builds

Advantage: Low cost; long life; no rust
Disadvantage: Gas pressure variable; cracks possible

Floating Drum Biogas Plant (PYQ — 4M)



Floating Drum (KVIC)

Also called: KVIC model (Khadi & Village Industries Commission)

Construction: Steel drum floats on slurry; rises as gas accumulates; provides constant pressure

Advantage: Constant gas pressure; visible gas production (drum rises); easy to operate

Disadvantage: Steel drum rusts; higher cost; maintenance needed

Biogas Plants — Comparison (PYQ — 4M)

Feature	Fixed Dome (Deenbandhu)	Floating Drum (KVIC)
Structure	Permanent brick/concrete dome	Steel drum floating on slurry
Gas pressure	Variable (changes with gas volume)	**Constant** pressure
Gas indicator	Not visible	Drum rises — visible
Cost	**Lower**	Higher (steel drum)
Life	**Longer** (20–30 years, no rusting)	Shorter (steel rusts: 10–15 yr)
Maintenance	Lower	Drum needs regular anti-rust t
Leakage	Possible (if cracks form)	Less common
Popularity	Most common in India	Older design; less common nov

➥ Both use cattle dung + water (1:1 ratio); daily feed; 4–8 weeks retention time.

Types of Biofuels

1st Generation: From food crops
➥ **Bioethanol:** Sugarcane, corn fermentation
➥ **Biodiesel:** Transesterification of vegetable oil (Jatropha, soybean)

2nd Generation: From agricultural/forestry waste
➥ Cellulosic ethanol from straw, grass

3rd Generation: From algae
➥ Very high yield per hectare; not commercially viable yet

India Biofuel Policy

National Biofuel Policy (2018):
➥ Target E20 (20% ethanol in petrol) by 2025
➥ Blending reduces oil import bill
➥ Jatropha plantation on wasteland
➥ GOBAR-Dhan scheme (biogas from waste)

E20 reduces CO_2 by $\approx$10%, CO by $\approx$50% vs pure petrol.

Improved Biomass Cook Stove (Exam Guide — 3M)

Problem with Traditional Chulhas

Traditional 3-stone cook stoves: efficiency 5–10%; produces thick smoke (CO, $PM_{2.5}$) $\Rightarrow$ **indoor air pollution** causes 4 million deaths/year globally (WHO).

Improved Cook Stove

- Efficiency: 25–40%
- Insulated combustion chamber
- Better air-fuel mixing
- Reduces fuel use 50–60%
- Less smoke and CO
- India: Pradhan Mantri Ujjwala Yojana (PMUY) — LPG connections

Gasifier Stove (Advanced)

- Biomass partly combusted; producer gas (CO, H_2) generated
- Burns cleanly; efficiency $>50\%$
- Biochar by-product is soil amendment
- Used in institutions, small industries
- India: several CSIR models available

Working Principle

Potential energy of stored water (behind dam) is converted to kinetic energy as water flows through penstocks, which drives turbines to generate electricity. **PE → KE → Electrical Energy.**

Types

Run-of-river: No large reservoir; uses natural flow
Reservoir: Dam stores water; steady generation
Pumped Storage: Off-peak electricity pumps water up; peak demand releases it
Micro-hydro: <100 kW; remote areas
Mini-hydro: 100 kW – 5 MW

Issues

- Large dams: displacement of communities
- Forest/biodiversity submergence
- Methane from reservoir organic decay
- Seismic risk

Example: Bhakra-Nangal, Tehri, Sardar Sarovar Dam (India)

Tidal, Wave & OTEC Energy (Exam Guide — 3M)

Type	Source	Working
Tidal	Moon's gravity causes tides	Tidal barrage; turbines in tidal flo
Wave	Wind-driven surface waves	Oscillating water column (OWC)
OTEC	Temp difference: surface vs deep ocean	Warm water evaporates working f

OTEC needs: $\Delta T \geq 20^\circ$C between surface and 1000 m depth. Tropical coasts (Tamil Nadu, Lakshadweep) suitable.
Tidal potential India: 8000 MW (Gulf of Khambhat highest).

Geothermal & Hydrogen Energy (Exam Guide — 3M)

Geothermal Energy

Source: Earth's internal heat (radioactive decay)

Types:
- ➥ Dry steam (direct use)
- ➥ Flash steam (85% plants)
- ➥ Binary cycle (low-temp)

Uses: Electricity, space heating, direct heat
India: **Manikaran** (Parvati Valley), Tattapani (MP)
World: Iceland (30% energy); Geysers, USA; New Zealand

Hydrogen Energy

Source: Green hydrogen = electrolysis using renewable electricity

Fuel cell: $H_2 + O_2 \rightarrow H_2O +$ electricity; zero emission

Advantages:
- ➥ Highest energy density
- ➥ Zero GHG at point of use
- ➥ Long-duration storage

India: National Green Hydrogen Mission (2023); target 5 MT/year by 2030

3.7 Energy Conservation & Efficiency

BEE Ratings · Energy Audit · Green Buildings

Energy Conservation — Principles (Exam Guide — 3M)

Definition

Energy conservation = reducing energy consumption by using less energy services OR improving efficiency (doing the same work with less energy).

4-R Approach

Reduce: Use less energy; turn off lights
Replace: Use energy-efficient alternatives (LED vs incandescent)
Recover: Waste heat recovery systems
Renew: Switch to renewable sources

Energy efficiency formula: $\eta = \frac{\text{Useful output}}{\text{Energy input}} \times 100\%$

Methods

- **Lighting:** LED (80% less energy than incandescent)
- **HVAC:** 5-star AC; proper insulation
- **Industry:** VFD motors, co-generation
- **Transport:** EVs, public transport
- **Buildings:** Passive design, green roofs

BEE Star Ratings (Exam Guide — 3M)

Bureau of Energy Efficiency (BEE)

BEE (under Ministry of Power, India, est. 2002) promotes energy efficiency through star labelling of appliances.

Appliance	1-Star	3-Star	5-Star	Key Metric
AC	High energy use	Medium	**Most efficient**	ISEER (kWh/kW
Refrigerator	High	Medium	**Low energy**	kWh/year
Fan	Low RPM	Medium	**High efficiency**	W per RPM
LED Bulb	–	–	Better than all CFL	lm/W

5-star AC saves Rs 6,000–12,000/year vs 1-star. India's UJALA scheme: 360+ million LED bulbs replaced; saves 38 billion units/year.

Energy Audit (Exam Guide — 3M)

Definition

Energy audit is a systematic examination of an organisation's energy flows to identify where energy is used and find opportunities for energy savings.

Types

Preliminary (Walk-through): Quick overview; identifies obvious waste

Detailed Audit: Comprehensive measurement; identifies all savings; recommended improvements with payback periods

Steps

1. Collect historical energy bills
2. Site walkthrough; identify major consumers
3. Measure energy use of each system
4. Calculate energy intensity
5. Identify savings opportunities
6. Cost-benefit analysis
7. Report & implement recommendations

Green Building

A **green building** is designed, constructed and operated to minimise environmental impact: efficient use of energy, water and materials; healthy indoor environment.

Rating Systems

GRIHA (Green Rating for Integrated Habitat Assessment): Indian system; from Ministry of New & RE

LEED (Leadership in Energy & Env. Design): US; used in India for commercial buildings

IGBC: Indian Green Building Council

Key Features

- Passive solar design (orientation, shading)
- Energy-efficient HVAC and lighting
- Rainwater harvesting
- Waste management on-site
- Green roofs and walls
- Solar panels on rooftop
- Use of locally-sourced, recycled materials

Smart Grid & Demand Response (Exam Guide — 3M)

Smart Grid

A smart grid uses digital communication technology to detect and react to local changes in energy use:

➥ 2-way communication between utility and consumer
➥ Real-time monitoring of generation and consumption
➥ Automatic fault detection
➥ Integrates renewable energy and EVs
➥ Smart meters for consumers

Energy Storage

Problem: Solar/wind are intermittent

Storage solutions:
➥ **Li-ion batteries:** Most common; EVs, grid
➥ **Pumped hydro:** 94% of global storage
➥ **Compressed air (CAES):** Underground
➥ **Hydrogen (LDES):** Long-duration storage
➥ **Flywheels:** Short-duration grid stability

India Energy Policy & Targets (Exam Guide — 3M)

Policy / Programme	Target	Year
Jawaharlal Nehru National Solar Mission	100 GW solar	Achieved 2
National Wind Energy Mission	140 GW wind	2030
UJALA Scheme	LED lighting (360M bulbs)	Ongoing
PM-KUSUM	10 GW (solar pumps)	2022
National Hydrogen Mission	5 MT green H_2	2030
GOBAR-Dhan Scheme	10,000 biogas plants	Ongoing
Perform, Achieve, Trade (PAT)	Industrial energy saving	Ongoing
Overall RE target	**500 GW**	**2030**
Net Zero	50% energy from renewables	**2070**

Comparison of Renewable Energy Sources (Exam Guide — 7M)

Source	Working	Efficiency	Advantages	Limitations
Solar PV	Photoelectric effect	15–22%	Abundant; modular	Intermittent; area
Solar Thermal	Heat collection	60–80% (FPC)	Simple; low cost	Cloudy days
Wind	Aerodynamic lift	35–45%	Low cost/unit	Variable; bird kills
Biomass	Combustion/AD	25–40%	Carbon-neutral; firm	Land; water; smoke
Biogas	Anaerobic digestion	50–65%	Rural; fertiliser by-product	Feedstock needed
Hydro	Potential energy	85–90%	Reliable; long life	Displacement; methane
Tidal	Tidal flow	25–40%	Predictable	High capital; few sites
Geothermal	Earth heat	10–23%	24/7 reliable; small area	Location-specific

Energy Efficiency Technologies (Exam Guide — 3M)

Sector	Technology	Energy Saving
Lighting	LED vs incandescent	80% saving
Appliances	5-star rated	30–50% saving
HVAC	Inverter AC, VRF system	30–60% saving
Motors (industry)	Variable Frequency Drive (VFD)	20–50% saving
Buildings	Insulation, double glazing	30–40% saving
Transport	Electric vehicles	60–70% vs IC engine
Industry	Waste heat recovery, cogeneration	20–40% saving

Negawatt: 1 unit saved = 1 unit NOT generated $\Rightarrow$ no pollution, no cost. Cheapest power = *power you don't use*.

Biogas — Anaerobic Digestion Process (Exam — 4M)

4-Stage Process

Stage 1 — Hydrolysis:
Complex organic molecules (fats, proteins, carbohydrates) broken into simpler molecules (sugars, fatty acids, amino acids) by hydrolytic bacteria.

Stage 2 — Acidogenesis:
Simple molecules converted to volatile fatty acids (acetic acid, propionic acid), CO_2, H_2 by acidogenic bacteria.

Stage 3 — Acetogenesis:
Fatty acids converted to acetic acid, H_2, CO_2 by acetogenic bacteria.

Stage 4 — Methanogenesis:
Methanogenic archaea (bacteria) convert acetic acid + CO_2 + H_2 $\rightarrow$ CH_4 (methane) + H_2O.

Conditions needed: Anaerobic; temperature 35–37°C; pH 7–8; no toxic substances.

Solar Cell vs Solar Thermal Collector (Exam Guide — 4M)

Feature	**Solar Cell (PV)**	**Solar Thermal Collector**
Output	Electrical energy (DC)	Heat energy (hot water/s
Working	Photovoltaic (photoelectric) effect	Absorption and heat tran
Efficiency	15–22%	60–80% (FPC)
Main material	Silicon semiconductor	Blackened copper/alumin
Application	Power generation, charging	Water heating, cooking,
Temperature output	Not applicable	60–200°C (FPC to evacu
Storage	Battery (costly)	Insulated tank (cheap)

SDG 7: Affordable Clean Energy

Targets:
➥ Universal access to affordable, reliable, modern energy by 2030
➥ Increase share of renewable energy globally
➥ Double the rate of energy efficiency improvement

1 billion people lack electricity; 3 billion cook on solid biomass (SDG 7.1)

Cross-cutting SDG Links

SDG 13: Climate action (renewables reduce GHG)
SDG 11: Sustainable cities (solar rooftop, EV)
SDG 3: Good health (clean cooking fuel reduces IAP)
SDG 8: Decent work (green jobs in RE sector)
SDG 9: Industry innovation (clean industry tech)

Q1: Solar panel output

A solar panel of area 2 m^2 receives solar radiation of 800 W/m^2. Efficiency = 18%. Find the electrical output.

Solution: Input power = $800 \times 2 = 1600$ W
Output = $1600 \times 0.18 =$ **288 W**

Q2: Wind power

Wind turbine: swept area = 50 m^2, wind speed = 8 m/s, air density = 1.25 kg/m^3, efficiency = 35%. Find output power.

Solution: $P_{wind} = \frac{1}{2}\rho A v^3 = \frac{1}{2} \times 1.25 \times 50 \times 8^3 = 16000$ W
Output = $16000 \times 0.35 =$ **5600 W = 5.6 kW**

Biomass Energy — Advantages & Challenges (Exam Guide — 3M)

Advantages

- **Carbon neutral:** CO_2 released was absorbed during growth
- **Firm power:** Available 24/7 (unlike solar/wind)
- **Rural employment:** Farmers supply biomass
- **Waste management:** Utilises agricultural waste
- **Biogas:** By-product fertiliser improves crops
- **Reduces firewood demand:** Protects forests

Challenges

- Land needed for energy crops (food vs fuel)
- Water-intensive: irrigation for energy crops
- Combustion still releases particulates
- Seasonal availability of feedstock
- Collection and transport logistics
- 1st-gen biofuels affect food prices

India's Energy Mix — Present & Future (Exam Guide — 3M)

India's Energy Mix (2024)

Source	**Installed Capacity (GW)**	**Share**
Coal (thermal)	≈215	≈50%
Renewables (total)	≈180	≈42%
– Solar	≈73	
– Wind	≈44	
– Hydro (large)	≈47	
Gas	≈25	6%
Nuclear	≈7	2%
Total	**≈430**	

India's COP26 commitments: (1) 500 GW RE by 2030; (2) 50% energy from renewables by 2030; (3) Reduce carbon intensity 45% vs 2005; (4) Net zero by 2070.

Q: Explain the working of a solar cell with diagram (4M)

Principle: Photovoltaic (photoelectric) effect — when photons of sufficient energy strike a semiconductor (silicon p-n junction), electron-hole pairs are created.

Working:
1. Photons from sunlight strike the silicon solar cell
2. At the p-n junction, built-in electric field separates electron-hole pairs
3. Free electrons flow through external circuit → **DC current generated**
4. Multiple cells connected in series/parallel form a **module**; modules form an **array**

Efficiency: Monocrystalline 18–22%; Polycrystalline 15–18%; Thin film 10–12%

Applications: Rooftop power, solar street lights, space satellites, water pumps.

Advantages: No moving parts; long life (25 yr); zero fossil fuel; modular.

Q: Explain fixed dome biogas plant with diagram (4M)

Also called: Deenbandhu / Janta model (India)

Construction: Underground fixed-dome structure made of brick/concrete. Inlet pipe for slurry (cattle dung + water 1:1). Outlet chamber for slurry displacement. Gas outlet pipe at top.

Working:
1. Fresh slurry (cattle dung + water) fed through inlet daily
2. Anaerobic bacteria digest organic matter in digester
3. Biogas (55–65% CH_4) accumulates in fixed gas space (dome top)
4. Gas pressure displaces slurry to expansion chamber (outlet side)
5. Biogas tapped for cooking or electricity via gas pipe
6. Spent slurry from outlet used as fertiliser (biofertiliser)

Retention time: 40–60 days **Temperature:** 30–40°C optimal

Q: Explain working of wind turbine (4M)

Principle: Kinetic energy of wind → mechanical rotation → electrical energy.

Main components: 3 aerofoil-shaped rotor blades; hub; gearbox; generator; tower; yaw and pitch control.

Working:
1. Wind strikes the 3 rotor blades; aerodynamic lift causes rotation
2. Blades rotate main shaft (low speed: 10–25 RPM)
3. **Gearbox** steps up shaft speed to 1000–1800 RPM
4. **Generator** converts rotational energy to AC electricity
5. **Yaw system** (HAWT) always orients nacelle to face wind direction
6. **Pitch control** adjusts blade angle to control power output
7. Transformer steps up voltage and power fed to grid

Wind speeds: Cut-in 3 m/s | Rated 12 m/s | Cut-out 25 m/s

PYQ Worked — Fixed Dome vs Floating Drum (Exam — 4M)

Q: Compare fixed dome and floating drum biogas plants (4M)

Feature	Fixed Dome (Deenbandhu)	Floating Drum (KVIC)
Structure	Permanent brick/concrete dome (underground)	Steel drum floating on slurry in pit
Gas pressure	Variable	**Constant** (drum weight = constant p
Gas storage indicator	Not visible	**Drum position** shows gas volume
Initial cost	**Lower**	Higher (steel drum)
Life span	20–30 years (no rust)	10–15 years (steel rusts)
Maintenance	**Less**	More (drum painting, rust prevention
Reliability	Cracks may cause gas leakage	Less leakage
Use in India	**Most popular**	Older model; less common now

➥ Both: dung:water = 1:1; 40–60 day retention; produce 55–65% CH_4 in biogas; slurry = biofertiliser.

PYQ Worked — Non-Conventional Energy Sources (Exam — 4M)

Q: Enumerate non-conventional energy sources with advantages (4M)

1. **Solar energy:** Sun's radiation; PV cells (electricity) + flat plate collector (heat). Advantage: abundant, zero GHG.
2. **Wind energy:** Kinetic energy of wind; HAWT/VAWT turbines. Advantage: zero fuel, low operating cost.
3. **Biomass energy:** Organic matter; biogas, biofuels. Advantage: carbon-neutral, rural benefit.
4. **Tidal energy:** Sea tides; tidal barrage/stream. Advantage: predictable, coastal.
5. **Wave energy:** Ocean waves; OWC turbines. Advantage: consistent on coastlines.
6. **Geothermal energy:** Earth's internal heat; steam turbines. Advantage: 24/7 reliable, small footprint.
7. **Ocean Thermal Energy (OTEC):** Temp difference; Rankine cycle. Advantage: tropical countries.
8. **Hydrogen fuel cell:** Green $H_2 + O_2 \rightarrow H_2O$ + electricity. Zero GHG at

PYQ Worked — Energy Conservation Methods (Exam — 4M)

Q: Describe 5 methods of energy conservation (4M)

1. Replace incandescent with LED:
LED uses 80% less electricity; same luminous output. India's UJALA: 360M LEDs replaced.

2. Switch off unused appliances:
Standby mode still consumes 5–15% of rated power; switch off and unplug.

3. Use energy-efficient appliances (BEE 5-star):
5-star AC saves Rs 6,000/year vs 1-star.

4. Proper insulation of buildings:
Double-glazed windows; wall insulation; reduces heating/cooling energy 30–40%.

5. Use public transport / EVs:
EVs: 3–4$\times$ more efficient than IC engines; bus/metro reduces per-capita energy 5–10$\times$.

6. Renewable energy adoption:
Rooftop solar, solar water heaters avoid fossil fuel consumption entirely.

MCQ Practice — Unit 3 (GTU PYQ)

1. The working principle of a solar cell is:
(A) Thermoelectric effect **(B) Photovoltaic effect**
(C) Piezoelectric effect (D) Magnetoelectric effect

2. In a fixed dome biogas plant, the gas pressure is:
(A) Variable (B) Constant (C) Zero at start (D) Regulated by valve

3. HAWT stands for:
(A) High-Altitude Wind Technology **(B) Horizontal Axis Wind Turbine**

4. Biogas contains primarily:
(A) CO_2 and H_2 **(B) CH_4 and CO_2** (C) H_2 and N_2

5. BEE stands for:
(A) Bureau of Environmental Efficiency **(B) Bureau of Energy Efficiency**

6. KVIC model biogas plant = ?
(A) Fixed dome **(B) Floating drum** (C) Tubular (D) Plug flow

Common Mistakes in Unit 3 (Exam Warning)

Wrong	Correct
Solar cell works on thermoelectric effect	**Photovoltaic (photoelectric) effect**
Fixed dome has constant pressure	**Floating drum has constant pressure**; fixed dome has variable
Floating drum is more popular in India	**Fixed dome (Deenbandhu) more popular** (cheaper, longer life)
Biogas = 100% methane	Biogas = 55–65% CH_4 + 30–40% CO_2
VAWT is more efficient than HAWT	**HAWT more efficient** (35–45% vs 25–35%)
Hydropower efficiency is low	Hydro is **most efficient** RE (85–90%)
Solar panel is same as solar cell	Cell → Module → Array → System (different scales)

Flash Revision 1 — Solar & Wind Energy (Quick Recall)

Solar Energy

- Solar constant: 1361 W/m^2
- India: 4–7 kWh/m^2/day (300+ sunny days)
- PV = photovoltaic; p-n junction silicon
- Efficiency: Mono 18–22%; Poly 15–18%
- Solar water heater: 60–80°C; thermosiphon
- Box solar cooker: 150°C
- India solar capacity: ≈73 GW (2024)
- World's largest solar park: Bhadla, Rajasthan (2.7 GW)
- Cost: Rs 2/unit (solar now cheapest energy in India)

Wind Energy

- Power $\propto v^3$ (wind speed cubed)
- HAWT: horizontal axis; most efficient (35–45%)
- VAWT: vertical; all wind directions; less efficient
- Cut-in: 3 m/s; Rated: 12 m/s; Cut-out: 25 m/s
- India wind capacity: ≈44 GW
- Best states: TN, Gujarat, Rajasthan
- 3 rotor blades; hub; nacelle (gearbox + generator); tower
- Yaw system: orients nacelle to face wind
- Pitch control: adjusts blade angle

Flash Revision 2 — Biomass, Hydro, Geothermal

(Quick Recall)

Biomass & Biogas

- Biogas: 55–65% CH_4, 30–40% CO_2
- Anaerobic digestion: 4 stages (hydrolysis, acidogenesis, acetogenesis, methanogenesis)
- Fixed dome (Deenbandhu): variable pressure; low cost; no rust
- Floating drum (KVIC): constant pressure; steel rusts
- Dung:Water = 1:1; retention 40–60 days
- Biofuel: 1st gen = food crops; 2nd gen = agricultural waste
- E20 petrol: 20% ethanol; target 2025

Hydro, Geo, Tidal

- Hydropower: most efficient RE (85–90%)
- Pumped storage = energy battery (pump up off-peak; release peak)
- Tidal: moon's gravity; Gulf of Khambhat 8000 MW potential
- OTEC: needs $\Delta T \geq 20^{\circ}C$ (surface vs deep ocean)
- Geothermal: Earth heat; flash steam most common
- India geothermal: Manikaran (HP), Tattapani (MP)
- Hydrogen fuel cell: $H_2+O_2 \rightarrow H_2O+$electricity; zero GHG

Flash Revision 3 — Policy & Conservation (Quick Recall)

India RE Policy

- MNRE = Ministry of New and Renewable Energy
- Target: 500 GW RE by 2030
- Net Zero: 2070 (COP26 pledge)
- JNNSM: 100 GW solar mission (achieved!)
- PM-KUSUM: solar pumps for farmers
- GOBAR-Dhan: biogas from waste
- National Green Hydrogen Mission: 5 MT H_2 by 2030
- UJALA: 360 million LED bulbs; saves 38 BU/year

Energy Conservation

- BEE (Bureau of Energy Efficiency): est. 2002
- 5-star rating = most efficient
- LED: 80% less energy than incandescent
- ISEER (Indian Seasonal Energy Efficiency Ratio) for ACs
- Energy audit: identify + fix energy waste
- Green building: GRIHA (India); LEED (US/India)
- Negawatt = 1 unit saved = 1 unit not generated
- 4-R: Reduce, Replace, Recover, Renew

Important Definitions Recap — Unit 3 (Exam Guide)

Term	Definition
Renewable energy	Energy from naturally replenished sources (sun, wind, biomass, water)
Solar cell	Semiconductor device converting solar radiation to DC electricity via photovoltaic effect
Insolation	Solar radiation received per unit area at Earth's surface (kWh/m^2/day)
Biogas	Combustible gas (55–65% CH_4) produced by anaerobic digestion of organic matter
Anaerobic digestion	Microbial breakdown of organic matter in absence of oxygen, producing biogas
Biofuel	Liquid fuel (ethanol, biodiesel) derived from biological sources (sugarcane, Jatropha)
Energy audit	Systematic examination of energy flows to identify conservation opportunities
Green building	Building designed for minimal energy/water/material use; rated by GRIHA/LEED
HAWT	Horizontal Axis Wind Turbine; rotor shaft horizontal and parallel to wind direction
BEE	Bureau of Energy Efficiency (India, Ministry of Power); administers star labelling

India's Renewable Energy Champions (GK for MCQ)

Achievement	Detail
World's largest solar park	Bhadla, Rajasthan (2.7 GW)
World's largest wind farm	Muppandal Wind Farm, Tamil Nadu
India's 1st solar city	Anandpur Sahib, Punjab
India's 1st solar-powered metro	Kochi Metro
Best solar state	Rajasthan (highest solar irradiation)
Best wind state	Tamil Nadu (oldest wind installations)
Geothermal: best sites	Manikaran (HP), Tattapani (MP)
India RE position globally	4th largest RE producer (2023)
Countries ahead in RE	China, USA, Germany
MNRE HQ	New Delhi (Ministry of New and Renewable Energy

Q. Write a short note on Solar Water Heater. (4M)
Ans: Flat plate collector tilted at latitude angle. Glass cover traps solar heat. Black absorber plate absorbs $>95\%$ radiation. Water heated to 60–80°C by thermosiphon (no pump). Insulated storage tank at top. Saves 1500–2000 units electricity/year per 100 LPD system.

Q. Write a short note on Wind farm. (4M)
Ans: A wind farm is a cluster of 10–200+ wind turbines at a windy site. HAWT turbines of 1–5 MW each. Located on ridges, plains or offshore. Grid-connected. India's largest wind states: Tamil Nadu, Gujarat. Challenges: bird mortality, noise, visual impact. India target: 140 GW by 2030.

Q. What is cogeneration? (3M)
Ans: Simultaneous generation of electricity and useful heat from same fuel source (e.g., steam turbine exhaust used for heating). Efficiency reaches 80% vs 35% for electricity alone. Used in industries, hospitals, hotels.

Unit 3 — Summary (25% Weightage)

Solar & Wind

- PV cell: photovoltaic effect; Si p-n junction
- FPC: absorber plate → hot water 60–80°C
- HAWT > VAWT efficiency; yaw + pitch control
- Wind power $\propto v^3$; cut-in 3 m/s, rated 12 m/s
- India: 73 GW solar, 44 GW wind (2024)

Biomass & Others

- Biogas: 55–65% CH_4 by anaerobic digestion
- Fixed dome (Deenbandhu): cheaper, variable pressure
- Floating drum (KVIC): constant pressure, rusts
- Biofuel: E20 petrol by 2025 (India)
- Hydro most efficient RE: 85–90%

Conservation & Policy

- BEE star ratings; 5-star = most efficient
- LED: 80% energy saving vs incandescent
- Energy audit: preliminary and detailed types
- Green building: GRIHA (India), LEED (US)
- India RE target: 500 GW by 2030; Net Zero 2070
- UJALA: 360 million LEDs; saves 38 BU/year

Key PYQs: Solar cell working, Biogas fixed dome, Wind turbine, Fixed dome vs floating drum, Non-conventional energy types, Conservation methods

Weightage: 25% | Hours: 7 | Equal to