ANNAMACHARYA INSTITUTE OF TECHNOLOGY & SCIENCES
(AUTONOMOUS)
UTUKUR (P), C. K. DINNE (V&M), KADAPA, YSR DIST.
Approved by AICTE, New Delhi & Affiliated to JNTUA, Anantapuramu.
Approved by S.B.T.E.T. Andhra Pradesh.
Accredited by NAAC with 'A' Grade, Bangalore & NBA (EEE, ECE & CSE).

SUSTAINABLE ENERGY TECHNOLOGIES

COURSE FILE

Department: Civil Engineering

Year: III B.Tech I Semester

Subject: Sustainable Energy Technologies

CODE: **23HOE0301**

Credits: 03

Regulation: HM23

FACULTY: Dr. K. HEMADRI M.Tech, Ph.D.

SUSTAINABLE ENERGY TECHNOLOGIES

Course Outcomes:

Course Outcomes On successful completion of this course the student will be able to		
CO1	Illustrate the importance of solar radiation and solar PV modules.	L1, L2
CO2	Discuss the storage methods in PV systems	L2,L3
CO3	Explain the solar energy storage for different applications	L2,L3
CO4	Understand the principles of wind energy, and bio-mass energy.	L2, L3
CO5	Attain knowledge in geothermal energy, ocean energy and fuel cells.	L1, L2,L3, L4

UNIT – 1
SOLAR RADIATION: Role and potential of new and renewable sources, the solar energy option, Environmental impact of solar power, structure of the sun, the solar constant, sun-earth relationships, coordinate systems and coordinates of the sun, extraterrestrial and terrestrial solar radiation, solar radiation on titled surface, instruments for measuring solar radiation and sun shine, solar radiation data, numerical problems.
SOLAR PV MODULES AND PV SYSTEMS:
PV Module Circuit Design, Module Structure, Packing Density, Interconnections, Mismatch and Temperature Effects, Electrical and Mechanical Insulation, Lifetime of PV Modules, Degradation and Failure, PV Module Parameters, Efficiency of PV Module, Solar PV Systems- Design of Off Grid Solar Power Plant. Installation and Maintenance.

UNIT – 2
STORAGE IN PV SYSTEMS:
Battery Operation, Types of Batteries, Battery Parameters, Application and Selection of Batteries for Solar PV System, Battery Maintenance and Measurements, Battery Installation for PV System.

UNIT – 3
SOLAR ENERGY COLLECTION: Flat plate and concentrating collectors, classif cat on of concentrat ng collectors, orientat on.

SOLAR ENERGY STORAGE AND APPLICATIONS: Different methods, sensible, latent heat and stratified storage, solar ponds, solar applications- solar heating/cooling technique, solar distillation and drying, solar cookers, central power tower concept and solar chimney.

UNIT – 4
WIND ENERGY: Sources and potentials, horizontal and vertical axis windmills, performance characteristics, betz criteria, types of winds, wind data measurement.
BIO-MASS: Principles of bio-conversion, anaerobic/aerobic digestion, types of bio-gas digesters, gas yield, utilization for cooking, bio fuels, I.C. engine operation and economic aspects.

UNIT – 5
GEOTHERMAL ENERGY: Origin, Applications, Types of Geothermal Resources, Relative Merits.
OCEAN ENERGY: Ocean Thermal Energy; Open Cycle & Closed Cycle OTEC Plants, Environmental Impacts, Challenges.
FUEL CELLS: Introduction, Applications, Classification, Different Types of Fuel Cells Such as Phosphoric Acid Fuel Cell, Alkaline Fuel Cell, PEM Fuel Cell, MC Fuel Cell.

Text Books:
Solar Energy – Principles of Thermal Collectionand Storage/Sukhatme S.P. and J.K.Nayak/TMH
Non-Conventional Energy Resources- Khan B.H/ Tata McGraw Hill, New Delhi, 2006

References:
Principles of Solar Engineering - D.Yogi Goswami, Frank Krieth& John F Kreider / Taylor & Francis
Non-Conventional Energy - Ashok V Desai /New Age International (P) Ltd
Renewable Energy Technologies -Ramesh & Kumar /Narosa
Non-conventional Energy Source- G.D Roy/Standard Publishers

Online Learning Resources:
https://nptel.ac.in/courses/112106318
https://youtube.com/playlist?list=PLyqSpQzTE6M-ZgdjYukayF6QevPv7WE-r&si=- mwIa2X-SuSiNy13
https://youtube.com/playlist?list=PLyqSpQzTE6M-ZgdjYukayF6QevPv7WE- r&si=Apfjx6oDfz1Rb_N3
https://youtu.be/zx04Kl8y4dE?si=VmOvp_O

SUSTAINABLE ENERGY TECHNOLOGIES

UNIT – 1

SOLAR RADIATION: Role and potential of new and renewable sources, the solar energy option, Environmental impact of solar power, structure of the sun, the solar constant, sun-earth relationships, coordinate systems and coordinates of the sun, extraterrestrial and terrestrial solar radiation, solar radiation on titled surface, instruments for measuring solar radiation and sun shine, solar radiation data, numerical problems.

Role and Potential of New and Renewable Sources of Energy

Role:

- Reduce dependence on fossil fuels (coal, oil, gas).
- Mitigate environmental issues such as air pollution and greenhouse gas emissions.
- Promote energy security and sustainability.
- Create employment in green technologies.

Potent al:

- **Solar Energy**: Huge potential, especially in tropical countries.
- **Wind Energy**: Viable in coastal and open plain regions.
- **Biomass**: Useful in rural/agricultural settings.
- **Hydropower (micro/small)**: Renewable and dispatchable.
- **Geothermal & Ocean Energy**: Site-specific but promising.

Solar Energy Option

- Abundant and freely available source of energy.
- Can be harnessed using **thermal** (solar collectors) and **photovoltaic (PV)** systems.
- Applications: lighting, heating, electricity, water pumping, cooking, and industrial processes.

Environmental Impact of Solar Power

Posit ve Impacts:

- No direct emissions of greenhouse gases.
- No air or water pollution during operation.
- Reduces fossil fuel dependence.

Negat ve Impacts:

- **Land use**: Large solar farms may require vast land.
- **Material usage**: PV panels use rare or toxic materials.
- **Waste disposal**: Panel disposal at end-of-life needs care.
- **Visual impact**: Large installations may affect landscape aesthetics.

Structure of the Sun

- **Core**: Central region (~15 million °C), site of nuclear fusion.
- **Radiative Zone**: Energy transported outward by radiation.
- **Convective Zone**: Energy moved by convection.
- **Photosphere**: Visible surface (~5,500 °C).
- **Chromosphere**: Thin, hot layer above photosphere.
- **Corona**: Outermost layer, visible during solar eclipse.

Solar Constant

- Definition: Amount of solar radiation received per unit area at the outer edge of Earth's atmosphere on a surface normal to the sun's rays at the mean Earth-Sun distance.
- Value: **1367 W/m²**

Sun-Earth Relationship

- Earth's orbit is elliptical, causing variation in received solar radiation.
- **Perihelion**: Closest to Sun (early January).
- **Aphelion**: Farthest from Sun (early July).
- Earth's axial tilt (23.45°) causes **seasons**.

Coordinate Systems and Coordinates of the Sun

Solar Angles:

1. **Declination (δ)**: Angle between the rays of the sun and the plane of the Earth's equator.
    - Varies ±23.45° throughout the year.
    - Calculated by:

$$\delta = 23.45^\circ \times \sin \quad \frac{360}{365}(284 + n)$$

    Where n is day of the year.

2. **Hour Angle (ω)**: Angular displacement of the sun east or west of the local meridian due to rotation of the Earth.
    - 15° per hour, negative before noon, positive after noon.
3. **Solar Altitude Angle (α)**: Angle between the sun's rays and the horizontal plane.
4. **Solar Zenith Angle (θz)**: Angle between the sun's rays and the vertical.
5. **Solar Azimuth Angle (γs)**: Angle measured from north (or south) to the projection of the sun's rays on the horizontal plane.
6. **Latitude (φ)**: Geographic coordinate of the observer.

Extraterrestrial and Terrestrial Solar Radiation

- **Extraterrestrial Radiation**: Solar radiation outside Earth's atmosphere.
- **Terrestrial Radiation**: After atmospheric attenuation, this is what reaches Earth's surface.

At enuat on factors:

- Scattering (Rayleigh, Mie)
- Absorption (O_2, O_3, H_2O vapor, CO_2)
- Reflection by clouds/aerosols

Solar Radiation on Tilted Surface

- Most solar panels/collectors are tilted to maximize solar gain.
- Radiation components:
  - **Beam radiation (Ib)**: Direct sunlight on a surface.
  - **Diffuse radiation (Id)**: Scattered sunlight.
  - **Reflected radiation (Ir)**: From the ground or surroundings.

Total radiation on tilted surface:

$$I_T = I_b \cos(\theta) + I_d \cdot F_d + I_r$$

Where:

- θ: Angle of incidence
- F_d: Diffuse view factor (usually ~0.5 for horizontal)

□ Instruments for Measuring Solar Radiation and Sunshine

Instrument	Purpose
Pyranometer	Measures global solar radiation (beam + diffuse)
Pyrheliometer	Measures direct beam solar radiation
Sunshine Recorder	Measures duration of sunshine (hours/day)
Albedometer	Measures reflected solar radiation
Net Radiometer	Measures net radiation (incoming – outgoing)

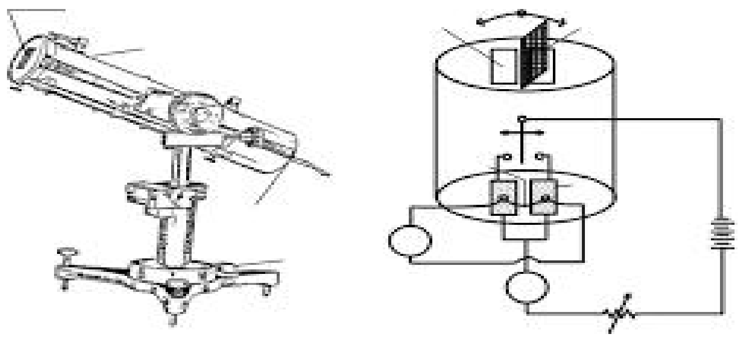
Solar Radiation Measuring Instruments (Radiometers):

A radiometer absorbs solar radiation at its sensor, transforms it into heat and measures the resulting amount of heat to ascertain the level of solar radiation. Methods of measuring heat include taking out heat flux as a temperature change (using a water flow pyrheliometer, a silver-disk pyrheliometer or a bimetallic pyranograph) or as a thermo electromotive force (using a thermoelectric pyrheliometer or a thermo electric pyranometer).

In current operation, types using a thermopile are generally used. The radiometers used for ordinary observation are pyrheliometers and pyranometers that measure direct solar radiation and global solar radiation, respectively.

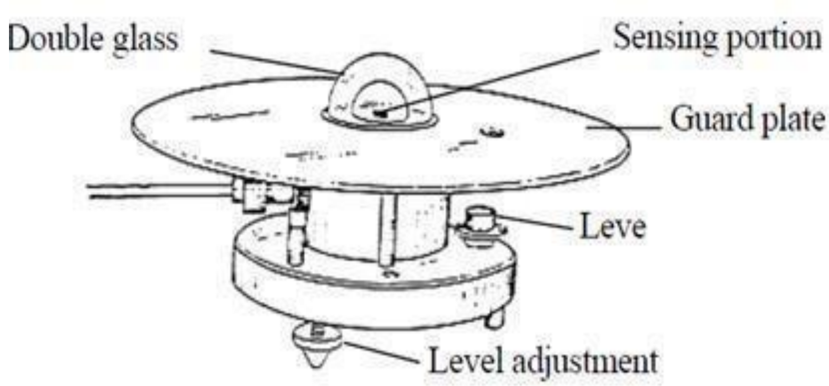
Pyrheliometers:

A pyrheliometer is used to measure direct solar radiation from the sun and its marginal periphery. To measure direct solar radiation correctly, its receiving surface must be arranged to be normal to the solar direction. For this reason, the instrument is usually mounted on a sun-tracking device called an equatorial mount.



Pyranometers:

A pyranometer is used to measure global solar radiation falling on a horizontal surface. Its sensor has a horizontal radiation-sensing surface that absorbs solar radiation energy from the whole sky (i.e. a solid angle of 2π sr) and transforms this energy into heat. Global solar radiation can be ascertained by measuring this heat energy. Most pyranometers in general use are now the thermopile type, although bimetallic pyranometers are occasionally found.



Solar Radiation Data

Parameters:

- **Global radiation (G)**: Total solar energy received on a horizontal surface.
- **Direct radiation (D)**: Portion of G that comes directly from the sun.
- **Diffuse radiation**: Scattered portion.
- **Sunshine hours**: Number of hours the sun shines in a day.

SOLAR PV MODULES AND PV SYSTEMS: PV Module Circuit Design, Module Structure, Packing Density, Interconnections, Mismatch and Temperature Effects, Electrical and Mechanical Insulation, Lifetime of PV Modules, Degradation and Failure, PV Module Parameters, Efficiency of PV Module, Solar PV Systems-Design of Off Grid Solar Power Plant. Installation and Maintenance.

SOLAR PV MODULES AND PV SYSTEMS

1. PV Module Circuit Design

- **PV Cell:** Basic building block, generates DC electricity.
- **Series Connection:** Increases voltage.
- **Parallel Connection:** Increases current.
- **Bypass Diodes:** Prevent hot spots during partial shading.
- **Blocking Diodes:** Prevent reverse current flow.
- **Typical PV Module:** Several cells in series; e.g., 36 or 72 cells for 12V/24V systems.

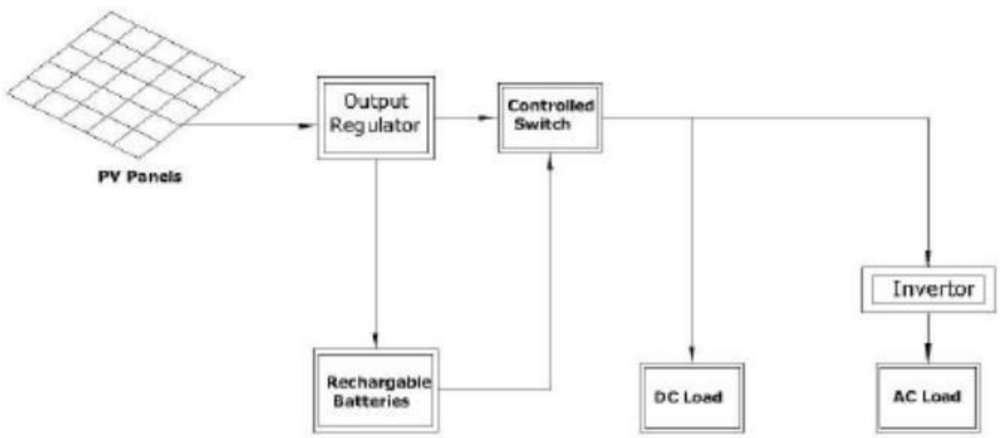


Fig: Schematic diagram for the PV system

2. Module Structure

- **Top Layer:** Tempered glass – protects from weather & impact.
- **Encapsulant (EVA):** Bonds layers, protects against moisture.
- **PV Cells:** Crystalline silicon or thin-film types.
- **Backsheet:** Insulates and protects from mechanical damage.
- **Frame:** Usually aluminum, for mounting and structural integrity.

3. Packing Density

- Refers to the **ratio of active PV area to total module area**.
- High packing density improves **space utilization** and **power output per m²**.
- **Trade-offs:** High density may increase heat and reduce airflow.

4. Interconnect ons

- **Busbars:** Metal strips conducting current from cell to cell.
- **Tabbing Wires:** Connect cells in series or parallel.
- **Soldering:** Ensures electrical contact; must resist thermal cycling.
- **Contact Resistance:** Should be minimized for higher efficiency.

---

5. Mismatch and Temperature Ef ects

Mismatch E ects:

- Caused by different electrical characteristics among cells.
- Leads to **power loss** and **hot spots**.
- Use of **bypass diodes** helps mitigate the effect.

Temperature E ects:

- PV module efficiency **decreases with rising temperature**.
- **Temperature Coefficient (Pmax):** Typically -0.4% to -0.5%/°C for silicon modules.
- Proper ventilation and **cooling design** reduce negative impact.

6. Electrical and Mechanical Insulation

- **Electrical Insulation:** Backsheet + encapsulant layers prevent shocks and shorts.
- **Mechanical Insulation:** Frame + glass protect against hail, wind loads, and vibration.
- Must comply with **IEC 61215 and 61730 standards**.

---

7. Lifetime of PV Modules

- Standard life: **25 to 30 years**.
- Gradual loss of output over time, typically **0.5% to 1% per year**.
- Ensured by **accelerated aging tests** during certification.

---

8. Degradation and Failure

- **Degradation Types:**
  - Light-Induced Degradation (LID)
  - Potential Induced Degradation (PID)
  - Thermal cycling and UV exposure
  -
- **Failure Modes:**
  - Delamination
  - Cell cracks
  - Junction box failure
  - Corrosion

9. PV Module Parameters

Parameter	Description
Voc (Open Circuit Voltage)	Max voltage with no load
Isc (Short Circuit Current)	Max current when terminals are shorted
Vmp (Voltage at max power)	Voltage when P = V×I is max
Imp (Current at max power)	Current at maximum power point
Fill Factor (FF)	Ratio of max power to Voc×Isc
Efficiency (η)	Ratio of electrical output to incident solar input

10. Efficiency of PV Module

- Depends on **cell material, temperature, shading, dirt, angle of incidence.**
- **Crystalline Silicon Modules:** ~17–22% efficient.
- **Thin-Film Modules (e.g., CdTe, CIGS):** ~10–14%.
- Efficiency =

$$\eta = \frac{P_{out}}{A \cdot G}$$

  Where:

  - P_{out}: Output Power
  - A: Module area
  - G: Solar irradiance

11. Design of Off-Grid Solar Power Plant

Design Steps:

1. Load Assessment:
   - Calculate total daily energy consumption in Wh.
2. PV Array Sizing:

$$\text{PV Size} = \frac{\text{Total Load}}{\text{PSH} \times \text{Efficiency}}$$

   - PSH = Peak Sun Hours
3. Battery Sizing:

$$\text{Battery Capacity (Ah)} = \frac{\text{Daily Load} \times \text{Backup Days}}{\text{Battery Voltage} \times \text{DOD}}$$

   - DOD = Depth of Discharge

1. **Inverter Sizing:**
   - Should handle peak load + surge.
2. **Charge Controller:**
   - MPPT or PWM; sized based on PV current and voltage.

Example System Components:

- PV Panels (e.g., 1 kW)
- Battery Bank (e.g., 12V, 200Ah × 2)
- MPPT Charge Controller
- Inverter (e.g., 1 kVA)
- Mounting structures, wiring, protection devices

12. Installat on and Maintenance

Installat on:

- **Site Selection:** Shade-free, south-facing (in northern hemisphere).
- **Tilt Angle:** Equal to local latitude for fixed systems.
- **Structure:** Galvanized iron/aluminum frames, properly anchored.
- **Earthing & Lightning Protection:** Essential for safety.

Maintenance:

- **Cleaning:** Regular cleaning of module glass.
- **Visual Inspection:** Check for cracks, discoloration, and corrosion.
- **Electrical Tests:** Check voltage, current, insulation.
- **Battery Maintenance:** Water levels (for flooded cells), terminals.
- **Record Keeping:** Log energy output and maintenance.

UNIT-II

STORAGE IN PV SYSTEMS

Battery Operation, Types of Batteries, Battery Parameters, Application and Selection of Batteries for Solar PV System, Battery Maintenance and Measurements, Battery Installation for PV System.

1. Battery Operation in PV Systems

- **Function**: Stores excess energy produced by PV modules for use during periods of low solar radiation or night-time.
- **Working Principle**:
  - During daylight, the PV system charges the battery.
  - When sunlight is not available, the battery discharges to supply power to the load.
- **Battery Bank**: Multiple batteries connected in series or parallel to achieve required voltage/current.

2. Types of Batteries Used in Solar PV Systems

Battery Type	Description	Pros	Cons
Lead-Acid (Flooded/VRLA)	Oldest and most widely used.	Inexpensive, reliable.	Heavy, shorter life, regular maintenance.
AGM (Absorbent Glass Mat)	Type of VRLA, sealed.	Low maintenance, less leakage risk.	Costlier than flooded.
Gel Battery	Electrolyte is in gel form.	Deep discharge ability, long life.	Sensitive to overcharging.
Lithium-Ion (LiFePO4)	Modern, lightweight.	High energy density, long cycle life, low maintenance.	Expensive.
Nickel-Cadmium (NiCd)	Used in specific applications.	Durable, wide temp. range.	Toxicity, memory effect.

3. Bat ery Parameters

Key parameters to consider:

- **Capacity (Ah)**: Amount of charge the battery can store.
- **Voltage (V)**: Usually 6V, 12V, or 24V per unit.
- **Depth of Discharge (DoD)**: % of battery discharged; lower DoD extends life.
- **State of Charge (SoC)**: Current energy content as a percentage.
- **Cycle Life**: Number of charge/discharge cycles before capacity drops significantly.
- **Efficiency**: Ratio of output energy to input energy (typically 85–95%).
- **Charge/Discharge Rate (C-Rate)**: Rate at which battery is charged/discharged relative to its capacity.
- **Self-discharge Rate**: Loss of charge over time without use.

4. Applicat on and Select on of Bat eries for Solar PV Systems

Application Areas:

- Off-grid residential and commercial systems.
- Rural electrification and microgrids.
- Solar street lighting.
- Solar water pumping systems.
- Backup power supply for grid-connected PV systems.

Selection Criteria:

- **System voltage & energy demand**.
- **Autonomy requirement**: Days of backup needed.
- **Battery type compatibility with inverter/charge controller**.
- **Climatic conditions**.

- **Maintenance capabilities**.
- **Cost vs. lifecycle**.

---

5. Bat ery Maintenance and Measurements

Maintenance Tasks:

- **For Lead-Acid (Flooded)**:
  - Regular water topping (distilled).
  - Cleaning terminals and checking for corrosion.
  - Equalization charging.
- **For VRLA, Li-ion**: Minimal maintenance, periodic checks.

Measurements:

- **Voltage Check**: Multimeter or battery monitor.
- **Specific Gravity (for flooded batteries)**: Hydrometer to assess SoC.
- **Internal Resistance Testing**: Indicates battery health.
- **Temperature Monitoring**: Prevents overheating/damage.

---

6. Bat ery Installat on for PV System

Guidelines:

- **Location**: Cool, dry, and well-ventilated area.
- **Mounting**: Use insulated racks; avoid direct ground contact.
- **Wiring**:
  - Use proper gauge wire based on current.
  - Ensure tight and corrosion-free connections.
- **Series/Parallel Configurations**:
  - **Series**: Increases voltage.
  - **Parallel**: Increases capacity.
- **Safety**:
  - Provide proper fusing and circuit protection.
  - Install charge controller to prevent overcharge/discharge.
  - Label connections and isolate battery bank for maintenance.

1. Introduction

Bat eries designed to capture surplus electricity generated by your solar PV system allow you to store solar electricity for use later in the day. This guide sets out the main features you might need to take into account when deciding if a bat ery storage system is suitable for you and your solar PV system. Included are 20 quest ons to ask your installer should you consider a bat ery system.

Potentially batteries can help you use more of the electricity generated by your PV system, saving you money on your electricity bill. But they’re not for everyone, as you generally need to be generating ‘surplus’ solar electricity to store. It is also important to note that, contrary to expectations, some battery storage systems are not designed to work during power-cuts. In addition they are not cheap: at today’s prices, poorly designed systems may not repay their initial investment (in what they save on electricity bills). But prices continue to fall and the technology is also improving, meaning that battery storage is becoming a viable economic option for some households and businesses.

2. Storage for solar PV systems: the basics

Solar PV system

The solar PV system on your roof will generate electricity during the day that you can use in your home. Without a means of storing that solar electricity, any surplus energy that you don’t use is ‘exported’ to the local electricity grid. During times when the panels are no longer generating (or not generating enough for your needs), you need to buy electricity from your electricity supplier.

2.1 Solar PV plus storage

'Energy storage' lets you store the surplus solar electricity, instead of exporting it. Battery storage lets you use more of your solar PV system's output (in the jargon, it 'increases 'self-consumption'). This reduces the amount of grid electricity you need to buy, saving you money on your electricity bill.

During the day :

- the solar PV system generates solar electricity
- the battery storage system will check if all the generation is being used to power your lights and appliances
- if you're not using all the electricity that the solar PV system is generating, then the system will ensure that any surplus energy is used to charge the battery
- once the battery is fully charged, if there is still more solar electricity being generated, this will be exported to the grid (or in some systems, will be diverted to other uses e.g. to an immersion heater)

In the evening or at time of low solar generation:

- the solar PV panels have a reduced or zero output
- the battery system can discharge the stored electricity, providing you with renewable-generated electricity at no additional cost
- once the battery is discharged, if you need to use more electricity, you buy it from your electricity supplier

Battery types

The two types of batteries most commonly offered for solar PV storage in the home are lithium-ion and

lead-acid batteries. Some of their key features and differences are set out here:

Lithium-ion batteries (commonly found in electronic devices such as laptops and mobile phones)	**Lead-acid batteries** (used in cars)
• More expensive • Increasingly common in domestic grid-connected solar PV storage systems • Lighter • Require integrated controller, that manages charge / discharge • More efficient • Can discharge more stored energy • Longer expected lifetime	• Cheaper • Typically used for off-grid properties where more storage is required • Heavier and larger • Need good charging and discharging routine to maintain battery health • Less efficient • Shorter expected lifetime

Examples of battery systems from Enphase and Wattstor (Lithium Ion and Lead acid based systems)

Batteries and battery systems can vary considerably in shape, size and weight. The greater the battery capacity, the greater the battery size and weight. Typical domestic systems vary from being the size of a small computer to the size of a washing machine.

2.2 Battery capacity

Battery storage systems are often provided with a power rating in kiloWatts (kW). Storage batteries for a grid connected solar PV storage system are typically around 1kW to 7kW. This is the capability of the battery to provide power.

A battery's stated electricity capacity, as expressed in kilowatt-hours (kWh)[1] is generally larger than the battery's actual useable capacity, because:

- all batteries lose some energy in charging and discharging, though some have better 'charge-discharge efficiency' than others.
- most batteries are not designed to be routinely fully discharged (can reduce battery life). Some have deeper discharge

capability than others. Typical Lead-acid battery systems may be setup to limit the 'depth of discharge' to around 50%,

Lithium-ion systems to 75% or more.

1 Electrical capacity can alternatively be given in Amp-hours (Ah); where Ah x Voltage = kWh

Safety note: Batteries can pose a fire and explosion risk if mistreated. They can also be heavy and difficult to move. They must only be installed in suitable locations for safe battery operation and out of the reach of children.

2.3 What a battery storage system could power

A fully-charged medium-sized system could store sufficient energy to power during the evening your lights and lower-powered items like your fridge-freezer, TV and laptop. Over four or five hours, all of these together will use at most a few "units" or kiloWatt-hours (kWh), of electricity.

However, the battery will quickly run out if you put on heavy energy users like the washing-machine or tumble-dryer: these can consume 2 - 3kWh in a single use.

And in winter, the battery might not store enough to provide for even the lower-powered items for many hours (see Section 4.1 'Winter mode').

2.4 Battery lifetime

A battery's efficient lifetime depends on the technology and the way the battery is used - significantly on the number of 'cycles' (complete full battery charge and discharge) that they undergo.

Manufacturers generally give an expected lifetime in years and/or in 'charge-discharge cycles'. For example:

- 'Life expectancy = 10 years or 10,000 cycles, whichever is the sooner'

Lithium-ion batteries last longer than lead-acid: you may see a 10-year lifetime expectancy claimed and this is improving all the time.

Normally the battery storage system will monitor the battery performance and should give you an indication when your batteries need replacing.

Some battery system manufacturers operate a battery leasing and/or replacement scheme for worn-out batteries and arrange for the safe disposal/recycling of the battery.

Batteries also store and discharge DC, which similarly has to be converted to AC by an inverter.

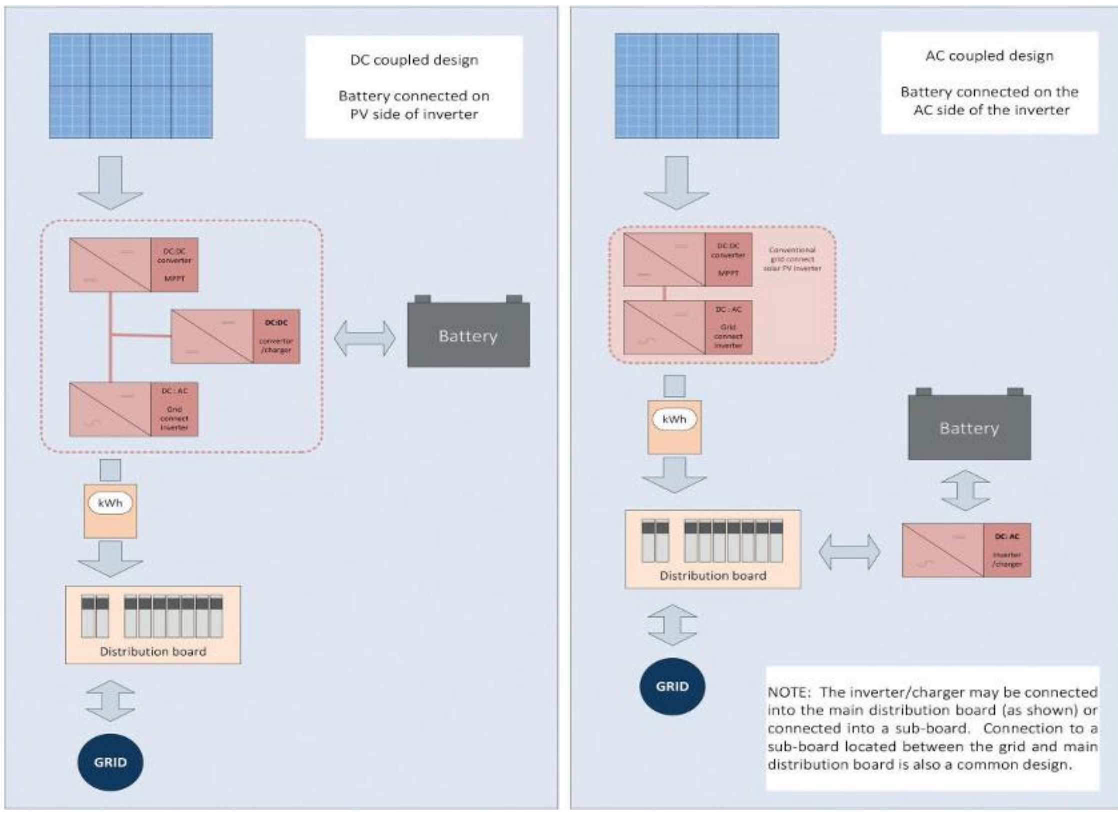
2.5 DC and AC coupled

There are two main ways of linking a battery storage system into such a system:

- DC Coupled: the batteries are installed on the same side of the solar inverter as the solar PV panels, they charge from the panels, and their DC is only converted to AC when it's used ('DC-coupled')

OR

- AC Coupled: the batteries are installed on the grid-side, where the solar PV's DC has already been converted to AC ('AC-coupled'). A separate inverter converts the AC back to DC for storing in the battery. When the battery discharges, the same separate inverter converts the DC back to AC.



You're more likely to be offered an AC-coupled system if you're looking to add a battery storage system to an existing solar PV system (they're more suited to such 'retrofit' applications).

For retro-fit applications, the installer will need to verify that the new equipment being installed is compatible with the existing equipment. DC coupled systems can be installed as a retrofit but more equipment will need to be added or replaced.

You're more likely to be offered a DC-coupled system if you're installing a solar PV system and a battery storage system from scratch. Many DC- coupled systems will not operate in a power-cut (see below) and it may affect your Feed-In tariff income (see Section 5.2 'The impact on your Feed-in tariff income from solar PV').

Batteries in Solar PV Systems:

Batteries are crucial components in stand-alone (off-grid) solar PV systems, providing energy storage to ensure a continuous power supply when solar irradiation is low or absent (e.g., at night, during cloudy weather).

---

1. Bat ery Operat on (Fundamentals)

An electric battery consists of one or more electrochemical cells. Each cell comprises:

- **Two Electrodes:** A positive electrode (cathode) and a negative electrode (anode).
- **Electrolyte:** A chemical medium that facilitates the movement of ions between the electrodes.

How it Works:

- **Discharging:** When a battery is connected to an external load, a chemical reaction occurs between the electrodes and the electrolyte. This reaction converts stored chemical energy into electrical energy, causing electrons to flow from the negative electrode, through the load, and back to the positive electrode. This generates an electric current.
- **Charging:** In rechargeable (secondary) batteries, the process is reversed. An external electrical source (like a solar PV array via a charge controller) forces current back into the battery, reversing the chemical reactions and converting electrical energy back into stored chemical energy within the electrodes.

2. Types of Bat eries

Batteries are broadly classified into primary (non-rechargeable) and secondary (rechargeable) types. For solar PV systems, only **secondary batteries** are used due to their ability to be recharged repeatedly.

Common Types of Secondary Batteries for PV Systems:

2.1 Lead-Acid Batteries

This is the most commonly used type for renewable energy systems due to their relatively low cost and proven technology.

- **Flooded (Vented) Lead-Acid Batteries:**
    - **Description:** The electrodes are fully submerged in a liquid electrolyte (sulfuric acid).
    - **Operation:** During charging, small amounts of hydrogen and oxygen gases are produced and vented to the atmosphere through holes at the top.
    - **Maintenance:** Requires periodic topping up with distilled water as water is lost during gassing.
    - **Advantages:** Low cost, high efficiency.
    - **Disadvantages:** Requires maintenance, gassing (requires ventilation), relatively lower lifetime compared to other types.
    - **Types:** Flat plate and Tubular plate. Tubular plates generally offer better deep cycle performance and longer life.
- **Sealed (Valve Regulated Lead-Acid - VRLA) Batteries:**
    - **Description:** Electrolyte is immobilized (either gelled or absorbed in a glass mat). These batteries are sealed, meaning gasses are recombined internally, reducing water loss.
    - **Types:**

  - **Gelled Electrolyte (Gel Batteries):** Silicon dioxide is added to the electrolyte to form a gel. Gases produced during charging recombine within the gel.
    - **Advantages:** Maintenance-free, spill-proof, suitable for remote applications, less electrolyte freezing problems.
    - **Disadvantages:** Requires controlled charging (can be damaged by overcharging), generally more expensive than flooded.
  - **Absorbed Glass Mat (AGM Batteries):** The electrolyte is absorbed in a fiberglass mat sandwiched between the plates.
    - **Advantages:** Maintenance-free, spill-proof, good performance in various temperatures, lower self-discharge than flooded.
    - **Disadvantages:** Requires controlled charging, typically have a shorter cycle life than gel or flooded deep-cycle batteries if frequently deep discharged.

2.2 Nickel-Cadmium (Ni-Cd) Batteries

- **Description:** Uses nickel hydroxide as the positive electrode and cadmium as the negative electrode, with potassium hydroxide as the electrolyte.
- **Advantages:** Longer deep cycle life, tolerant to temperature extremes, good for high-current applications.
- **Disadvantages:** "Memory effect" (can lose capacity if repeatedly partially discharged), cadmium is toxic and poses environmental concerns, higher cost than lead-acid. Due to environmental regulations, their use is declining.

2.3 Nickel-Metal Hydride (Ni-MH) Batteries

- **Description:** Similar to Ni-Cd but uses a metal hydride alloy for the negative electrode, replacing cadmium.
- **Advantages:** Higher energy density than Ni-Cd, less pronounced memory effect, environmentally friendlier than Ni-Cd.
- **Disadvantages:** Higher self-discharge rate than Ni-Cd, more expensive than lead-acid and Ni-Cd, can be damaged by overcharging.

2.4 Lithium-Ion (Li-ion) Batteries

- **Description:** A family of batteries characterized by lithium ions moving between the anode and cathode during charge and discharge.
- **Advantages:** Very high energy density (3 times that of lead-acid), lightweight, long cycle life, low self-discharge, no memory effect, high efficiency.
- **Disadvantages:** Higher upfront cost, requires sophisticated battery management system (BMS) for safety (overcharge/discharge protection, thermal management), specific charging requirements. Increasingly popular for solar PV due to performance benefits.

3. Bat ery Parameters

Understanding these parameters is crucial for selecting and managing batteries in a PV system:

- **Nominal Voltage (V):** The standard voltage of a battery, typically 2V, 6V, 12V for individual batteries. Battery banks are often configured for 12V, 24V, or 48V.

- **Capacity (Ah - Ampere-hours):** The amount of charge a battery can deliver over a certain period at a specific discharge rate. For PV systems, capacity is often rated at C/10 or C/20 (meaning it can deliver the rated Ah over 10 or 20 hours, respectively).
- **State of Charge (SOC):** The current energy level of the battery, expressed as a percentage of its total capacity (0% to 100%).
- **Depth of Discharge (DOD):** The percentage of the battery's capacity that has been discharged. For example, a 50% DOD means half the battery's capacity has been used. Deep-cycle batteries are designed for higher DODs. Exceeding recommended DOD significantly reduces battery lifespan.
- **Cycle Life:** The number of charge-discharge cycles a battery can withstand before its capacity significantly degrades (e.g., to 80% of its initial capacity). This is heavily influenced by the DOD. A battery typically has a higher cycle life at lower DODs.
- **Self-Discharge Rate:** The rate at which a battery loses its charge when not in use. Lead-acid batteries have a relatively high self-discharge rate compared to Li-ion.
- **Efficiency (Round-trip efficiency):** The ratio of energy discharged from the battery to the energy put into it during charging. Represents energy losses during charge/discharge cycles.
- **Internal Resistance (Ri):** The opposition to current flow within the battery. A lower internal resistance indicates better performance and less energy loss as heat.
- **Temperature Performance:** Battery capacity and life are affected by temperature. Extreme hot or cold temperatures can reduce performance and accelerate degradation.
- **Specific Energy (Wh/kg):** Energy per unit mass. Indicates how much energy a battery can store relative to its weight. Important for portable applications.
- **Specific Power (W/kg):** Power per unit mass. Indicates how much power a battery can deliver relative to its weight.
- **Charge Rate (C-rate):** A measure of the rate at which a battery is charged or discharged relative to its maximum capacity. A 1C rate means a current that would fully charge or discharge the battery in one hour.

4. Applicat on and Select on of Bat eries for Solar PV Systems

Batteries in solar PV systems serve to:

- **Store excess energy:** Generated by PV panels during the day for use at night or on cloudy days.
- **Provide stable power:** Smooth out fluctuations in solar output.
- **Ensure continuous supply:** Act as a backup power source.

Selection Criteria:

1. **System Voltage (12V, 24V, 48V, etc.):** The battery bank voltage should match the system's nominal voltage. Higher voltages reduce current, minimizing cable losses and allowing for smaller wire gauges.
2. **Required Capacity (Ah or kWh):**
    - **Calculate daily energy demand:** Sum the Watt-hours per day for all connected loads.
    - **Consider days of autonomy:** How many days the system needs to operate without solar input (e.g., during prolonged cloudy periods).
    - **Account for system losses:** Battery inefficiencies, inverter losses, wire losses (typically 15-20%).
    - **Consider Depth of Discharge (DOD):** Factor in the maximum allowable DOD for the chosen battery type to ensure longevity.

- **Formula for Battery Capacity (Ah):** Capacity(Ah)=Battery Voltage(V)×Max DOD×Battery EfficiencyTotal daily load(Wh/day)×Days of Autonomy
3. **Cycle Life vs. Cost:**
   - **Deep-cycle batteries** are essential for PV systems as they are designed for repeated deep discharges.
   - **Lead-acid (flooded or gel):** Generally the most cost-effective upfront, but may have a shorter cycle life than Li-ion, especially with frequent deep discharges. Suitable for budget-conscious systems with moderate daily cycling.
   - **Li-ion:** Higher upfront cost but offers significantly longer cycle life, higher efficiency, and lower maintenance, leading to a lower total cost of ownership over the system's lifespan. Ideal for long-term reliability and performance.
4. **Maintenance Requirements:**
   - **Flooded lead-acid:** Requires regular maintenance (water topping, specific gravity checks).
   - **VRLA (Gel/AGM) & Li-ion:** Largely maintenance-free.
5. **Operating Temperature Range:** Ensure the chosen battery can perform reliably within the expected temperature extremes of the installation site.
6. **Safety and Ventilation:**
   - Flooded lead-acid batteries produce explosive gases (hydrogen) during charging, requiring well-ventilated battery enclosures.
   - Li-ion batteries, while generally safe with a proper BMS, require careful handling and installation to prevent thermal runaway.
7. **Environmental Impact:** Consider the disposal and recycling options for batteries at the end of their life.

5. Bat ery Maintenance and Measurements

Proper maintenance is critical for maximizing battery lifespan and ensuring system reliability.

General Maintenance Practices:

- **Regular Cleaning:** Keep battery terminals and tops clean and free of corrosion. Use a mixture of baking soda and water to neutralize acid, then rinse with clean water.
- **Ventilation:** Ensure proper ventilation, especially for flooded lead-acid batteries, to dissipate hydrogen gas.
- **Temperature Control:** Keep batteries within their recommended operating temperature range. Extreme temperatures reduce performance and life.
- **Connections:** Periodically check and tighten all electrical connections to prevent voltage drops and arcing.

Maintenance for Flooded Lead-Acid Batteries:

- **Electrolyte Level Check:** Regularly check the electrolyte level and top up with distilled water (never tap water) to cover the plates. This typically needs to be done every 1-3 months depending on usage and charging.
- **Specific Gravity Measurement:** Use a hydrometer to measure the specific gravity of the electrolyte in each cell. This indicates the battery's state of charge and helps identify weak cells. All cells should have similar specific gravity readings.
- **Equalization Charge:** Periodically perform an equalization charge (controlled overcharge) to balance the charge across all cells, remove sulfation from plates, and ensure all cells are fully

charged. This is usually done monthly or bi-monthly, or as recommended by the manufacturer/charge controller.
- **Voltage Readings:** Measure individual cell voltages and overall battery bank voltage.

Measurements:

- **Voltage:**
  - **Open Circuit Voltage (OCV):** Voltage when no load is connected. Gives a rough indication of SOC.
  - **Under Load Voltage:** Voltage when current is being drawn.
  - **Individual Cell Voltage:** Crucial for multi-cell batteries (like lead-acid) to identify unbalanced or failing cells.
- **Current:**
  - **Charging Current:** Current flowing into the battery.
  - **Discharging Current:** Current flowing out of the battery to the load.
- **Specific Gravity (for flooded lead-acid):** Directly indicates the electrolyte concentration and SOC.
- **Temperature:** Monitor battery temperature to prevent overheating or freezing.
- **Capacity Testing:** Periodically discharge the battery bank to a safe DOD while measuring the actual Ah delivered to assess its true capacity and health.

Common Battery Faults and Troubleshooting:

- **Sulfation:** White crystalline deposits on lead-acid battery plates, reducing capacity. Can often be reversed with equalization charges if caught early.
- **Stratification:** Acid concentration becomes uneven in flooded lead-acid batteries, with denser acid at the bottom. Equalization charge helps mix the electrolyte.
- **Overcharging/Undercharging:** Both can severely damage batteries, reducing life. A good charge controller is essential.
- **Deep Cycling:** Repeatedly discharging batteries beyond their recommended DOD shortens their lifespan.
- **Loose/Corroded Connections:** Lead to high resistance, voltage drop, and potential fire hazards.

6. Bat ery Installat on for PV System

Proper installation ensures safety, optimal performance, and longevity of the battery bank.

Pre-Installation Considerations:

- **Location:**
  - **Cool, Dry, and Ventilated:** Choose a location that is cool, dry, and well-ventilated to prevent overheating and safely dissipate gases (especially for flooded lead-acid).
  - **Accessibility:** Easy access for maintenance, cleaning, and inspection.
  - **Protection:** Protect from direct sunlight, rain, dust, and extreme temperatures.
  - **Away from Living Areas:** If using flooded lead-acid batteries, due to gassing.
- **Battery Enclosure/Rack:**
  - **Non-Conductive Material:** Use shelves or racks made of wood, plastic, or coated metal.
  - **Level and Sturdy:** Ensure the surface is level and strong enough to support the significant weight of the batteries.
  - **Ventilation:** If enclosed, ensure adequate ventilation openings.
- **Safety Equipment:**

- **Eye Protection and Gloves:** Always wear appropriate PPE when handling batteries.
- **Spill Containment:** Have acid spill kits (baking soda) readily available for flooded lead-acid batteries.
- **Fire Extinguisher:** A Class C fire extinguisher is recommended.
- **Insulated Tools:** Use insulated tools to prevent accidental short circuits.

Installation Steps:

1. **Read Manufacturer's Instructions:** Always follow the specific instructions provided by the battery manufacturer.
2. **Wiring Configuration (Series and Parallel):**
   - **Series Connection:** Connect the positive terminal of one battery to the negative terminal of the next to increase voltage (e.g., two 12V batteries in series create a 24V bank). The total capacity (Ah) remains the same.
   - **Parallel Connection:** Connect positive to positive and negative to negative terminals to increase capacity (Ah) while maintaining the same voltage (e.g., two 100Ah, 12V batteries in parallel create a 200Ah, 12V bank).
   - **Series-Parallel Connection:** A combination of both to achieve desired voltage and capacity (e.g., for a 48V, high-capacity bank).
3. **Cable Sizing:** Use appropriately sized cables (AWG or mm^2) to minimize voltage drop and safely carry the maximum current. Longer runs and higher currents require thicker cables.
4. **Terminal Connections:**
   - **Clean Contacts:** Ensure battery terminals and cable lugs are clean and free of corrosion.
   - **Secure Connections:** Tighten all connections firmly to prevent resistance and heat buildup.
   - **Use Anti-Corrosion Grease:** Apply a thin layer of anti-corrosion grease on terminals after tightening.
5. **Fusing and Disconnects:**
   - **Battery Bank Fuse/Breaker:** Install a DC-rated fuse or circuit breaker close to the battery bank's positive terminal for protection against short circuits.
   - **Disconnect Switches:** Consider installing disconnect switches to easily isolate the battery bank for maintenance or emergencies.
6. **Charge Controller Connection:** Connect the battery bank to the solar charge controller. The charge controller is crucial for regulating the charging process to prevent overcharging and deep discharging, thereby extending battery life.
7. **Initial Charge:** After installation, perform an initial full charge of the battery bank as per manufacturer recommendations before putting the system into full operation.

Post-Installation Checklist:

- Verify all connections are secure and correct polarity.
- Check battery voltage with a multimeter.
- Ensure proper ventilation in the battery area.
- Educate system users on basic safety and maintenance procedures.

UNIT-III
SOLAR ENERGY COLLECTION

SOLAR ENERGY COLLECTION: Flat plate and concentrating collectors, classification of Concentrating collectors, orientation.

Introduction to Solar Energy Collection

Solar energy collection is the process of converting solar radiation into a usable form of energy, typically heat or electricity. The devices used to perform this function are known as solar collectors. Solar collectors are broadly categorized into two main types: flat plate collectors and concentrating collectors.

Flat Plate Collectors

Flat plate collectors are the most common type of solar thermal collector, widely used for residential and commercial applications like domestic hot water heating, space heating, and swimming pool heating. They are relatively simple in design and are effective at collecting both direct and diffuse solar radiation.

Components of a Flat Plate Collector

A typical flat plate collector consists of the following components:

- **Transparent Cover (Glazing):** Usually made of glass or a special plastic, this cover allows sunlight to pass through while reducing heat loss from the collector plate. This "greenhouse effect" helps to trap the absorbed heat inside.
- **Absorber Plate:** A thin, dark-colored plate (often made of copper or aluminum) that absorbs solar radiation and converts it into heat. The dark color maximizes absorption, while a special selective coating can be applied to further improve efficiency by minimizing radiative heat loss.
- **Tubes or Passages:** A network of tubes or channels are attached to the absorber plate. A heat transfer fluid (such as water, air, or a water-glycol mixture) flows through these passages, picking up the heat from the absorber plate.
- **Insulation:** Insulation is placed on the back and sides of the collector to minimize heat loss to the surrounding environment. This helps maintain the high temperatures achieved by the absorber plate.
- **Casing:** A sturdy frame or container that encloses all the components, protecting them from the elements.

Working Principle

Sunlight passes through the transparent cover and strikes the absorber plate. The plate's dark surface absorbs the solar energy and heats up. This heat is then transferred to the fluid circulating in the tubes. The heated fluid can then be used directly (e.g., in a domestic hot water system) or stored in a tank for later use.

Advantages of Flat Plate Collectors

- Simple and robust design.

- Low maintenance requirements.
- Can utilize both direct and diffuse solar radiation, making them effective even on cloudy days.
- Relatively low cost.
- Do not require complex sun-tracking mechanisms.

Disadvantages of Flat Plate Collectors

- Lower operating temperatures compared to concentrating collectors (typically up to 80∘C).
- Larger surface area required to achieve significant energy collection.
- Can be less efficient in very cold or windy conditions due to heat loss.

Concentrating Collectors

Concentrating solar collectors use reflective surfaces (mirrors) or lenses to focus a large area of sunlight onto a smaller absorber area. This concentration of solar radiation allows for the achievement of much higher temperatures than flat plate collectors, making them suitable for industrial process heating, solar cooling, and generating electricity in solar thermal power plants.

Classification of Concentrating Collectors

Concentrating collectors are classified based on their geometry and how they track the sun. The main types are:

1. Line Focus Collectors: These collectors focus sunlight onto a linear receiver.

- **Parabolic Trough Systems:** A series of long, parabolic-shaped mirrors arranged in a trough. They track the sun along a single axis and concentrate sunlight onto a receiver tube running along the focal line of the trough. A fluid (like synthetic oil or molten salt) flowing through the tube is heated to high temperatures (up to 400∘C) and used to generate steam for a turbine.
- **Linear Fresnel Reflector:** Similar to a parabolic trough but uses a series of long, flat or slightly curved mirrors arranged in parallel rows. These mirrors reflect sunlight onto a fixed receiver tube. This design can be simpler and less expensive to manufacture than parabolic troughs.

2. Point Focus Collectors: These collectors focus sunlight onto a single point receiver.

- **Parabolic Dish Systems:** A large, dish-shaped reflector (similar to a satellite dish) that tracks the sun along two axes. It focuses sunlight onto a receiver at its focal point. These systems can achieve very high temperatures (up to 1500∘C) and are often used with a Stirling engine or another heat engine to generate electricity.
- **Solar Power Tower (Central Receiver Systems):** A field of large, flat, sun-tracking mirrors called heliostats. These heliostats individually track the sun and reflect sunlight onto a single receiver located at the top of a central tower. The concentrated solar energy heats a fluid (often molten salt) in the receiver to extremely high temperatures (up to 1000∘C) to produce steam for a turbine.

Advantages of Concentrating Collectors

- Can achieve very high temperatures, suitable for electricity generation and industrial processes.
- Smaller absorber area reduces heat loss.
- Higher efficiency at higher temperatures.

- Can be used to store energy more effectively (e.g., in molten salt tanks) for use after sunset.

Disadvantages of Concentrating Collectors

- Require complex sun-tracking mechanisms (single or dual-axis).
- Can only utilize direct solar radiation, making them less effective on cloudy days.
- Higher manufacturing and maintenance costs.

Orientation of Solar Collectors

The orientation of a solar collector is crucial for maximizing the amount of solar radiation it receives. The optimal orientation depends on the type of collector, its location (latitude), and the intended use of the collected energy.

Key Angles

The orientation of a solar collector is defined by two primary angles:

- **Tilt Angle (β):** The angle between the plane of the collector and the horizontal.
- **Azimuth Angle (γ):** The planar rotation of the collector from true south (in the Northern Hemisphere) or true north (in the Southern Hemisphere).

General Rules for Optimal Orientation

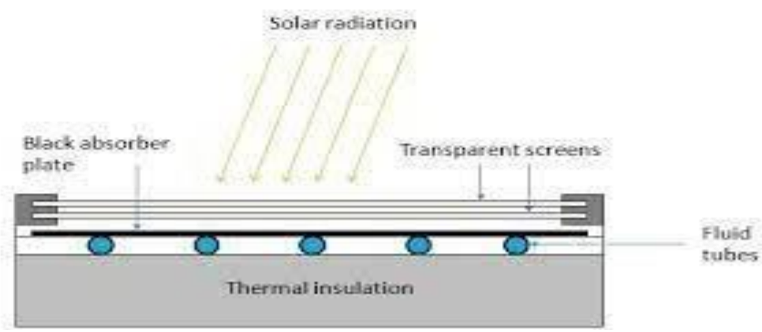
- **Fixed Flat Plate Collectors:** For maximum annual energy collection, fixed collectors should face the equator (true south in the Northern Hemisphere, true north in the Southern Hemisphere) and have a tilt angle approximately equal to the local latitude. For example, a collector in New Delhi, India (latitude approximately 28.6∘N), would ideally be tilted at an angle of around 28.6∘ and face true south. Small deviations in azimuth (up to 15∘ east or west) and tilt have a negligible impact on annual performance.
- **Seasonal Adjustments:** If the system is designed to maximize performance during a specific season, the tilt angle can be adjusted.
  - **Winter:** To maximize winter performance, the tilt angle should be increased by 10∘ to 15∘ from the latitude.
  - **Summer:** To maximize summer performance, the tilt angle should be decreased by 10∘ to 15∘ from the latitude.
- **Concentrating Collectors:** These collectors require sun-tracking systems to keep the reflecting surfaces pointed directly at the sun throughout the day.
  - **Single-axis tracking:** Typically used for parabolic troughs, the collector rotates to follow the sun's east-to-west movement.
  - **Dual-axis tracking:** Used for parabolic dishes and heliostats in power towers, this system allows the collector to follow the sun's position both east-to-west and north-to-south, ensuring the sun's rays are always perpendicular to the collector's aperture. This is essential for achieving the highest concentration of solar energy.

Solar Collectors:

Solar collectors are the key component of active solar-heating systems. Solar collectors gather the sun's energy, transform its radiation into heat, and then transfer that heat to water, solar fluid, or air. The solar thermal energy can be used in solar water heating systems, solar pool heaters, and solar space- heating systems. There are several types of solar collectors:

- Flat-plate collectors
- Evacuated-tube collectors

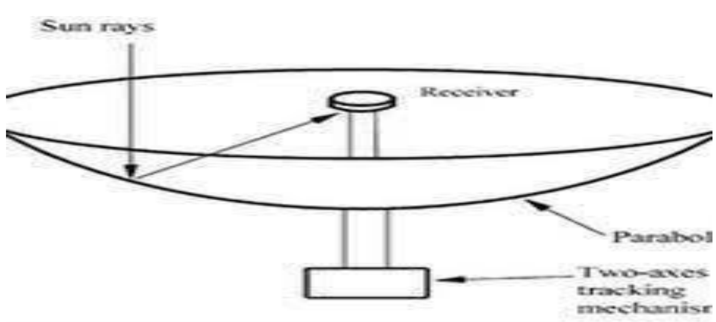
Flat-plate collectors:



Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors' heat liquid or air at temperatures less than 180°F.Flat-plate collectors are used for residential water heating and hedonic space-heating installations.

Concentrating collectors:

Point Focusing:



Here in parabola reflector the sun rays falls on to th3e vertex and reflects.

These reflected rays falls on the focus where absorber is there, which absorbs radiation and heat is transferred to the transfer fluid.

Line Focusing:

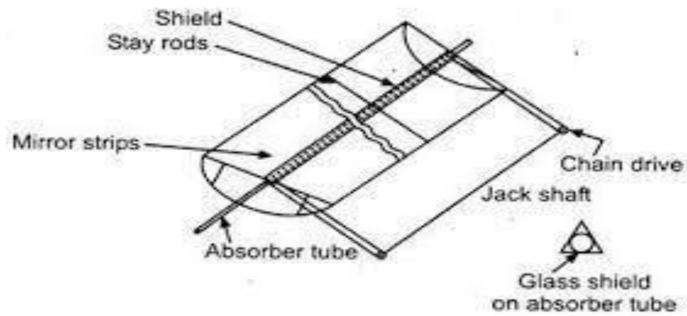
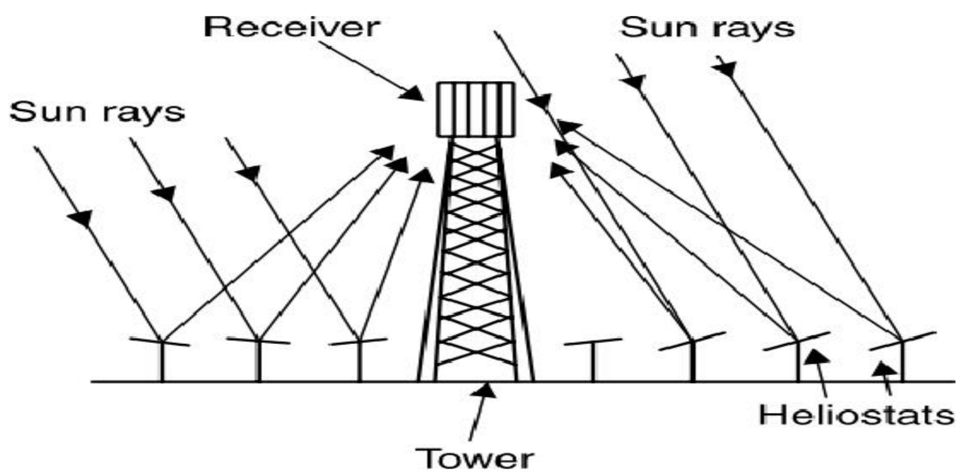


Fig. 3.5. Cylindrical parabolic system.

Here sun rays falls on cylindrical shape reflector has mirror strips and rays reflector and falls on the straight which contains absorber tube. The absorber tube contains fluid absorbs heat.

Heliostat:

This type of heliostat point focusing reflector used in large power generation
Here each mirror is called heliostat
There is a central receiver.



<u>Non concentrating type solar collector</u>	**<u>Concentrating type solar collector</u>**
In this collectors it absorbs the radiation as it is received on the surface of the collector	In these collectors solar radiation is converged from a large area into a smaller area using optical means. or in this case is first increase the concentration of radiation per unit area before absorbing it
Both beam and diffused radiation is required	**Concentration** can be obtained by reflection or refraction of **solar** radiation by the use of mirrors or lens
It is simple in construction and No need of	Solar tracker is required

solar tracker is required

High temperature is not obtained because of absence of optical concentration, the area from which heat is lost is large	High temperature can be obtained due to concentration of radiation
It is fixed on a rigid platform and because it requires less maintenance.	Diffused radiation cannot be obtained.
It has simple and compact construction	It has flexible construction.

SOLAR ENERGY STORAGE AND APPLICATIONS: Different methods, sensible, latent heat and stratified storage, solar ponds, solar applications- solar heating/cooling technique, solar distillation and drying, solar cookers, central power tower concept and solar chimney.

Solar Energy Storage

Solar energy is an intermittent source, available only during the day and affected by weather conditions. To ensure a continuous and reliable supply of energy, especially for applications like space heating or electricity generation, it is essential to store the collected solar energy. Solar energy storage can be broadly classified into different methods, primarily based on how the energy is stored.

1. Sensible Heat Storage

Sensible heat storage is the most common and straightforward method. It involves storing thermal energy by changing the temperature of a material without changing its phase (solid, liquid, or gas). The amount of energy stored is directly proportional to the mass of the storage material, its specific heat capacity, and the temperature change.

- **Materials:** Water, rocks, sand, and molten salts are common materials used for sensible heat storage. Water has a high specific heat capacity, making it an excellent medium for storing heat. Rocks and sand are often used in systems that use air as the heat transfer fluid.
- **Working Principle:** Solar collectors heat a fluid (like water or air), which is then circulated through a well-insulated tank containing the storage material. The heat is transferred to the storage material, raising its temperature. When energy is needed, the heat is extracted from the storage material to be used for heating or other applications.
- **Stratified Storage:** A special type of sensible heat storage, stratified storage, takes advantage of the natural tendency of hot water to rise and cold water to sink. In a stratified storage tank, the hottest water is kept at the top and the coldest water at the bottom. This stratification maintains a temperature gradient, allowing for the efficient withdrawal of hot water for use while introducing colder water at the bottom, without significant mixing. This improves the overall efficiency of the system.

2. Latent Heat Storage

Latent heat storage involves storing energy by changing the phase of a material, typically from solid to liquid. This method is also known as Phase Change Material (PCM) storage.

- **Materials:** PCMs are materials that melt and solidify at a specific temperature. Common examples include paraffin waxes, salt hydrates, and fatty acids.
- **Working Principle:** When a PCM is heated by a solar collector, it absorbs a large amount of energy at a constant temperature as it melts. This stored energy, called latent heat of fusion, is released when the PCM solidifies. The advantage of latent heat storage is its high energy density, meaning a large amount of energy can be stored in a smaller volume compared to sensible heat storage.
- **Applications:** Latent heat storage is particularly useful in solar heating/cooling systems where a constant temperature is required.

3. Solar Ponds

A solar pond is a large-scale solar thermal energy collector and storage system. It is a body of water with a salinity gradient that prevents convection, thereby trapping solar heat at the bottom.

- **Structure:** A typical solar pond has three layers:
  - **Surface Layer (Convective Zone):** A low-salinity, cool layer at the top.
  - **Middle Layer (Non-Convective Zone):** A layer with a salinity gradient, with salt concentration increasing with depth. This gradient prevents the hot, dense water at the bottom from rising, acting as an insulating layer.
  - **Bottom Layer (Storage Zone):** A high-salinity, hot layer at the bottom, where solar energy is absorbed and stored as heat.
- **Working Principle:** Sunlight penetrates the surface layers and is absorbed at the bottom, heating the high-salinity water. The high salt concentration makes the water at the bottom denser, preventing it from rising and transferring heat to the surface. This trapped heat can be extracted using a heat exchanger and used for various applications, such as power generation or industrial process heat.

Solar Applicat ons

Solar energy has a wide range of applications, from domestic use to large-scale industrial processes.

1. Solar Heat ng and Cooling Techniques

- **Solar Heating:** Solar energy is used to heat spaces or water. This can be done passively (e.g., through large south-facing windows in the Northern Hemisphere) or actively using solar collectors. Active solar heating systems use collectors to heat a fluid, which is then circulated to a storage tank or directly to a radiator or under floor heating system.
- **Solar Cooling:** This involves using solar thermal energy to drive a cooling process. The most common method is using an absorption chiller, which uses a heat source (from solar collectors) to drive a refrigeration cycle. This is particularly efficient as cooling is most needed when solar energy is most abundant.

2. Solar Dist llat on and Drying

- **Solar Distillation:** This process uses solar energy to purify water. A simple solar still consists of a basin with salty or contaminated water, covered by a transparent glass or plastic cover. Sunlight heats the water, causing it to evaporate. The water vapour then condenses on the cooler underside of the cover and drips into a collection trough, leaving the impurities behind.
- **Solar Drying:** A simple, low-cost method for preserving food and other agricultural products. Solar dryers can be natural (open-air drying) or forced-convection (using a fan to circulate air

heated by solar collectors). This method reduces spoilage, preserves nutrients, and is particularly useful in rural areas.

3. Solar Cookers

Solar cookers use sunlight as a heat source for cooking. They are simple, environmentally friendly devices that can save fuel and reduce indoor air pollution.

- **Types:**
  - **Box Cookers:** Insulated box with a transparent cover and a reflector to direct sunlight into the box.
  - **Panel Cookers:** A simple reflector system that directs sunlight onto a cooking pot.
  - **Parabolic Cookers:** Use a parabolic reflector to focus sunlight onto a single point, achieving high temperatures suitable for frying and boiling.

4. Central Power Tower Concept and Solar Chimney

These are large-scale applications for electricity generation.

- **Central Power Tower (or Solar Power Tower):** A large-scale solar thermal power plant. A field of thousands of sun-tracking mirrors, called heliostats, reflect and concentrate sunlight onto a central receiver at the top of a tower. The intense heat boils a fluid (e.g., molten salt), which then drives a steam turbine to generate electricity. This method can achieve very high temperatures, making it a highly efficient way to generate electricity.
- **Solar Chimney (Solar Updraft Tower):** A conceptual design for a renewable energy power plant. It consists of a large, black-painted collector area at ground level and a tall central chimney. Sunlight heats the air under the collector, causing it to rise. The hot air flows into the chimney, creating a strong updraft that drives turbines at the base of the chimney to generate electricity. While not yet a widespread technology, it is a promising concept for large-scale solar power generation.

Storage of Solar Energy – Thermal Storage

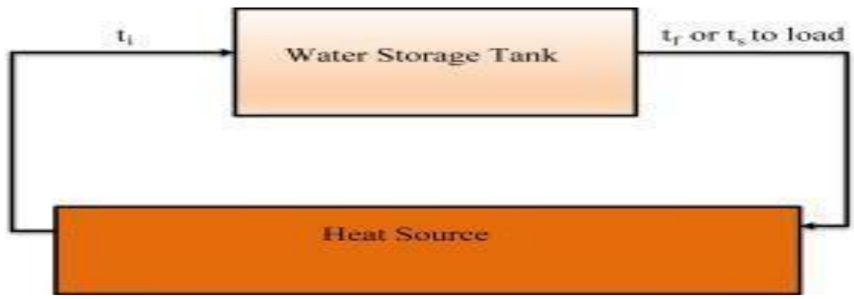
Thermal energy storage (TES) refers to the **accumulation of solar heat** for use at a later time, especially when solar radiation is unavailable (like at night or during cloudy weather). This is essential for making **solar thermal systems reliable and continuous** in their energy output.

Sensible heat storage:

The use of sensible heat energy storage materials is the easiest method of storage. In practice, water, sand, gravel, soil, etc. can be considered as materials for energy storage, in which the largest heat capacity of water, so water is used more often. In the 70’s and 80’s, the use of water and soil for cross- seasonal storage of solar energy was reported. But the material’s sensible heat is low, and it limits energy.

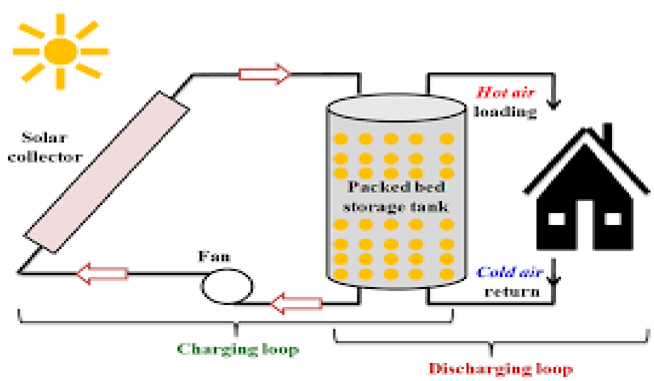
Sensible Heat Storage

- **Heat is stored by raising the temperature of a solid or liquid.**
- **Materials Used**: Water, rocks, molten salts, oils, sand, concrete.



Latent heat-storage:

Latent heat-storage units are storing thermal energy in latent (= hidden, dormant) mode by changing the state of aggregation of the storage medium. Applicable storage media are called "phase change materials" (PCM). Commonly salts crystal is used in low-temperature storage, such as sodium sulfate dehydrate /calcium chloride, sodium hydrogen phosphate 12-water. However, we must solve the cooling and layering issues in order to ensure the operating temperature and service life.



Latent Heat Storage

- **Uses Phase Change Materials (PCMs)** to store/release heat during **melting/freezing**.
- **Materials Used**: Paraffin wax, salts, eutectic compounds.
- **Advantages**:
  - Higher energy density than sensible heat storage.
  - Constant temperature during phase change.
- **Disadvantage**: More complex design and costlier materials.

. Thermochemical Energy Storage

- **Stores heat through reversible chemical reactions**.
- Heat is absorbed or released during breaking/forming of chemical bonds.

Advantages of Thermal Storage:

- Reduces mismatch between energy supply and demand.

- Improves reliability and efficiency of solar systems.
- Enables 24/7 power generation in solar thermal power plants.

Solar Energy applications

Energy from sun can be categorised in two ways: in the form of heat and light. We use the solar energy every day in many different ways. When we hang laundry outside to dry in the sun, we are using the solar heat to dry our clothes. Plants make their food in the presence of sunlight. Animals and humans get food from plants. Fossil fuels are actually *solar energy* stored millions and millions of years ago.

There is variety of products that uses solar energy. These products are called solar devices (or appliances) or solar thermal collectors. Solar thermal technologies uses the solar heatenergy to heat water or air for applicat ons such as space heat ng, pool heat ng and water heat ng for homes and businesses

Some of the major applications of solar energy are as follows

 Solar water and air heating

 Solar pumping

 Solar cooking

 Solar pumping

Solar Cooker

A 'solar cooker' is a device which uses the energy of direct sunlight to heat, cook or pasteurize food or drink. Many solar cookers currently in use are relatively inexpensive, low-tech devices, although some are as powerful or as expensive as traditional stoves, and advanced, large-scale solar cookers can cook for hundreds of people.

Because they use no fuel and cost nothing to operate, many non-profit organizations are promoting their use worldwide in order to help reduce fuel costs (especially where monetary reciprocity is low) and air pollution, and to slow down the deforestation and desertification caused by gathering firewood for cooking.

Solar cooking is a form of outdoor cooking and is often used in situations where minimal fuel consumption is important, or the danger of accidental fires is high, and the health and environmental consequences of alternatives are severe.

Types of solar cooker

1. For household cooking: Box type solar cooker

2. For community cooking: Concentrator type solar cookers

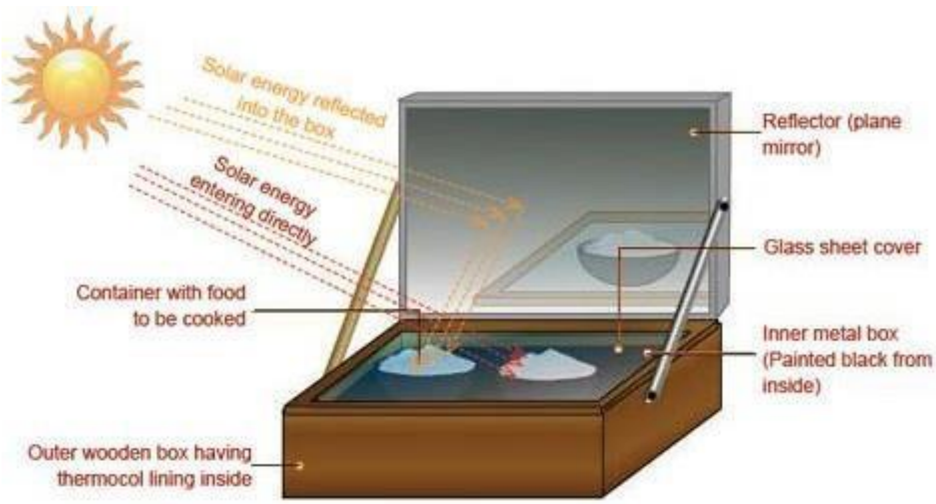
Box Type solar cooker

The solar rays penetrate through the glass covers and absorbed by blackened metal trays (Boxes) kept inside the cooker. The upper cover has two glass sheets each 3 mm thick fixed in the wooden frame with 20 mm distance between them. This prevents the loss of heat due to re radiation from blackened surface.

The loss due to convection is minimized by making the box air-light by providing a rubber strap all round between the upper lid and the box. Insulating material like glass wool saw dust or any other material is filled in the space which minimizes heat loss due to conduction.

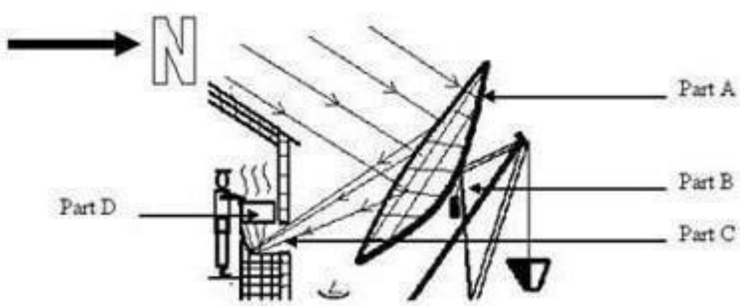
When this type of cooker is placed in the sun, the blackened surface starts absorbing sunrays and temperature rises. The food in the trays is cooked. The temperature of cooking depends upon the intensity of radiation. The size of a box type cooker is 50×50×12 cm.

Overall dimensions of the latest model are 60×60×20 cm. This type of cooker is termed as family solar cooker as it cooks sufficient dry food materials for a 49 family of 5 to 7 people. The temperature attained is about 100ºC. With the addition of single glass reflector, 15-20ºC more temperature is obtained and the cooking time is reduced.



Concentrator type solar cooker for community cooking

It works on the principle of solar energy concentration using a Reflecting Parabolic Solar Concentrator. A parabolic solar concentrator is used for concentrating solar radiation on a focal area where the cooking vessel is placed.



• Part A - Solar Concentrating Disc (Primary Reflector) - The disc which helps in concentrating solar energy to a focal point.

 Part B- Automatic Tracking System - With the help of a simple automatic mechanical tracking system the solar disc rotates in the direction of the movement of the Sun to give continuous and accurate solar energy concentration.

 Part C - Secondary Reflector - This is provided opening in the north-facing wall of the kitchen or the cooking place just below the cooking vessel. This reflector receives the concentrated solar radiation and reflects it

Merits of solar cooker

 No requirement of cooking gas or kerosene, electricity, coal or wood.

 No need to spend on fuel, as solar energy is available free.

 No loss of vitamins in the food: Food cooked in solar cooker is nutritious. About 10-20% of protein retention is more as compared to that in conventional cooking .Vitamin thiamine retention is about 20 to 30% more whereas vitamin A is retained 5 to 10% more when food is cooked in solar cooker.

 No orientation to sun is needed

 No attention is needed during cooking.

 No fuel, maintenance and recurring cost.

 Simple to use and fabricate.

 Solar cooking is pollution free and safe.

 Solar cookers come in various sizes. Based on the number of family members, the size of the cooker can be chosen.

 All cooking activities (like boiling, roasting) can be done using a solar cooker.

 There are government schemes which offer subsidies to purchase solar cookers.

Demerits of solar cooker

 Adequate sunshine is required for cooking: Cooking can be done only when there is sunshine.

 Takes longer time to cook food than the conventional cooking methods

 All types of foods cant are cooked.

Solar water heater

A solar water heating unit comprises a blackened flat plate metal collector with an associated metal tubing facing the general direction of the sun. The plate collector has a transparent glass cover above and a layer of thermal insulation beneath it. The metal tubing of the collector is connected by a pipe to an insulated tank that stores hot water during cloudy days.

The collector absorbs solar radiations and transfers the heat to the water circulating through the tubing either by gravity or by a pump.

This hot water is supplied to the storage tank via the associated metal tubing. This system of water heating is commonly used in hotels, guest houses, tourist bungalows, hospitals, canteens as well as domestic and industrial units.

It consists mainly of:

A thermal panel (solar collector) installed on the roof;

 A tank to store hot water;

 Accessories, such as a circulating pump to carry the solar energy from the collector to the tank, and a thermal regulator.

Small capacity domestic solar water heaters are also available in simpler design, in which the functions of the collector and storage tank are combined in one unit. The hot water is used for domestic purposes or meeting the needs of industries and commercial establishments.

Solar water heating systems can be classified into two categories:

(i) Natural circulation (thermo-syphon) system

(ii) Forced circulation system

Natural circulation water heating system

Basic elements of a solar water heating system are:

(i) Flat plate collector,
(ii) Storage tank,
(iii) Circulation system
(iv) Auxiliary heating system and
(v) Control of the system.

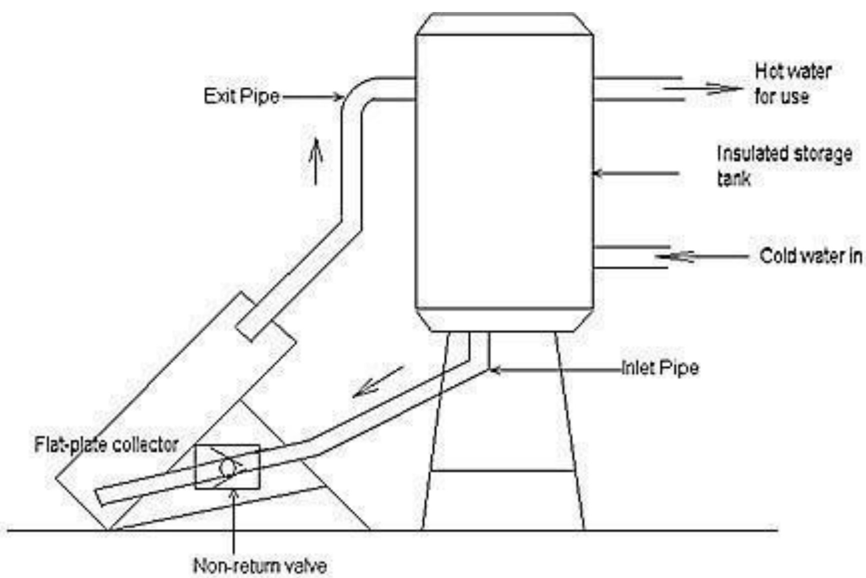
Natural circulation system consists of a tilted collector, with transparent cover plates, a separate, highly insulated water storage tank, and well-insulated pipes connecting the collector and storage tank.

The bottom of the storage tank is at least a foot higher than the top of the collector, and 52 no auxiliary energy is required to circulate water through it. Circulation occurs through natural convection, or thermo-siphoning.

When water in the collector is heated by the sun, it expands (becomes less dense) and rises up the collector, through a pipe and into the top of the storage tank. This forces cooler water at the bottom of the tank and flow out from storage tank by gravity, enter into the bottom of the collector through pipe provided at the bottom of the storage tank.

This water, in turn, is heated and rises up into the tank. As long as the sun shines the water will quietly circulate, getting warmer.

After sunset, a thermo-siphon system can reverse its flow direction and loss heat to the environment during the night. To avoid reverse flow, the top heater of the absorber should be at least 1 foot below the bottom of the storage tank. To provide heat during long, cloudy periods, an electrical immersion heater can be used as a backup for the solar system.



Forced circulation water heating system

The forced circulation water heating system is suitable for supplying hot water to community centres such as hostels, hotels etc., and industries. Large array of flat-plate collectors are then used and forced circulation is maintained with a water pump.

The restriction to keep storage tank at a higher level is not required, as done in the case of natural circulation water heating system. Depending on the size of storage tank, a group of flat plate collectors are selected and connected together.

The storage tank is maintained with cold water fully by connecting to a make-up water tank which is provided with ball-float control mechanism. The pump for maintaining the forced circulation is operated by an on-off controller which senses the difference between the temperature of water at the exit of collectors and a suitable location inside the storage tank.

When the temperature in the storage tank is reduced, the thermal controlling system operates the pump and cold water is pumped to the collectors. The cold water gets heated up in the collector and the flow to the storage tank. If the temperature of water in the storage tank reaches to a predetermined value, the pump automatically stop the pumping water from the tank to collector.

If the temperature of hot water falls, the pump starts working and water flows to collector. In the absence of solar energy, the auxiliary heater operated by electrical power is used. The auxiliary heater has to be kept in the storage tank

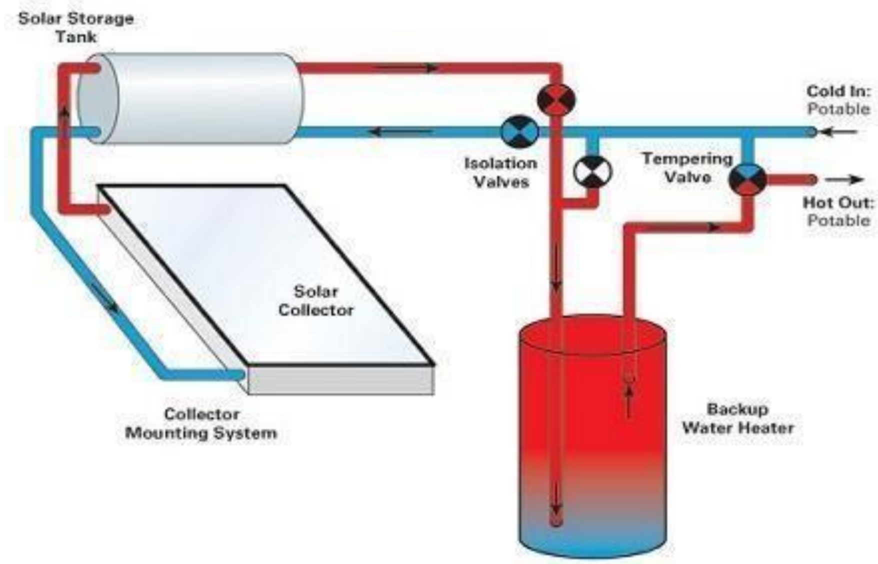


Fig: Solar water heating system

UNIT-IV

WIND ENERGY: Sources and potentials, horizontal and vertical axis windmills, performance Characteristics, Betz criteria, types of winds, wind data measurement.

WIND ENERGY

1. Sources and Potentials

- **Source**:
  - Wind energy originates from the **solar radiation** causing differential heating of the earth's surface, which creates pressure differences and wind currents.
- **Global Potential**:
  - The technically exploitable wind power potential is vast, estimated at ~ **6,000 GW** worldwide.
- **In India**:
  - Estimated potential: **over 300 GW** (MNRE, 2023) at 100m hub height.
  - High potential states: Tamil Nadu, Gujarat, Karnataka, Maharashtra, Andhra Pradesh, Rajasthan.

2. Horizontal and Vertical Axis Windmills

(a) Horizontal Axis Wind Turbines (HAWTs)

- **Features**: Rotor shaft parallel to ground; blades face the wind.
- **Advantages**:
  - High efficiency (40–50%).
  - Mature and widely used technology.
  - Large-scale power generation.
- **Disadvantages**:
  - Requires yaw mechanism to face wind.
  - Taller towers needed.
- **Examples**: Most modern wind farms.

(b) Vertical Axis Wind Turbines (VAWTs)

- **Features**: Rotor shaft vertical, wind direction not critical.
- **Types**:
  - **Darrieus rotor** (egg-beater shape, lift-based).
  - **Savonius rotor** (S-shaped, drag-based).
- **Advantages**:
  - Accepts wind from any direction (no yaw needed).
  - Easier to maintain (generator near ground).
- **Disadvantages**:
  - Lower efficiency.
  - Not suitable for large-scale power.

3. Performance Characteristics

- Power in Wind:

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

  where:

  - ρ = air density (1.225 kg/m³ at sea level)
  - A = swept area of rotor (πR² for HAWT, 2RH for VAWT)
  - V = wind speed
- Coefficient of Performance (Cp):

$$C_p = \frac{P_{extracted}}{P_{wind}}$$

  Efficiency is limited by Betz limit (~59.3%).
- Tip Speed Ratio (λ):

$$\lambda = \frac{\text{Blade Tip Speed}}{\text{Wind Speed}} = \frac{\omega R}{V}$$

  - Determines optimal performance.

    - For HAWTs: λ = 6–8; For Savonius: λ < 1.

4. Betz Criteria (Betz Limit)

- **Maximum extractable power** from wind is 59.3% of total available.
- Derived from momentum theory:

$$C_{p,max} = \frac{16}{27} = 0.593$$

- No wind turbine can capture more than this fraction due to flow continuity.

---

5. Types of Winds

1. **Planetary Winds**: Large-scale, permanent winds (trade winds, westerlies).
2. **Local Winds**: Region-specific (land–sea breeze, mountain–valley winds).
3. **Seasonal Winds**: Monsoons.
4. **Turbulent Winds**: Random fluctuations caused by obstacles/terrain.
5. **Gradient Winds**: Due to pressure gradient and Coriolis effect.

6. Wind Data Measurement

- **Purpose**: To determine wind speed, direction, and distribution for site selection.
- **Instruments**:
  - **Anemometer**: Measures wind speed (cup, propeller, ultrasonic).
  - **Wind Vane**: Measures wind direction.
  - **LIDAR/SODAR**: Remote sensing of wind profiles.
- **Data Parameters**:
  - Mean wind speed, turbulence intensity.
  - Weibull distribution (k = shape factor, c = scale factor).
  - Wind rose diagrams (directional frequency).
- **Measurement Height**: Typically at **hub height (50–120 m)** for accuracy.

==

Types of wind turbines:

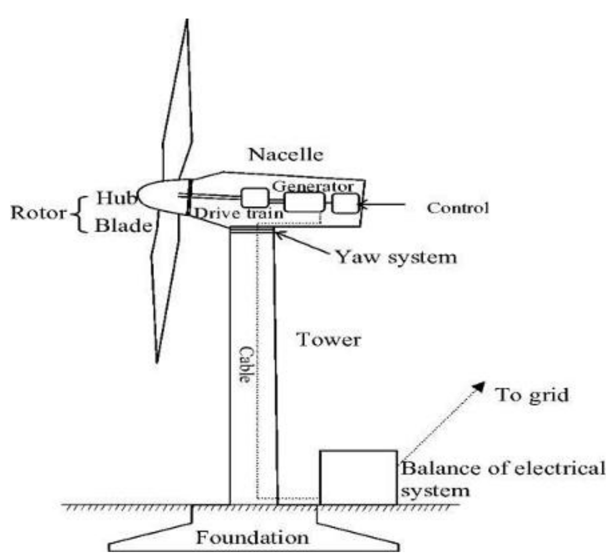
Wind turbines can be separated into two basic types determined by which way the turbine spins. Wind turbines that rotate around a horizontal axis are more common (like a wind mill), while vertical axis wind turbines are less frequently used (Savonius and Darrieus are the most common in the group).

<u>Basic Components of Wind Energy Conversion Systems (WECS)</u>

1. **Rotor** – Converts wind energy into mechanical energy.
2. **Gearbox** – Steps up or steps down the rotational speed.
3. **Generator** – Converts mechanical energy into electrical energy.
4. **Nacelle** – Housing for components like gearbox and generator.
5. **Tower** – Supports the turbine and provides elevation.
6. **Yaw System** – Aligns rotor with the wind direction.
7. **Brake System** – Stops the rotor in case of faults or high wind.
8. **Controller** – Manages operation, cut-in, cut-out, and safety mechanisms.

1. Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines (HAWT) are the common style that most of us think of a wind turbine. A HAWT has a similar design to a wind mill, it has blades that look like a propeller that spin on the horizontal axis.



Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbine are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.

Important point to remember recording HAWT is

• Lift is the main force
• Much lower cyclic stress
• 95% of the existing turbines are HAWTs
• Nacelle is placed at the top of the tower
• Yaw mechanism is required

Advantages:

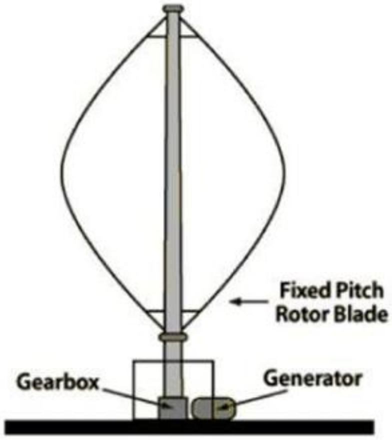
1) The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increaseby20%and the power output by34%.
2) High efficiency, since the blades always move perpendicular to the wind, receiving power through the whole rotation.

Disadvantages:

 Massive tower construction is required to support the heavy blades, gearbox, and generator.
 Components of horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lift editor position.
 Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.
 Download variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower‘s wind shadow (for this reason, the majority of HAWTs use an up wind design, with the rotor facing the wind in front of the tower).
 HAWTs require an additional yaw control mechanism to turn the blade steward the wind.

HAWTs generally require a braking or yawing device in high winds to stop the turbine.

1. **Vertical Axis Wind Turbines(VAWT)**



Vertical axis

Vertical wind turbines (VAWTs), have the main rotor shaft arranged vertically .The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This makes them suitable in places where the wind direction is highly variable or has turbulent winds. With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT is that, it generally creates drag when rotating into the wind.

Important points to remember for VAWT:

• Nacelle is placed at the bottom.
• Drag is the main force
• Yaw mechanism is not required
• Lower starting torque
• Difficulty in mounting the turbine
• Unwanted fluctuations in the power output

VAWT Advantages:

• No yaw mechanisms is needed
• AVAWT can be located nearer the ground, making it easier to maintain the moving parts.
• VAWT shaves lower wind start up speeds than the typical HAWTs.
• VAWTs may be built at locations where taller structures are prohibited.
• VAWTs situated close to the ground can take advantage of locations where rooftops, means hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

VAWT Disadvantages:

• In contrast to HAWT, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring air foil surfaces to the wind leads to inherently lower efficiency.

==

BIO-MASS: Principles of bio-conversion, anaerobic/aerobic digestion, types of bio-gas digesters, gas yield, utilization for cooking, bio fuels, I.C. engine operation and economic aspects.

BIOMASS ENERGY

1. Principles of Bio-Conversion

- **Definition**: Biomass is organic material derived from plants, animals, and organic waste. It stores solar energy in chemical bonds.
- **Bio-conversion**: Conversion of biomass into useful forms of energy (heat, electricity, fuels).
- **Methods**:
  - **Thermo-chemical conversion** (combustion, gasification, pyrolysis).
  - **Bio-chemical conversion** (anaerobic digestion, aerobic digestion, fermentation).
- **Advantages**: Renewable, reduces waste, carbon neutral, rural employment.

---

2. Anaerobic and Aerobic Digestion

- **Anaerobic Digestion**:
  - Micro-organisms break down biomass **without oxygen**.
  - Produces **biogas** (mainly CH_4 and CO_2) + slurry (fertilizer).
  - Steps: Hydrolysis → Acidogenesis → Acetogenesis → Methanogenesis.
- **Aerobic Digestion**:

- Decomposition of biomass **in presence of oxygen**.
- Produces CO_2, H_2O, heat, and compost.
- Used in composting and wastewater treatment.

3. Types of Biogas Digesters

1. **Floating Drum Type (KVIC Model)**
   - Steel drum floats on slurry, rises & falls with gas production.
   - Easy to operate, but corrosion of drum is a problem.
2. **Fixed Dome Type (Janata Model)**
   - Masonry dome constructed underground, gas stored in fixed chamber.
   - Low maintenance, longer life, widely used in India.
3. **Bag Type (Balloon Digester)**
   - Made of plastic or rubberized material.
   - Portable, low cost, but short life span.

---

4. Gas Yield

- **Biogas composition**:
  - Methane (CH_4): **50–70%**
  - Carbon dioxide (CO_2): **30–40%**
  - Others (H_2, N_2, H_2S): traces
- **Yield**:
  - 1 kg cattle dung → **0.04 m³ biogas**.
  - Daily requirement per family (~5 members): **2–3 m³ biogas**.

---

5. Utilization of Biogas

- **Cooking & Heating**: Replaces LPG, firewood, kerosene.
- **Lighting**: Biogas lamps.
- **Power Generation**: Used in dual-fuel I.C. engines or gas turbines.
- **Fertilizer**: Slurry used as rich organic manure.

---

6. Biofuels

- **Solid biofuels**: Wood, briquettes, pellets.
- **Liquid biofuels**:
  - **Ethanol** (from sugarcane, maize → blended with petrol).
  - **Biodiesel** (from jatropha, pongamia, sunflower oils → blended with diesel).
- **Gaseous biofuels**: Biogas, producer gas, syngas.

---

7. I.C. Engine Operation with Biogas

- **Biogas in engines**:
    - Can be used in **dual-fuel mode** with diesel (20–30% diesel, rest biogas).
    - Can also run in **spark ignition engines** (after CO_2 removal).
- **Applications**:
    - Small-scale rural power generation.
    - Agricultural pumps, flour mills.

8. Economic Aspects

- **Advantages**:
    - Low-cost energy for rural households.
    - Reduces dependence on firewood, LPG, kerosene.
    - Produces manure (additional benefit).
    - Reduces GHG emissions.
- **Limitations**:
    - High initial cost for plant construction.
    - Seasonal availability of feedstock.
    - Requires community participation for large-scale plants.

===

BIO MASS ENERGY

Introduction:

Biomass energy is organic matter produced by plants which growth both on land and in water. The source of all energy in biomass is the sun, the biomass acting as a kind of chemical energy store. Biomass is constantly undergoing a complex series of physical and chemical transformations and being regenerated while giving off energy in the form of heat to the atmosphere.

- Solar energy--> photo synthesis--> Biomas--> energy generation

- **Solid biomass** - the use of trees, crop residues, animal and human waste (all though not strictly a solid biomass source, it is often included in this category for the sake of convenience), household or industrial residues for direct combustion to provide heat. Often the solid biomass will undergo physical processing such as cutting, chipping, briquetting, etc. but retains its solid form.

Biogas - biogas is obtained by anaerobically (in an air free environment) digesting organic material to produce a combustible gas known as methane. Animal waste and municipal waste are two common feed stocks for anaerobic digestion.

Aerobic Digestion:

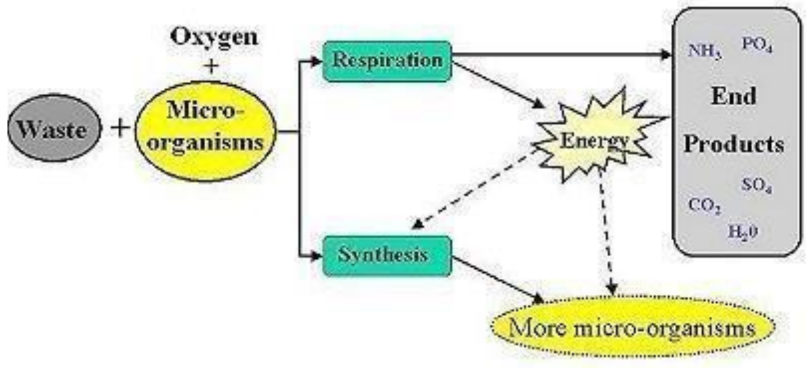
Aerobic digestion of waste is the natural biological degradation and purification process in which bacteria that thrive in oxygen-rich environments break down and digest the waste.

During oxidation process, pollutants are broken down into carbon dioxide (CO_2), water (H_2O), nitrates, sulphates and biomass (microorganisms). By operating the oxygen supply with aerators, the process can be significantly accelerated. Of all the biological treatment methods, aerobic digestion is the most widespread process that is used throughout the world.

Advantages :

- Aerobic bacteria are very efficient in breaking down waste products.
- The result of this is; aerobic treatment usually yields better effluent quality that that obtained in anaerobic processes.

- The aerobic pathway also releases a substantial amount of energy.
- A portion is used by the microorganisms for synthesis and growth of new microorganisms.



Aerobic Decomposition:

A biological process, in which, organisms use available organic matter to support biological activity. The process uses organic matter, nutrients, and dissolved oxygen, and produces stable solids, carbondioxide, and more organisms. The microorganisms which can only survive in aerobic conditions are known as aerobic organisms.

In sewer lines the sewage becomes anoxic if left for a few hours and becomes anaerobic if left for more than 1 1/2 days. Anoxic organisms work well with aerobic and anaerobic organisms. Facultative and anoxic are basically the same concept.

Anaerobic Digestion:

Anaerobic digestion is a complex biochemical reaction carried out in a number of steps by several types of microorganisms that require little or no oxygen to live. During this process, a gas that is mainly composed of methane and carbon dioxide, also referred to as biogas, is produced. The amount of gas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition and gas production.

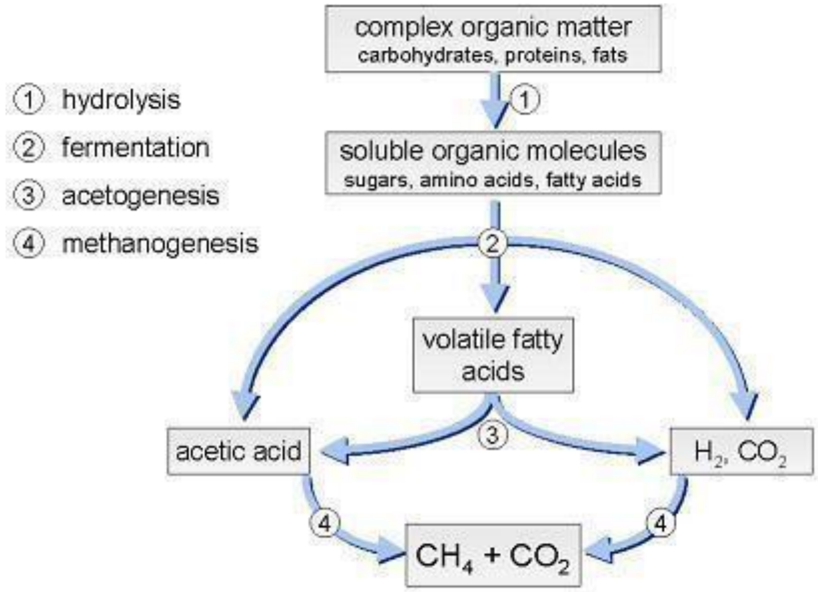
Anaerobic digestion occurs in four steps:

• Hydrolysis : Complex organic matter is decomposed into simple soluble organic molecules using water to split the chemical bonds between the substances.

• Fermentation or Acidogenesis: The chemical decomposition of carbohydrates by enzymes, bacteria, yeasts, or molds in the absence of oxygen.

• Acetogenesis: The fermentation products are converted into acetate, hydrogen and carbon dioxide by what are known as acetogenic bacteria.

• Methanogenesis: Is formed from acetate and hydrogen/carbon dioxide by methanogenic bacteria.



Advantages of Anaerobic Digestion:

Wastewater pollutants are transformed into methane, carbon dioxide and smaller amount of bio-solids. The biomass growth is much lower compared to those in the aerobic processes. They are also much more compact than the aerobic bio-solids.

Biomass two types

- Traditional solid mass (wood and agriculture residue)

- Non Traditional form (liquid fuels)

Based on Category – 3 types

1) Is to burn the biomass directly & get the energy

2) Is converted in to ethanol(ethyl alcohol) and methonol (methyl alcohol) , liquid form

3) Fermentation of biomass to obtain a gaseous fuel called biogas

Bio mass conversion :

Bio conversion taken in different forms

- Direct combustion of wood

- Thermo chemical conversion

Bio chemical conversion

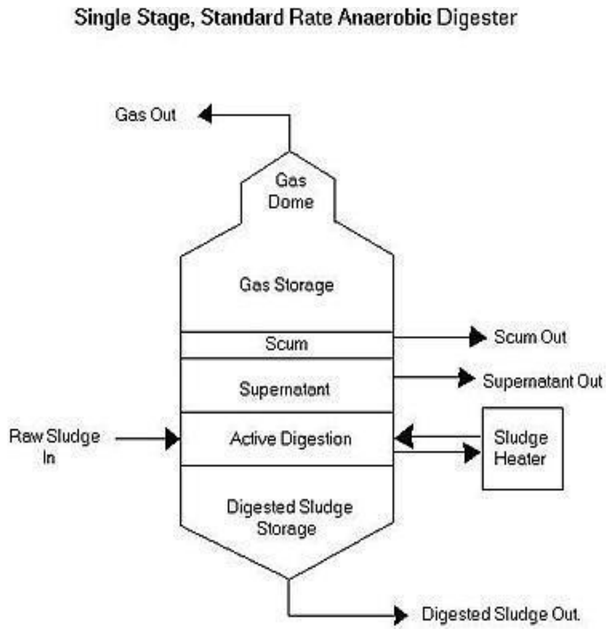
Classification of biogas plants:

1) Continuous and batch type
- Single stage
- Double stage

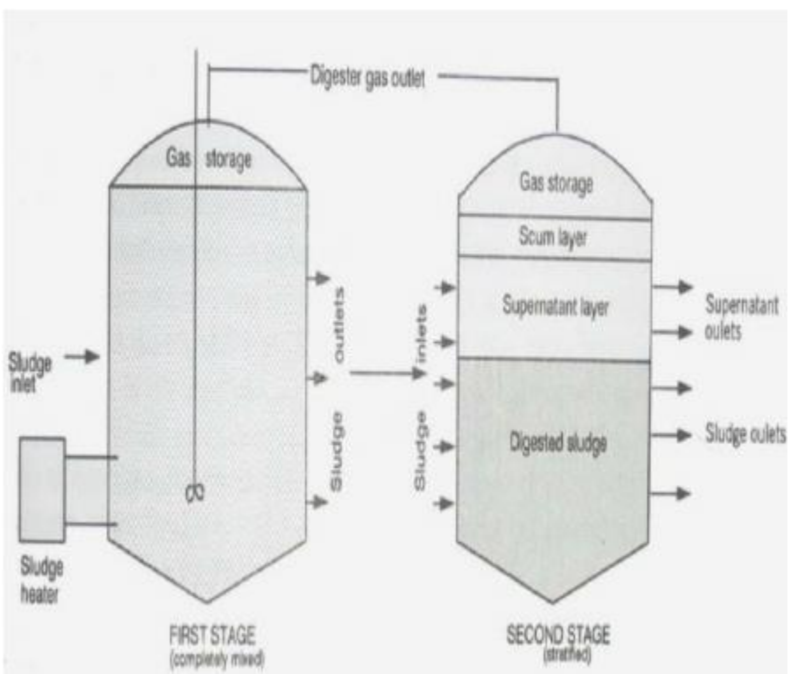
2) Dome and drum type
- The floating gas holder digester

- Fixed dome digester

Single stage:

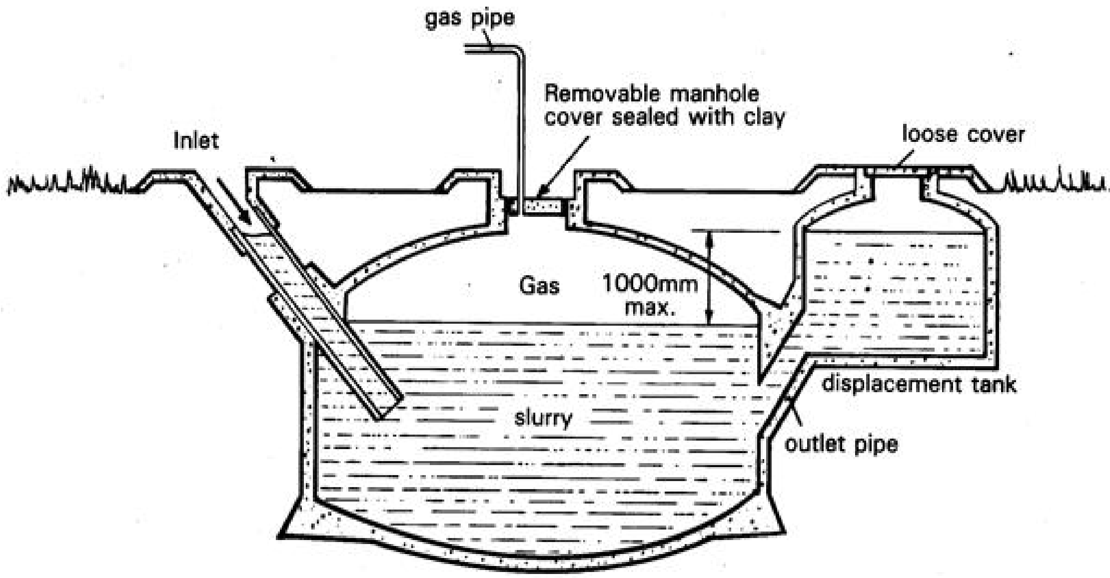


This refers to mixed fermentation with only one biogas digester (or fermentation device), and its fermentation process is only carried out in one fermentation digester. The equipment for single-stage fermentation is simple, but its condition control is difficult.



In order to improve the digestibility and removal rate of organic matter, a two-stage or multistage biogas fermentation process has been developed. This type of fermentation is characterized by fermentation in two or more connected fermentation ponds. The raw materials are decomposed and gas is produced in the first fermentation pool over a certain period of time, then the feed liquid is transferred from the first fermentation pool to the second or other fermentation pools for further fermentation. The fermentation process has a long detention period and decomposes organic matter completely, but the investment cost is higher.

Fixed dome type:



A fixed-dome plant comprises of a closed, dome-shaped digester with an immovable, rigid gas-holder and a displacement pit, also named compensation tank'. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gasholder, the gas pressure is low.

Digester:

The digesters of fixed-dome plants are usually masonry structures, structures of cement and ferro-cement exist. Main parameters for the choice of material are:

Technical suitability (stability, gas- and liquid tightness);

cost-effectiveness;

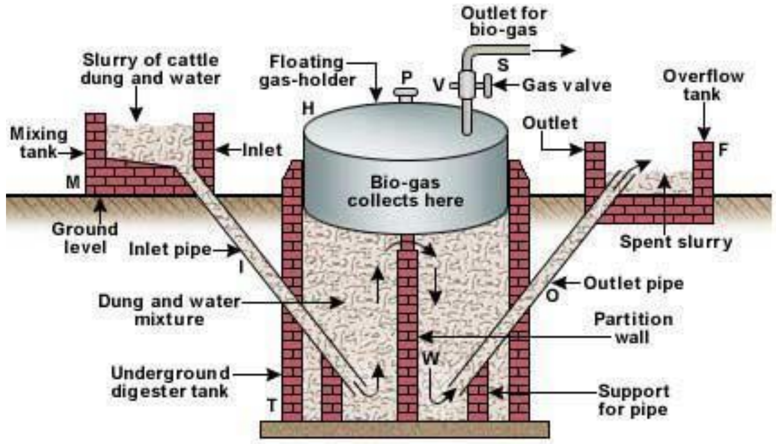
- availability in the region and transport costs;
- availability of local skills for working with the particular building material.

Fixed dome plants produce just as much gas as floating-drum plants, if they are gas-tight. However, utilization of the gas is less effective as the gas pressure fluctuates substantially. Burners and other simple appliances cannot be set in an optimal way. If the gas is required at constant pressure (e.g., for engines), a gas pressure regulator or a floating gas-holder is necessary.

Advantages: Low initial costs and long useful life-span; no moving or rusting parts involved; basic design is compact, saves space and is well insulated; construction creates local employment.

Disadvantages: Masonry gas-holders require special sealants and high technical skills for gas-tight construction; gas leaks occur quite frequently; fluctuating gas pressure complicates gas utilization; amount of gas produced is not immediately visible, plant operation not readily understandable; fixed dome plants need exact planning of levels; excavation can be difficult and expensive in bedrock.

Fixed dome plants can be recommended only where construction can be supervised by experienced biogas technicians.



Floating gas-holder type bio-gas plant.

In the past, floating-drum plants were mainly built in India. A floating-drum plant consists of a cylindrical or dome shaped digester and a moving, floating gas-holder, or drum. The gas-holder floats either directly in the fermenting slurry or in a separate water jacket. The drum in which the biogas collects has an internal and/or external guide frame that provides stability and keeps the drum upright. If biogas is produced, the drum moves up, if gas is consumed, the gas holder sinks back.

Floating-drum plants are used chiefly for digesting animal and human feces on a continuous feed mode of operation, i.e. with daily input. They are used most frequently by small- to middle-sized farms (digester size: 5-15m3) or in institutions and larger agro-industrial estates(digester size: 20-100m3).

Advantages: Floating-drum plants are easy to understand and operate. They provide gas at a constant pressure, and the stored gas-volume is immediately recognizable by the position of the drum. Gas-tightness is no problem, provided the gasholder is de-rusted and painted regularly.

Disadvantages: The steel drum is relatively expensive and maintenance-intensive. Removing rust and painting has to be carried out regularly. The life-time of the drum is short (up to 15 years; in tropical coastal regions about five years). If fibrous substrates are used, the gas-holder shows a tendency to get "stuck" in the resultant floating scum.

UNIT-V

GEOTHERMAL ENERGY: Origin, Applications, Types of Geothermal Resources, Relative Merits
OCEAN ENERGY: Ocean Thermal Energy; Open Cycle & Closed Cycle OTEC Plants, Environmental Impacts, Challenges
FUEL CELLS: Introduction, Applications, Classification, Different Types of Fuel Cells Such as Phosphoric Acid Fuel Cell, Alkaline Fuel Cell, PEM Fuel Cell, MC Fuel Cell.

GEOTHERMAL ENERGY

1. Origin of Geothermal Energy

- Geothermal energy is the **heat stored beneath the Earth's surface**, which can be used for power generation and direct heating.
- The Earth's internal heat originates from:
  1. **Primordial Heat** – residual heat left during the Earth's formation (about 4.5 billion years ago).
  2. **Radioactive Decay** – continuous decay of radioactive isotopes like Uranium-238, Thorium-232, and Potassium-40 in the Earth's crust and mantle generates heat.
  3. **Tectonic and Volcanic Activity** – heat is concentrated along plate boundaries, rift zones, and volcanic regions.
  4. **Heat Flow Mechanism** – conduction through rocks and convection by circulating water transport heat towards the surface.
- The temperature increases with depth due to the **geothermal gradient** (average 25–30 °C per km in normal crust, higher in volcanic regions).

2. Applications of Geothermal Energy

A. Electricity Generation

- **Dry Steam Plants** – use natural underground steam directly to turn turbines (e.g., Larderello, Italy).
- **Flash Steam Plants** – high-pressure hot water is depressurized (flashed) into steam, driving turbines.
- **Binary Cycle Plants** – hot water transfers heat to a secondary fluid (low boiling point, like isobutane), which vaporizes and runs the turbine.

B. Direct Heat Uses

- **District Heating Systems** – supply hot water to heat buildings (common in Iceland).
- **Agriculture** – greenhouse heating, soil warming, drying of crops.
- **Aquaculture** – maintaining optimal temperatures for fish farming.
- **Industrial Applications** – pulp and paper industry, textile dyeing, milk pasteurization, chemical processing.
- **Recreation** – hot springs, spas, swimming pools.

C. Geothermal Heat Pumps (Ground Source Heat Pumps)

- Use shallow underground temperatures (10–20 °C) for space heating/cooling.
- Widely used in residential and commercial buildings.

3. Types of Geothermal Resources

1. **Hydrothermal Resources (Most common, currently used)**
   - **Hot Water Reservoirs** – hot water found in aquifers and hot springs.
   - **Steam Reservoirs** – rare natural dry steam sources (e.g., The Geysers, California).
2. **Geopressurized Resources**
   - Deep reservoirs under pressure, containing hot brines and dissolved methane.
   - Potentially valuable but technologically challenging.
3. **Hot Dry Rock (HDR) / Enhanced Geothermal Systems (EGS)**
   - Found where rocks are hot but dry (no water present).
   - Artificial fractures are created, water is injected, heated by rocks, and recovered as steam.
   - Experimental stage but promising for future expansion.
4. **Magma Resources**
   - Direct use of heat from molten rock.
   - Extremely high potential but still experimental.

4. Relative Merits of Geothermal Energy

Advantages

- **Renewable and Sustainable** – continuously replenished by Earth's heat.
- **Eco-friendly** – minimal greenhouse gas emissions compared to fossil fuels.
- **Reliable and Base-load Power** – unlike solar/wind, operates continuously (24/7).
- **High Efficiency** – modern plants can achieve high conversion efficiency.
- **Dual Applications** – suitable for both power generation and direct heating.
- **Low Operating Costs** – after initial setup, running costs are relatively low.

Disadvantages / Limitations

- **Geographic Limitation** – only feasible in tectonically active regions (e.g., Iceland, Philippines, India's Himalayas).
- **High Initial Cost** – exploration and deep drilling are expensive.
- **Resource Depletion Risk** – excessive withdrawal may reduce reservoir temperature or pressure.
- **Environmental Concerns** – may release toxic gases like H_2S, CO_2, and cause surface subsidence.
- **Scaling and Corrosion** – geothermal fluids often contain dissolved minerals that corrode equipment.

5. Examples in India

- **Puga Valley (Ladakh, J&K)** – high geothermal potential.
- **Tattapani (Chhattisgarh)** – hot spring region.
- **Bakreshwar (West Bengal), Manikaran (Himachal Pradesh), Tapoban (Uttarakhand)** – geothermal activity sites.
- **Cambay Graben (Gujarat)** – promising geothermal exploration site.

Ocean Energy: Ocean Thermal Energy Conversion (OTEC)

1. Introduction to Ocean Thermal Energy

- **Definition**: Ocean Thermal Energy is the energy derived from the temperature difference between the warm surface water of the ocean (heated by the sun) and the cold deep water at depths (~1000 m).
- **Principle**: Based on the **Rankine cycle** or **thermodynamic cycles** using low-boiling point fluids.
- **Temperature Gradient Requirement**: Minimum temperature difference of **20°C** between surface and deep water is necessary for efficient operation.
- **Global Potential**: Oceans cover ~70% of Earth's surface → vast and renewable energy resource.
- **OTEC** = *Ocean Thermal Energy Conversion* technology used to harness this energy.

2. Types of OTEC Plants

(a) Open Cycle OTEC

- **Working Principle**: Uses warm seawater directly as the working fluid.
- **Process**:
  1. Warm seawater (25–30°C) is evaporated under low pressure in a vacuum chamber.
  2. The steam produced drives a **low-pressure turbine**.
  3. After expansion, the steam is condensed using **cold deep seawater** (4–5°C).
- **Byproduct**: Produces **desalinated freshwater** (important for arid coastal regions).
- **Advantages**:
  - Freshwater production.
  - Simple design (no separate working fluid).
- **Limitations**:
  - Low efficiency due to low-pressure steam.
  - Large turbines required.

(b) Closed Cycle OTEC

- **Working Principle**: Uses a **secondary working fluid** (e.g., ammonia, propane, freon) with a low boiling point.
- **Process**:
  1. Warm seawater passes through a **heat exchanger** and vaporizes the working fluid.
  2. The vapor expands and drives a turbine.
  3. Cold deep seawater is used in another heat exchanger to condense the vapor back to liquid.
  4. The cycle repeats in a closed loop.
- **Advantages**:
  - Compact system.
  - Can operate continuously.
- **Limitations**:
  - Complex and costly heat exchangers.
  - No freshwater production.

(c) Hybrid Cycle OTEC

- Combination of **open** and **closed** cycles.
- Uses open cycle to produce **desalinated water** and closed cycle for **power generation**.
- More efficient and multipurpose.

3. Environmental Impacts of OTEC

Positive Impacts

- **Clean & Renewable**: No greenhouse gas emissions, minimal pollution.
- **Freshwater Supply**: Open cycle & hybrid OTEC provide potable water.
- **Climate Benefits**: May reduce ocean surface temperature slightly (localized cooling).

Negative Impacts

- **Marine Ecosystem Disturbance**:
  - Mixing warm surface and cold deep water alters local ecology.
  - Nutrient upwelling may affect plankton and fish populations.
- **Thermal Pollution**: Discharge of used water can disrupt local marine temperature balance.
- **Construction Impact**: Large structures may disturb habitats (coral reefs, coastal ecosystems).
- **Risk of Leakage**: In closed cycle OTEC, leakage of working fluids (like ammonia) can be harmful.

4. Challenges in OTEC

1. **Low Efficiency**:
   - Carnot efficiency is very low (~2–3%) due to small temperature differences.
   - Requires large volumes of water to generate small amounts of power.
2. **High Capital Cost**:
   - Expensive offshore structures, long cold-water pipes, and large heat exchangers.
3. **Technical Difficulties**:
   - Deep seawater pipes (~1000 m) must withstand high pressure and ocean currents.
   - Maintenance in marine environments is difficult.
4. **Location Specific**:
   - Only feasible in **tropical regions** (latitudes 20°N–20°S) where temperature difference is sufficient.
5. **Environmental Concerns**:
   - Ecological balance of ocean water layers may be disturbed.
6. **Grid Connection**:
   - Offshore OTEC plants require expensive undersea transmission cables.

5. Applications of OTEC

- **Electricity Generation** (main purpose).
- **Desalinated Freshwater Production** (open/hybrid cycles).
- **Aquaculture Support**: Nutrient-rich cold water can enhance fish farming.
- **Air Conditioning & Refrigeration** (using cold seawater).
- **Hydrogen Production**: OTEC plants can power electrolysis units for hydrogen fuel.

6. Prospects of OTEC

- **India's Potential**:
  - Lakshadweep, Andaman & Nicobar Islands, Tamil Nadu coast → suitable sites.
  - NIOT (National Institute of Ocean Technology) has worked on 1 MW demonstration OTEC plant near Tamil Nadu.
- **Global Potential**:
  - Best in equatorial/tropical oceans (Hawaii, Caribbean, Pacific Islands, Southeast Asia).

Summary

- **Ocean Thermal Energy Conversion (OTEC)** uses temperature differences in ocean water for power generation.
- **Open Cycle**: Direct seawater evaporation, produces freshwater.
- **Closed Cycle**: Uses low-boiling fluid in a heat exchanger.
- **Hybrid Cycle**: Combination of both.
- **Benefits**: Renewable, clean energy, freshwater production, aquaculture benefits.
- **Challenges**: Low efficiency, high cost, environmental impacts, location-specific feasibility.

FUEL CELLS

1. Introduction

- A **fuel cell** is an electrochemical device that converts the chemical energy of a fuel (commonly hydrogen) and an oxidant (oxygen or air) directly into **electricity, heat, and water** without combustion.
- It works on the principle of redox (oxidation-reduction) reactions.
- Unlike batteries, which store energy internally, fuel cells generate electricity as long as fuel and oxidant are continuously supplied.
- They have **high efficiency** (40–60% electrical, up to 85% in cogeneration systems) and are environmentally friendly since water is the main by-product when hydrogen is used.

2. Applications of Fuel Cells

1. **Transportation**
   - Power for cars, buses, trucks, submarines, and spacecraft.
   - Zero-emission vehicles (hydrogen fuel cell vehicles).
2. **Stationary Power Generation**
   - Power plants for residential, commercial, and industrial use.
   - Distributed power generation and backup systems.
3. **Portable Power**
   - Power supply for laptops, mobile phones, military equipment, and remote communication devices.
4. **Space Applications**
   - Used by NASA for electricity and drinking water in space missions (Apollo, Space Shuttle).
5. **Cogeneration (Combined Heat & Power - CHP)**
   - Produces both electricity and useful heat for domestic or industrial heating.

3. Classification of Fuel Cells

Fuel cells are generally classified based on:

1. **Electrolyte used**
   - Phosphoric acid, alkaline, polymer electrolyte membrane, molten carbonate, solid oxide, etc.
2. **Operating temperature**
   - Low temperature (<200°C): e.g., PEMFC, AFC
   - Intermediate temperature (200–600°C): e.g., PAFC
   - High temperature (>600°C): e.g., MCFC, SOFC
3. **Type of Fuel**
   - Hydrogen, hydrocarbons (natural gas, methanol), or reformed fuels.

4. Different Types of Fuel Cells

A. Phosphoric Acid Fuel Cell (PAFC)

- **Electrolyte:** Concentrated liquid phosphoric acid (H_3PO_4)
- **Operating Temperature:** ~150–220 °C
- **Fuel:** Pure hydrogen or hydrogen-rich gas
- **Electrodes:** Porous carbon electrodes with platinum catalyst
- **Features:**
  - First commercialized fuel cells for stationary applications
  - Electrical efficiency: 40–45%
  - Tolerant to CO_2 impurities in the fuel
- **Applications:** Power plants, hospitals, commercial buildings (200 kW – 10 MW range).

B. Alkaline Fuel Cell (AFC)

- **Electrolyte:** Aqueous KOH (potassium hydroxide) solution
- **Operating Temperature:** 60–90 °C (low temp), up to 250 °C (high temp)
- **Fuel:** Pure hydrogen; oxidant is oxygen/air
- **Features:**
  - High efficiency (up to 60%)
  - Very sensitive to CO_2 contamination (requires pure oxygen and hydrogen)
- **Applications:** NASA space missions (electricity + water production), submarines, military.

C. Proton Exchange Membrane Fuel Cell (PEMFC)

- **Electrolyte:** Solid polymer proton-conducting membrane (e.g., Nafion)
- **Operating Temperature:** 50–100 °C
- **Fuel:** Pure hydrogen, oxidant is oxygen/air
- **Catalyst:** Platinum-based catalyst
- **Features:**
  - High power density
  - Low operating temperature → fast startup
  - Compact and lightweight

- Sensitive to CO, requires clean fuel
- **Applications:** Vehicles (cars, buses), portable power systems, residential backup power.

D. Molten Carbonate Fuel Cell (MCFC)

- **Electrolyte:** Molten carbonate salts (Li_2CO_3–K_2CO_3 mixture)
- **Operating Temperature:** ~600–700 °C
- **Fuel:** Hydrogen, CO, natural gas (internal reforming possible)
- **Features:**
  - High efficiency (45–55%)
  - Can directly use hydrocarbon fuels (with internal reforming)
  - High temperature allows combined-cycle operation
  - Corrosion and durability issues with electrolyte and materials
- **Applications:** Large-scale power plants, industrial cogeneration.

5. Advantages of Fuel Cells

- High efficiency compared to combustion engines.
- Environmentally friendly (low/zero emissions).
- Silent operation.
- Modular and scalable for different power requirements.
- Quick refueling (in case of hydrogen).

6. Limitations of Fuel Cells

- High cost (catalysts, materials, hydrogen production/storage).
- Durability and reliability issues (especially for PEM and MCFC).
- Hydrogen infrastructure is limited.
- Sensitivity to fuel impurities (CO, sulfur).

OCEAN ENERGY

Introduction:

The sources of energy from ocean are Ocean Thermal Energy Conversion(OTEC). The conversion of solar energy stored as heat in the ocean in to electrical energy by making use of the temperature difference between warm surface water and the colder deep water.

Ocean thermal energy conversion is an electricity generation system. Ocean Thermal Energy, also called Ocean Thermal Energy Conversion (OTEC), refers to using the temperature difference between the deep parts of the sea, which are cold and the shallow parts of the sea, which are cold, to run a heat engine and produce useful work.

The deeper parts of the ocean are cooler because the heat of sunlight cannot penetrate very deep into the water. Here the efficiency of the system depends on the temperature difference. Greater the temperature difference, the greater the efficiency.

The temperature difference in the oceans between the deep and shallow parts is maximum in the tropics, 20o C to 25o C. Tropics receive a lot of sunlight which warms the surface of the oceans, increasing the temperature gradient.

Types of Ocean thermal electric conversion (OTEC).

- Open cycle OTEC system or Claude cycle
- The closed or Anderson OTEC cycle

Open cycle OTEC cycle:

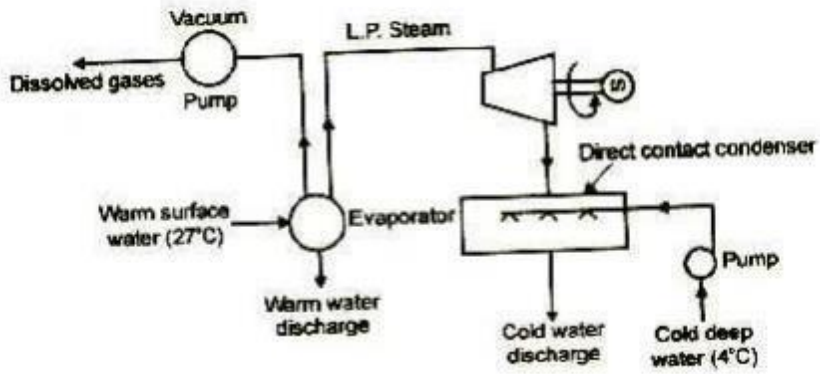


Figure: OTEC – open cycle.

Open cycle OTEC directly uses the warm water from the surface to make electricity. The warm seawater is first pumped into a low-pressure chamber, where it undergoes a drop in boiling point due to the pressure drop. This causes the water to boil. This steam drives a low-pressure turbine which is attached to an electrical generator.

The advantage this system has over a closed system is that, in the open cycle, desalinated water is obtained in the form of steam. Since it is steam, it is free from all impurities.

This water can be used for domestic, industrial, or agricultural purposes.Ocean Thermal Energy (OTEC) is a real candidate as one of the future sources of energy. Its environmental impact is negligible. The mixing of deep and shallow seawater brings up nutrients from the seafloor. The deepwater is rich in nitrates, which can also be used in agriculture.

Closed cycle OTEC system:

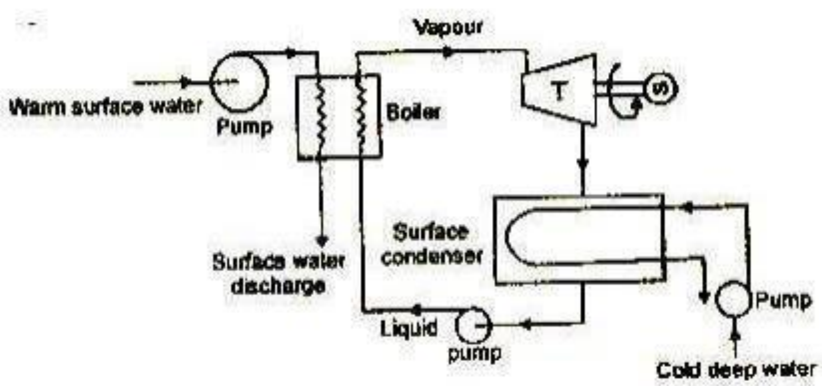


Figure: OTEC – closed cycle

Closed cycle Ocean Thermal Energy Conversion systems use a working fluid with a low boiling point, Ammonia, for example, and use it to power a turbine to generate electricity. Warm seawater is taken in from the surface of the oceans and cold water from the deep at 5o. The warm seawater vaporises the fluid in the heat exchanger, turning the generator's turbines.

The fluid now in the vapour state is brought in contact with cold water, which turns it back into a liquid. The fluid is recycled in the system, which is why it is called a closed system.

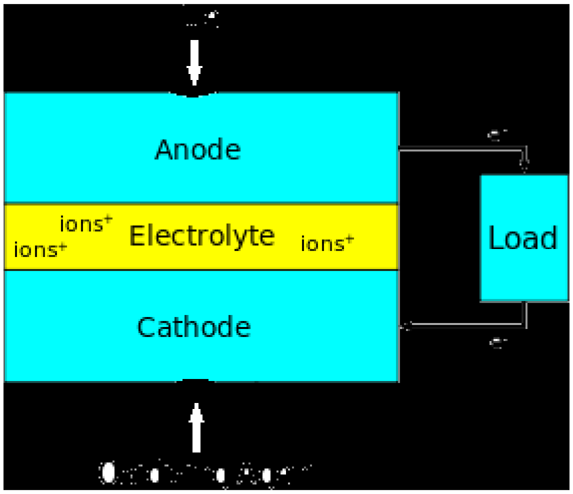
==

Fuel Cell: A fuel cell is an electric cell which produces electrical energy from chemical energy; through an oxidation reaction of provided fuel.

The main difference between normal secondary batteries and fuel cell is that; in secondary batteries the chemical energy is stored in the electrodes of the cell, but in Fuel cell the chemical energy is stored in a fuel. And the fuel, oxidizing agent are stored outside of the cell and fed into the cell when electricity is to be produced. Example of fuel cell is Hydrogen Fuel cell or Hydrogen-Oxygen Fuel cell.

Construction of a Fuel Cell:

A fuel cell consists of two porous electrodes separated by an electrolytic solution in between. The fuel which is usually Hydrogen or Carbon monoxide is fed into one of the electrodes and a Reacting agent; which is usually Oxygen or Air;is fed into another electrode. The electrodes are porous enough to pass through both fuels and electrolyte and also conduct electricity. The fuel and reacting agent reacts inside the fuel cell and produced electricity which can be obtained through terminals connected to the electrodes.



Advantages and Disadvantages of a Fuel Cell:

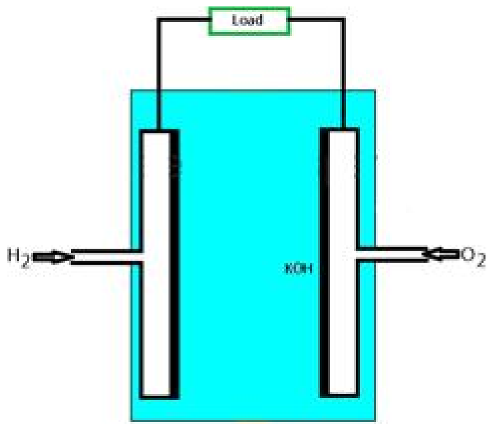
The electrode materials in a Fuel Cell are not changed during chemical reaction so a Fuel Cell does not requires recharging; they can be used as a continuous generator as long as the fuel and oxidizing agent are supplied. Also, fuel cells does not have any moving parts; so, unlike normal generators they does not produce sound , requires very little maintenance and produces no gasses or fumes. Fuel cell's efficiency and cost per KW of power is independent of their size; so, they also offer a design flexibility and a room for further research and development.

But, the initial design and manufacturing cost of fuel cell is very high. They produce small voltages and also, their service life is not much as compared to other cells.

Hydrogen Fuel Cell:

Hydrogen Fuel cell or Hydrogen-Oxygen Fuel cell is one of the most basic type of fuel cell. Hydrogen fuel cell uses Hydrogen (H) as the fuel and Oxygen(O) is the oxidizing agent.

The basic construction of a Hydrogen-Oxygen Fuel cell is:



The electrodes are made up of sintered Nickel plates having a coarse pores surface and a fine pores surface ; the two surfaces for gas and electrolyte respectively. A solution of KOH is used as electrolyte. The water vapor formed during the reaction is passed back by condensation from the opening for passing hydrogen into the cell.

A continuous flow of Hydrogen and oxygen is maintained, The oxygen and hydrogen reacts with potassium hydroxide at the surface of electrodes to produce electricity.

****

FUEL CELL:

A fuel cell is a device that converts chemical potential energy (energy stored in molecular bonds) into electrical energy.

Unlike a generator, a fuel cell directly "converts" an energy source into electricity through a chemical reaction. This involves one step rather than multiple steps. This allows a fuel cell to remain efficient, quiet and clean.

Difference between fuel cell and battery:

The biggest difference between the two is that a battery stores energy, while a fuel cell generates energy by converting available fuel. A fuel cell can have a battery as a system component to store the electricity it's generating.

Types of Fuel Cells

Fuel cells are classified primarily by the kind of electrolyte they employ.

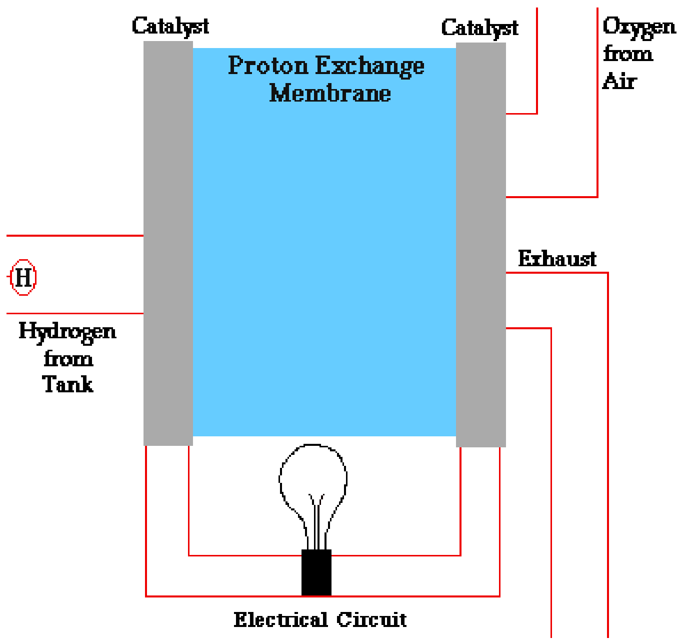
The electrolyte plays a key role. It must permit only the appropriate ions to pass between the anode and cathode. If free electrons or other substances could travel through the electrolyte, they would disrupt the chemical reaction.

Whether they combine at anode or cathode, together hydrogen and oxygen form water, which drains from the cell. As long as a fuel cell is supplied with hydrogen and oxygen, it will generate electricity.

- **Polymer electrolyte membrane fuel cells**. ...
- Direct methanol fuel cells. ...
- **Alkaline fuel cells**. ...
- **Phosphoric acid fuel cells**. ...
- **Molten carbonate fuel cells**. ...
- **Solid oxide fuel cells**. ...
- Reversible fuel cells.

How do fuel cells work?

There are several kinds of fuel cells, and each operates a bit differently. But in general terms, hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips them of their electrons. The hydrogen atoms are now "ionized," and carry a positive electrical charge. The negatively charged electrons provide the current through wires to do work. If alternating current (AC) is needed, the DC output of the fuel cell must be routed through a conversion device called an inverter.

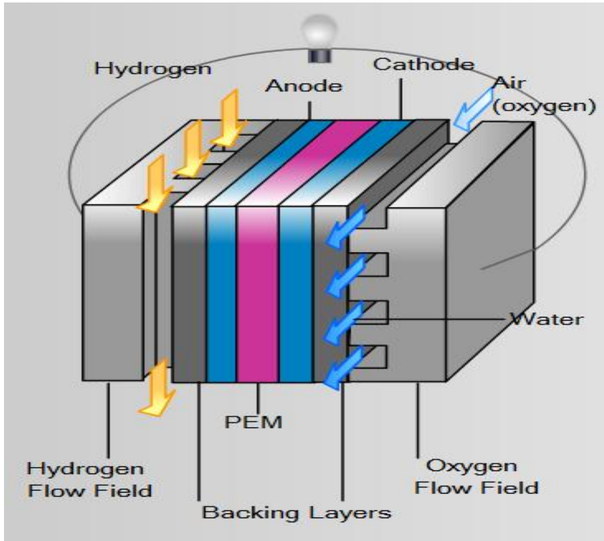


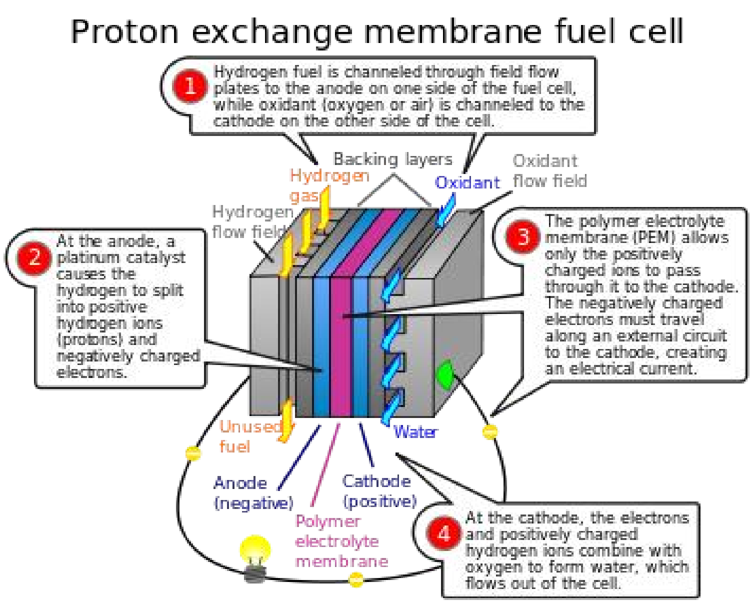
Hydrogen Fuel Cell

Hydrogen + Oxygen = Electricity + Water Vapor

A PEM (Proton Exchange Membrane) cell uses hydrogen gas (H2) and oxygen gas (O2) as fuel. The products of the reaction in the cell are water, electricity, and heat.

__There are four basic elements of a PEM Fuel Cell:__





How does it work?

Pressurized hydrogen gas (H_2) entering the fuel cell on the anode side. This gas is forced through the catalyst by the pressure. When an

H_2 molecule comes in contact with the platinum on the catalyst, it splits into two H^+ ions and two electrons (e^-). The electrons are conducted through the anode, where they make their way through the external circuit (doing useful work such as turning a motor) and return to the cathode side of the fuel cell.

Meanwhile, on the cathode side of the fuel cell, oxygen gas (O_2) is being forced through the catalyst, where it forms two oxygen atoms. Each of these atoms has a strong negative charge. This negative charge attracts the two H^+ ions through the membrane, where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule (H_2O).

.

Due to the high energetic content of hydrogen and high efficiency of fuel cells (55%), this great technology can be used in many applications like transport (cars, buses, forklifts, etc) and backup power to produce electricity during a failure of the electricity grid.

Detailed functions of different components:

The anode, the negative post of the fuel cell, has several jobs. It conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. It has channels etched into it that disperse the hydrogen gas equally over the surface of the catalyst.

The cathode, the positive post of the fuel cell, has channels etched into it that distribute the oxygen to the surface of the catalyst. It also conducts the electrons back from the external circuit to the catalyst, where they can recombine with the hydrogen ions and oxygen to form water.

The electrolyte is the proton exchange membrane. This specially treated material, which looks something like ordinary kitchen plastic wrap, only conducts positively charged ions. The membrane blocks electrons. For a PEMFC, the membrane must be hydrated in order to function and remain stable.

The catalyst is a special material that facilitates the reaction of oxygen and hydrogen. It is usually made of platinum nanoparticles very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen. The platinum-coated side of the catalyst faces the PEM.

As the name implies, the heart of the cell is the proton exchange membrane. It allows protons to pass through it virtually unimpeded, while electrons are blocked. So, when the H_2 hits the catalyst and splits into protons and electrons (remember, a proton is the same as an H^+ ion) the protons go directly through to the cathode side, while the electrons are forced to travel through an external circuit. Along the way they perform useful work, like lighting a bulb or driving a motor, before combining with the protons and O_2 on the other side to produce water.

Advantages of the technology:

By converting chemical potential energy directly into electrical energy, fuel cells avoid the "thermal bottleneck" (a consequence of the 2nd law of thermodynamics) and are more efficient in extracting energy from a fuel. Waste heat from some cells can also be harnessed, boosting system efficiency still further.

Thus fuel cells are inherently more efficient than combustion engines, which must first convert chemical potential energy into heat, and then mechanical work.

- Direct emissions from a fuel cell vehicle are just water and a little heat. This is a huge improvement over the internal combustion engine's litany of greenhouse gases.
- Fuel cells have no moving parts. They are thus much more reliable than traditional engines.
- Hydrogen can be produced in an environmentally friendly manner, while oil extraction and refining is very damaging.

Drawbacks of Fuel Cells:

The basic workings of a fuel cellis are simple. But building inexpensive, efficient, reliable fuel cells is a far more complicated business in terms of the choice of electrolyte, the design of electrodes and purity of fuel. Today, the main electrolyte types are alkali, molten carbonate, phosphoric acid, proton exchange membrane (PEM) and solid oxide.

The type of fuel also depends on the electrolyte. Some cells need pure hydrogen, and therefore demand extra equipment such as a "reformer" to purify the fuel. Other cells can tolerate some impurities, but might need higher temperatures to run efficiently.

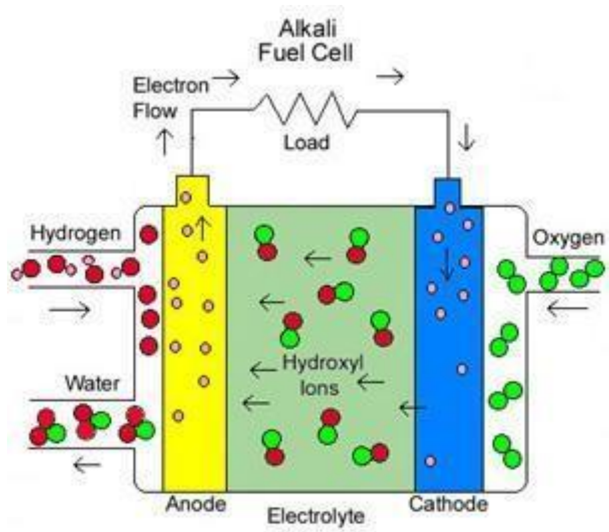
The type of electrolyte also dictates a cell's operating temperature–"molten" carbonate cells run hot, just as the name implies.

Each type of fuel cell has advantages and drawbacks compared to the others, and none is yet cheap and efficient enough to widely replace traditional ways of generating power, such as coal-fired, hydroelectric, or even nuclear power plants.

Different types of fuel cells.

Alkali fuel cells operate on compressed hydrogen and oxygen. They generally use a solution of potassium hydroxide (chemically, KOH) in water as their electrolyte. Efficiency is about 70 percent, and operating temperature is 150 to 200 degrees C.

In these cells, hydroxyl ions (OH-) migrate from the cathode to the anode. At the anode, hydrogen gas reacts with the OH- ions to produce water and release electrons. Electrons generated at the anode supply electrical power to an external circuit then return to the cathode. There the electrons react with oxygen and water to produce more hydroxyl ions that diffuse into the electrolyte.

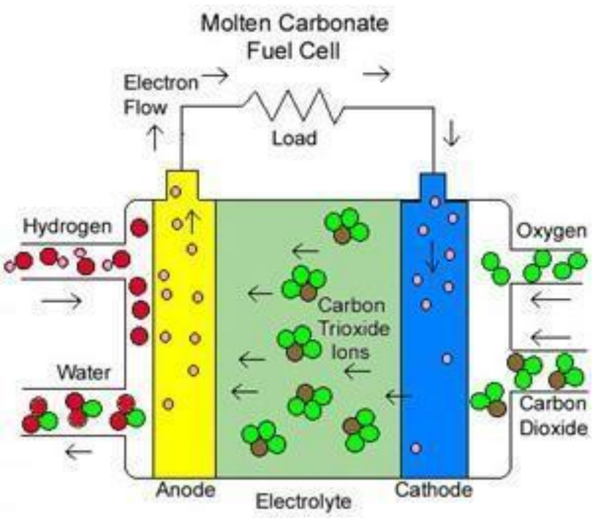


Applications:

Alkali cells were used in Apollo spacecraft to provide both electricity and drinking water. They require pure hydrogen fuel, however, and their platinum electrode catalysts are expensive. And like any container filled with liquid, they can leak.

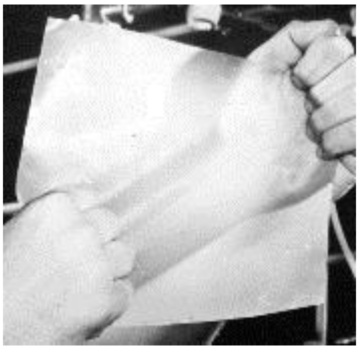
Molten Carbonate fuel cells (MCFC) use high-temperature compounds of salt (like sodium or magnesium) carbonates (chemically, CO3) as the electrolyte.
Efficiency ranges from 60 to 80 percent, and operating temperature is about 650 degrees C.

The salts melt and conduct carbonate ions (CO3) from the cathode to the anode. At the anode, hydrogen reacts with the ions to produce water, carbon dioxide, and electrons. The electrons travel through an external circuit, providing electrical power along the way, and return to the cathode. There, oxygen from air and carbon dioxide drawing of a molten carbonate cell



Proton Exchange Membrane (PEM)

Proton exchange membrane (PEM) fuel cells work with a polymer electrolyte in the form of a thin, permeable sheet. This membrane is small and light, and it works at low temperatures (about 80 degrees C, or about 175 degrees F). Other electrolytes require temperatures as high as 1,000 degrees C.



To speed the reaction a platinum catalyst is used on both sides of the membrane. Hydrogen atoms are stripped of their electrons, or "ionized," at the anode, and the positively charged protons diffuse through one side of the porous membrane and migrate toward the cathode. The electrons pass from the anode to the cathode through an exterior circuit and provide electric power along the way. At the cathode, the electrons, hydrogen protons and oxygen from the air combine to form water. For this fuel cell to work, the proton exchange membrane electrolyte must allow hydrogen protons to pass through but prohibit the passage of electrons and heavier gases.

Efficiency for a PEM cell reaches about 40 to 50 percent. An external reformer is required to convert fuels such as methanol or gasoline to hydrogen. Currently, demonstration units of 50 kilowatt (kw) capacity are operating and units producing up to 250 kw are under development.

===

Introduction

The word geothermal comes from the Greek words *geo* (Earth) and *thermo* (heat). Geothermal energy is heat from within the Earth. Geothermal energy is generated in the Earth's **core**, almost 4,000miles beneath the Earth's surface. The double-layered core is made up of very hot **magma** (melted rock) surrounding a solid iron canter. Very high temperatures are continuously produced inside the Earth by the slow decay of radioactive particles. This process is natural in all rocks.

Surrounding the outer core is the **mantle**, which is about 1,800 miles thick and made of magma and rock. The outermost layer of the Earth, the land that forms the continents and ocean floors, is called the **crust**.

The crust is three to five miles thick under the oceans and15 to 35 miles thick on the continents. The crust is not a solid piece, like the shell of an egg, but is broken into pieces called **plates**. Magma comes close to the Earth's surface near the edges of these plates. This is where volcanoes occur.

The lava that erupts from volcanoes is partly magma. Deep underground, the rocks and water absorb the heat from this magma. We can dig wells and pump the heated, underground water to the surface. People around the world use geothermal energy to heat their homes and to produce electricity.

Geothermal energy is called a **renewable** energy source because the water is replenished by rainfall and the heat is continuously produced deep within the Earth. We won't run out of geothermal energy.

Geothermal energy is defined as heat from the Earth. It is a clean, renewable resource that provides energy in the United States and around the world. It is considered a renewable energy resource because the heat emanating from the interior of the Earth is essentially limitless.

The heat continuously flowing from the Earth's interior is estimated to be equivalent to 42 million megawatts of power.5 One megawatt is equivalent to 1million watts, and can meet the power needs of about 1,000 homes. The interior of the Earth is expected to remain extremely hot for billions of year to come, ensuring an essentially limitless flow of heat.

Geothermal power plants capture this heat and convert it to energy in the form of electricity. The picture below shows the source of geothermal electric power production, heat from the Earth. As depth into the Earth's crust increases, temperature increases as well.

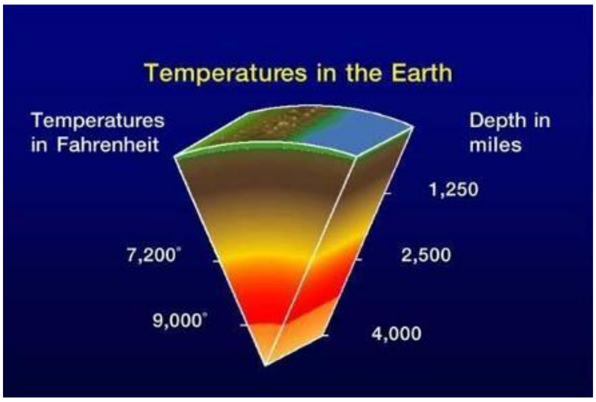


Figure 1: Earth's Temperatures

The word geothermal comes from Greek words geo means earth, and thermal means heat. Geothermal energy is heat from within the earth. We can use the steam and hot water produced inside the earth to heat buildings or generates electricity.

Energy inside the earth:

-Geothermal energy is generated in the earth's core, about 4,000 miles below the surface.

The earth has a number of different layers:

- The core itself has two layers: a **solid iron core** and an outer core made of very hot melted rock, called **Magma**.
- The **mantle** which surrounds the core and is about 1,800 miles thick. It is made up of magma and rock.

The crust is the outermost layer of the earth, the land that forms the continents and ocean floors. It can be three to five miles thick under the oceans and 15 to 35 miles thick on the continents. The earth's crust is broken into pieces called plates. Magma comes close to the earth's surface near the edges of these plates. This is where volcanoes occur. Deep underground, the rocks and water absorb the heat from this magma.

People around the world use geothermal energy to heat their homes and to produce electricity by digging deep wells and pumping the heated underground water or steam to the surface.

Classification of Geothermal fields:

Based on the classifying earth's surface divided into three broad groups.

- Non thermal area- having temperature of 10^{o} C to 40^{o} C per km depth
- Semi thermal area- having temperature of 70^{o} C per km depth
- Hyper thermal area- temperature more than non-thermal

Geothermal sources:

General kinds of geothermal sources are

1) Hydrothermal Convective system

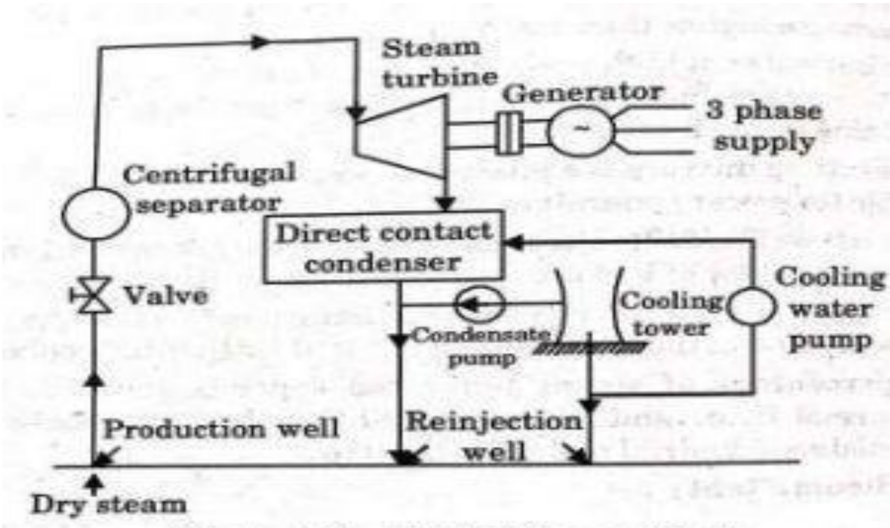
- Vapour dominated or dry steam fields
- Liquid dominated system or wet steam

2) Geo pressure resources

3) Magma resources

4) valconoes

Vapour dominated system (dry steam):



Vapour Dominated Power Plant

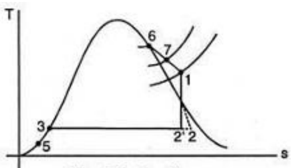
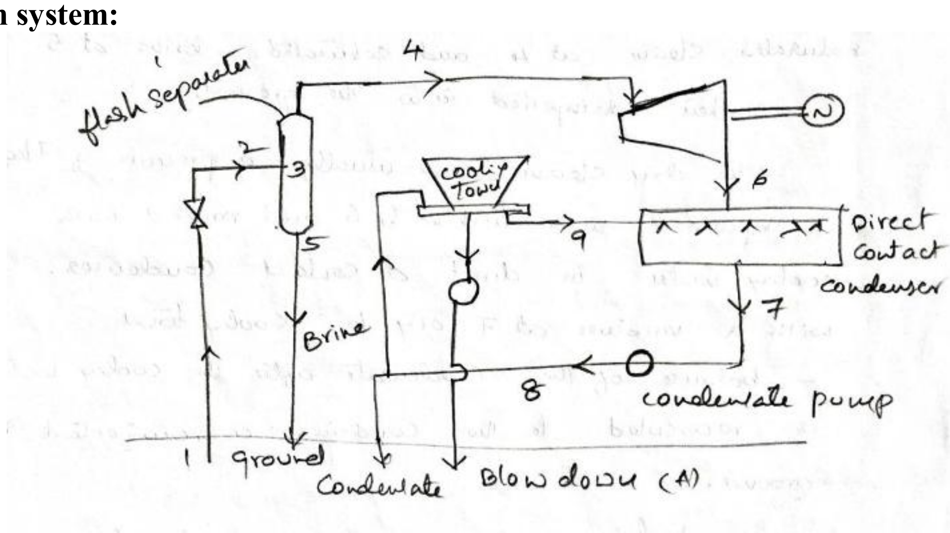


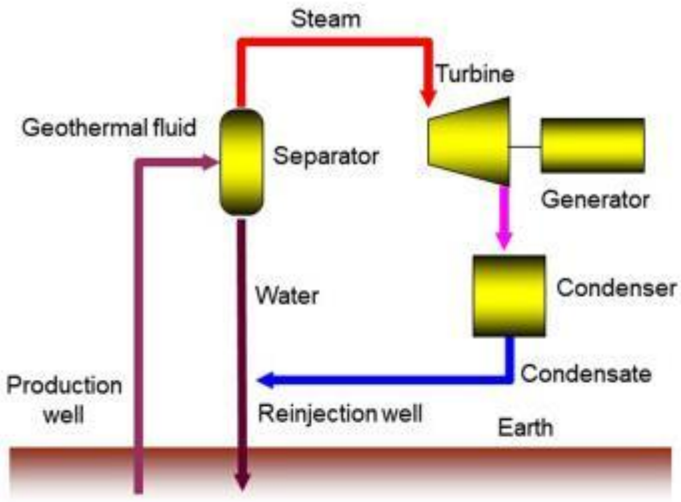
Fig. 7.2. T-s diagram

The energy conversion in geothermal power plants is based on the Rankine cycle. Dry steam at 35 bar and 200°C is available at the bottom of the well gets superheated due to pressure drop to 7 bar. The particulate matter is separated in a centrifugal separator. The process 6-7 and 7-1 are throttling processes so that enthalpy of steam remains constant. After passing through steam turbine and condenser, it is re-injected back to earth.

Liquid dominated system: (wet steam fields):

Flashed steam system:





Hot water is available above 150°C to 315°C underground. When tapped, the water can flow naturally under its own pressure or be pumped to the surface of the earth. The drop in pressure causes it to partially flash into steam and a liquid-dominated, low-quality, two-phase mixture of water and stream is available at the well head. The water contains dissolved solids. The flow diagram and T-s diagram of a flash-steam system are shown

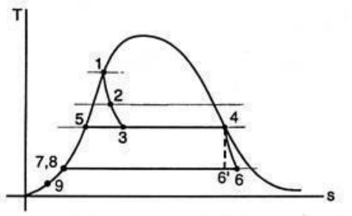
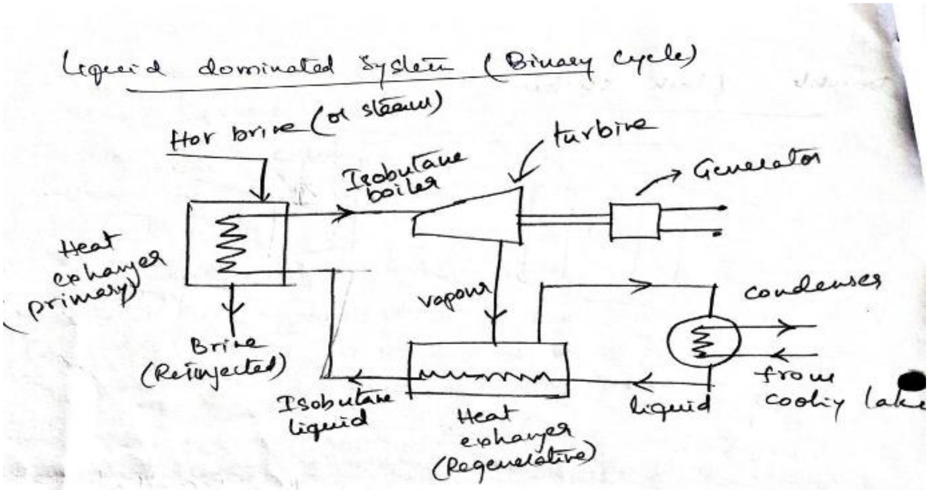
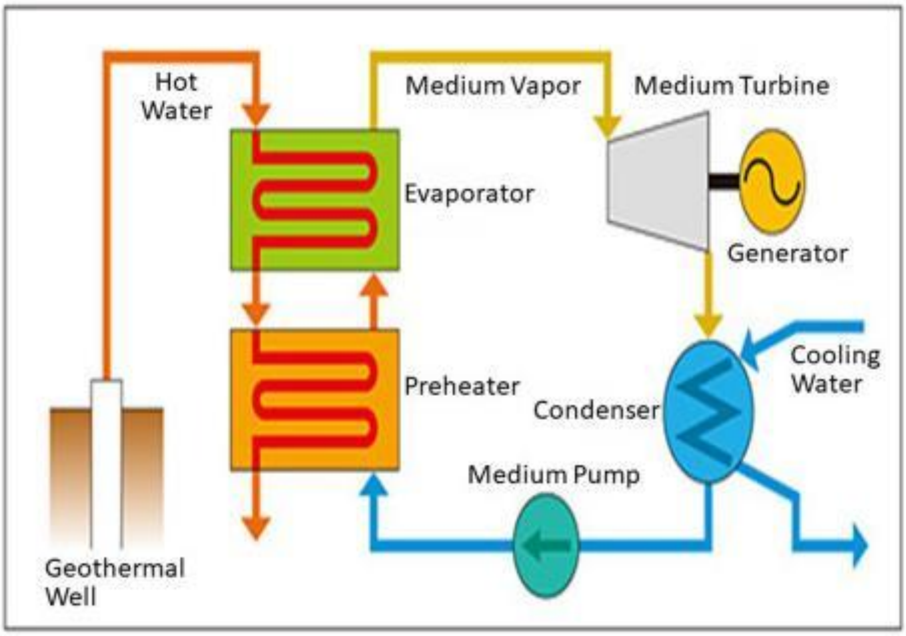


Fig. 7.4. T-s diagram of single-flash steam cycle

Hot water from reservoir (1) reaches the well head (2) Pressure p2 is lower than P1 and process 1-2 is a constant enthalpy throttling process. The two-phase mixture of low quality (2) is passed through a flash separator (3) the quality of steam is higher at point 3. The dry saturated steam (4) at pressure of about 8 bars is expanded in the steam turbine. The separated brine (5) is re-injected into the ground. The exhaust steam from turbine is mixed with cooling water in a direct- contact condenser. The mixture is cooled in a cooling tower.

Liquid dominated binary cycle:





Water in lower temperature ranges is unsuitable for power production. It can be used directly for domestic and industrial process heating. Hot water can also be used in heating an organic fluid with low boiling point and can be used to run a Rankine Cycle. The working fluids can be isobutene, Freon-12, ammonia or propane.

Hot brine from underground reservoir circulates through a heat exchanger (HX) and is pumped back to ground. The organic fluid is heated to superheated vapour and is used in a standard closed Rankine cycle. The vapour drives the turbine and is condensed in a surface condenser. The condenser is cooled by water from a natural source or a cooling tower circulation system. There is no problem of corrosion and scaling in the working cycle components.

Kamchatka binary cycle plant in Russia is 680 kW plant using hot water at 80°C. The working fluid is Freon-12.