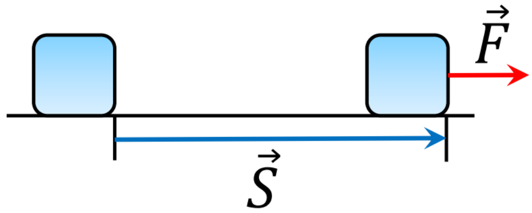
GEC1010

Chapter 1: Our Energy Heritage

Work Done

$$W = F \times S$$

S.I Unit: $N \cdot m = J$ (Joule)



Law of Conservation of Energy

Energy can neither be created nor destroyed, it can only be transformed from one form to another

Kinetic Energy

- object in linear motion

$$K = \frac{1}{2}mv^2$$

- rotational kinetic energy

$$K = \frac{1}{2}I\omega^2$$

$I =$ Moment of Inertia of object (dependent on mass distribution of object)

$\omega =$ Angular velocity of rotating object (S.I unit: rad/sec *1 revolution is 2π radians.)

Potential Energy

$$U = mgy$$

$g =$ acceleration due to gravity = $9.81ms^{-2}$

Power

$$P_{avg} = \frac{\triangle W}{\triangle t}$$

$\triangle W =$ Work done by a system in time $\triangle t$

S.I unit: Watt, $1W = 1J/s$

Energy Conversion Efficiency

$$Efficiency = \frac{Useful\ Output\ Energy}{Input\ Energy}$$

Requirements of an energy system

1. Energy Resource
2. High Power
3. High Energy Conversion Efficiency

Oil

Petroleum or **crude oil** is a naturally occurring flammable liquid.

$$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$$

Natural gas

Natural gas is a mixture of gases formed from the fossil remains of ancient plants and animals buried deep in the earth.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Compressed natural gas is a cleaner alternative to other fuels such as gasoline (petrol), diesel and coal.

Fossil Fuels: Coal

Coal is formed from the remains of plants that lived and died about 100 to 400 million years ago when part of the earth was covered with huge swampy forests. In the absence of legislation, US, China and India may turn to coal in place of more expensive fuels.

$$C + O_2 \rightarrow CO_2$$

- Its solid form causes difficulties in extraction, transportation and use.
- Its greater carbon content and more impurities lead to more carbon dioxide and greater air pollution on burning.
- Natural gas and Coal together contribute to 60% of total world electricity generation.

Excessive usage of fossil fuels: CO2 and other pollutants emission. Implication: enhanced green house effect by earth's atmosphere.

Greenhouse effect

- Earth's atmosphere is completely transparent to the short wavelength solar radiation which reaches earth's surface and is absorbed by it.
- Sunlight: Main components: Ultraviolet radiation, visible radiation, Infra red (IR) radiation
- Earth in turn radiates long wavelength IR back to atmosphere where it is absorbed by the green house gases (CO2 and water vapour): Green house effect.
- Earth's temperature started rising: GLOBAL WARMING Burning of Fossil fuels produces CO2 : Enhances green house effect.

Effects of Global Warming

- Sea Level Rise
- Global Temperature Rise

Clean Energy Technology (Renewable)

- Wind
- Hydro

Non-renewable clean energy technology

- Geothermal Energy
- Nuclear Energy

- Ocean
- Solar
- Biomass

Quantity	Unit	Definition
Force	Newton (N)	Force required to accelerate 1kg by $1m/s^2$.
Energy	Joule (J)	Work done by a force of 1N in moving an object through 1m.
Power	Watt, $W=Js^{-1}$	1 J/s
Energy	Kilowatt-hour (kWh)	$10^3 \times 60 \times 60 = 3.6 \times 10^6$ J≈3411 Btu
Energy	calorie	Energy required to heat 1 g of water by 1^0C≈4.2 J
Energy	Btu	Energy required to heat 1 lb of water by 1^0F≈1.055 kJ
Energy	Barrel	42 US gallons≈159 litres
Fuel Equivalence	1 tonne oil	1.5 tonnes hard coal ≈ 3.0 tonnes lignite ≈ 12000 kWh.
Power	1 Horse Power	0.746 kW

Chapter 2: Fundamentals of Thermal Energy

Heat and Temperature

- Change in temperature

$$\triangle Q = mc\triangle T$$

$c =$ Specific heat of the substance

- Change in state (Melting/ vaporising)

$$\triangle Q = mL$$

$L =$ Specific latent heat of the substance

Melting → latent heat of fusion

Evaporate → latent heat of vaporisation

Heat Transfer

1. Conduction of heat → vibration of matter particles (no bulk movement) high to low temp
2. Convection → motion of matter particles e.g. formation of wind
3. Radiation

Radiation

- $P_e =$ Energy emitted per second per unit area

$$P_e = \varepsilon\sigma T^4$$

$T =$ Surface temperature

- $P_a =$ Energy absorbed per second per unit area

$$P_a = \varepsilon\sigma T_0^4$$

$T_0 =$ Temperature of Surrounding

- $P =$ Net rate of emission per unit area per second

$$P = P_e - P_a = \varepsilon\sigma(T^4 - T_0^4)$$

$\epsilon =$ Emissivity of the surface, its value lies between 0 and 1 depending on the nature of the surface

$\sigma =$ Stefan's Boltzmann's constant $= 5.67 * 10^{-8} W m^{-2} K^{-4}$

First Law of Thermodynamics

$$Q - W = \triangle U$$

$\triangle U =$ Change in internal energy of the thermodynamic system

$Q =$ Heat absorbed

$W =$ Work done by system

Conventional Power Plants: Underlying Principles

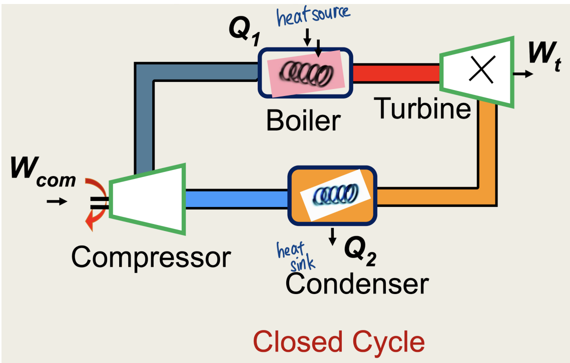
1. Upon absorption of heat: Rise in temperature of the fluid and change of state
2. Laws of thermodynamics
3. Heat exchange with the environment due to the temperature difference

Types of Power Plants

- Steam Power Plant:
    1. Uses steam as the fluid
    2. Operating temperature is low
- Gas Power Plant:
    1. Uses natural gas as the fuel
    2. Operating temperature is high

Steam Power Plant

The working fluid (water) undergoes a phase change at different stages in a closed cycle and is reused in subsequent cycles.



Key stages:

1. Compression W_{com}
    - Work done on the system to compress cold water to high pressure
2. Boiling Q_1
    - Heat added to the system to convert cold water into steam
3. Turbine Rotation W_t
    - Work done by the system (steam) on the turbine blades
4. Condensation Q_2

- Heat lost from the system to the environment in converting steam back to cold water

- Efficiency of closed cycle for steam power plant

After each complete cycle, the working fluid has the same energy U as it had in the beginning of the cycle.

Hence $\triangle U = 0$

Net work done by the system $= W_t - W_{com}$

Net heat absorbed $= Q_1 - Q_2$

By first Law of Thermodynamics: $Q_1 - Q_2 - (W_t - W_{com}) = 0$

$$\eta = \frac{Net\ output\ work}{heat\ input} = \frac{W_t - W_{com}}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

Since Q_2 is always positive $\Rightarrow \eta < 1$

Thermal Properties of Water and Steam

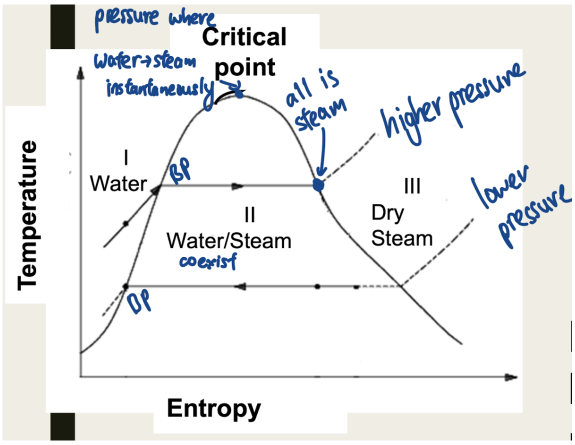
I: Water (Left of Bell)

II: Two phase mixture of water + Steam (Inside Bell)

III: Dry Steam (Right of Bell)

Note:

- Two lines that water follow represent higher and lower pressure



Rankine Cycle for Steam power plant without Reheat

Compressor e→f: compressor increases pressure of the water before entering the boiler

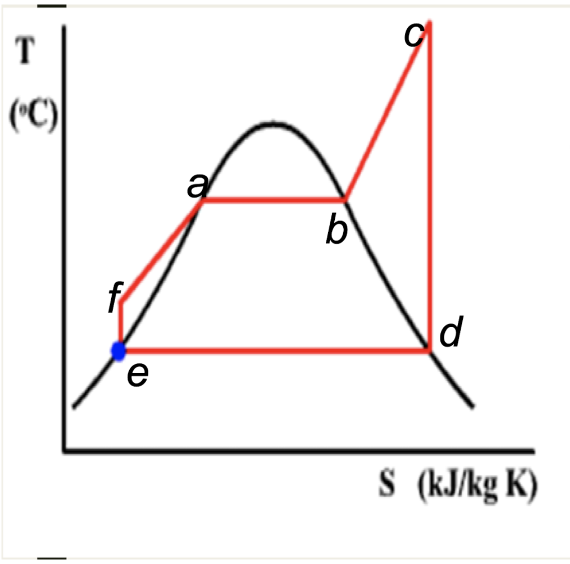
Economiser f→a (Boiler): Water is heated at high pressure until it starts boiling

Evaporator a→b (Boiler): Two phase mixture of water and steam is heated at constant pressure until all the water is converted in to dry steam

Superheater b→c (Boiler): Dry steam is then heated at constant pressure in superheater

Turbine c→b: Dry steam enters the turbine at high pressure and rotates the turbine, thereby doing work

Condenser d→e: Wet steam enters the condenser. Here all the steam is converted into water before entering the compressor again



Practical Limitations:

- Pressure drop through the boiler due to frictional losses. Unable to completely eliminate
- Unable to completely eliminate the formation of water droplets in stage (c→d)
- The droplets hit the turbine with high momentum and damage its blades

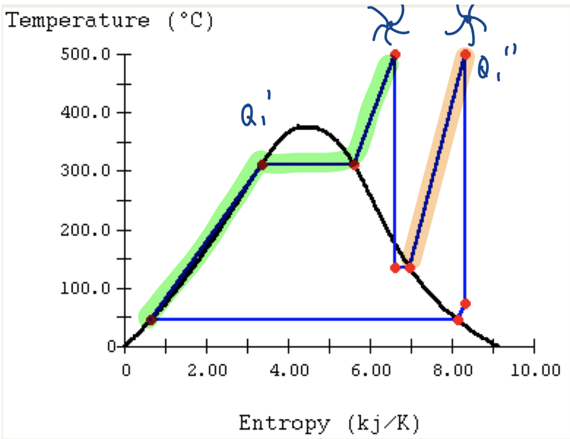
Rankine Cycle for Steam power plant with Reheat

This steam power plant has two-three turbines:

- Higher Pressure(HP)
- Intermediate Pressure (IP)
- Low Pressure (LP)

Steam is reheated several times before entering the condenser

Steam leaves HP then reheated and goes to IP followed by second reheating and then LP



Advantages:

- Overall efficiency increases
- Higher the operating temperature of super heater, higher will be the efficiency.
- Problem of water droplets formation is decreased
- Practically achieved efficiency: 40-45%

Practical Limitation:

- Highest temperature of the super heater is 650°C
- Metal fatigue puts a limitation beyond this

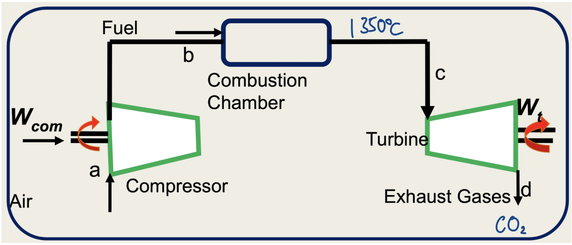
Gas Turbines and Brayton Cycle

Modification over Rankine's Cycle: Uses gas

Compression → Air enters the compressor at atmospheric pressure and it is compressed

Combustion → Air is mixed with fuel and produces hot gases

Turbine → These hot gases rotate the turbine leading to electricity production. The exhaust gases are vented to atmosphere



Advantages:

- Simple gas turbines, $\eta = 40\%$
- Achievable Temperature: 1300°C
- Turbine blades are covered with ceramic coating of low thermal conductivity to avoid metallurgical damage of blades
- The blade assembly is water cooled, to keep their temperature low
- More compact w/o condenser
- Cheaper w/o condenser

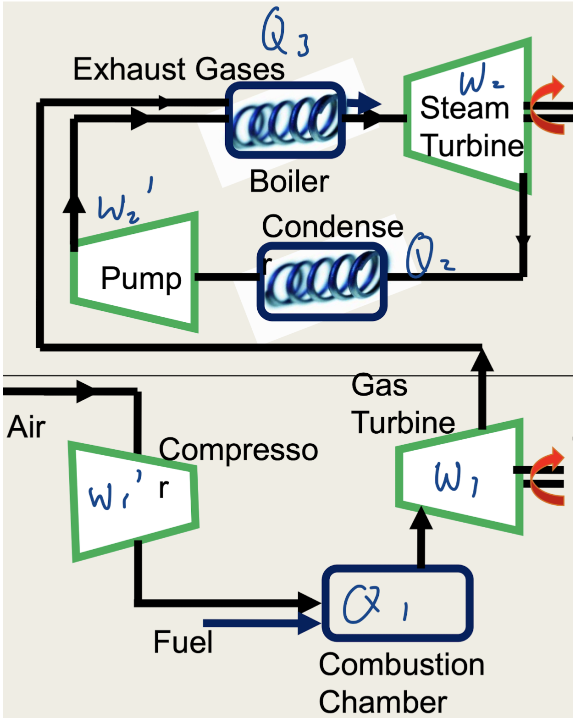
Disadvantages:

- Gas used to turn, not water molecules there fore turning is not as good
- Working substance replenished with successive cycles

Combined Cycle Gas Turbine CCGT

Brayton Cycle + Rankine Cycle

$$\eta_{CCGT} = \frac{output}{input} = \frac{W_1 + W_2 - W_1' - W_2'}{Q_1}$$



Advantages

Net effect is a single cycle operating between the upper temperature of Brayton cycle and the lower temperature of Rankine cycle.

- $\eta > 60\%$ is also achievable
- Waste heat from the condenser may be used for district heating in local community

Disadvantages

The cost involved is high: Finds application in industrial complexes or densely populated urban areas.

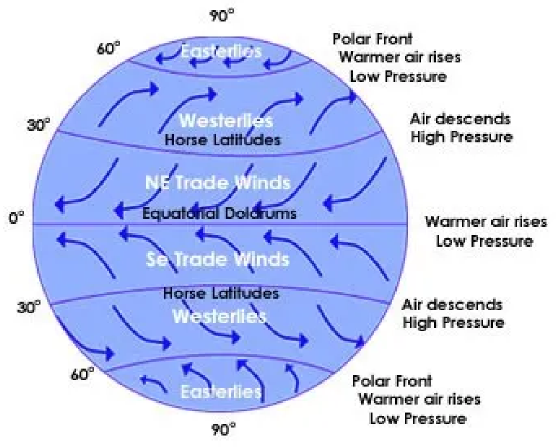
Chapter 3: Wind Power

Coriolis Force

High intensity of solar radiation at equator causes warm air to rise up and cooler air to flow from the north to the south. Wind varies both with time and location. Earth's rotation decides the places of high and low wind.

- Wind moving north or south will have a component of velocity sideward.

- At 30° latitude, wind flow becomes unstable and north-south motion of the wind dissipates.
- In northern hemisphere, the sinking air at 30° latitude gives rise to north east trade winds and westerly wind belt.



Globle Winds

Energy and Power in Wind

$$\frac{E}{Vol} = \frac{1}{2}\rho u^2$$

$$\frac{E}{Vol} \times \frac{Vol}{t} = \frac{1}{2}\rho u^2 \times \frac{Vol}{t}$$

$$since\ \frac{Vol}{t} = uA\ (vol\ of\ air\ flowing\ per\ unit\ time)$$

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

$u =$ Wind Speed

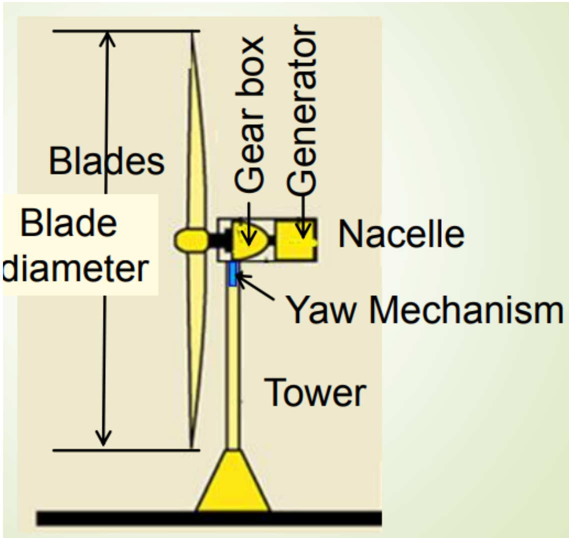
$\rho =$ Air density

- If wind speed (u) is doubled ⇒ $2u$: $P_{new} = \frac{1}{2}\rho A(2u)^3 = 8 \times \frac{1}{2}\rho A u^3 = 8P$
- $P \propto A \therefore$ doubling blade diameter increases power by 4.

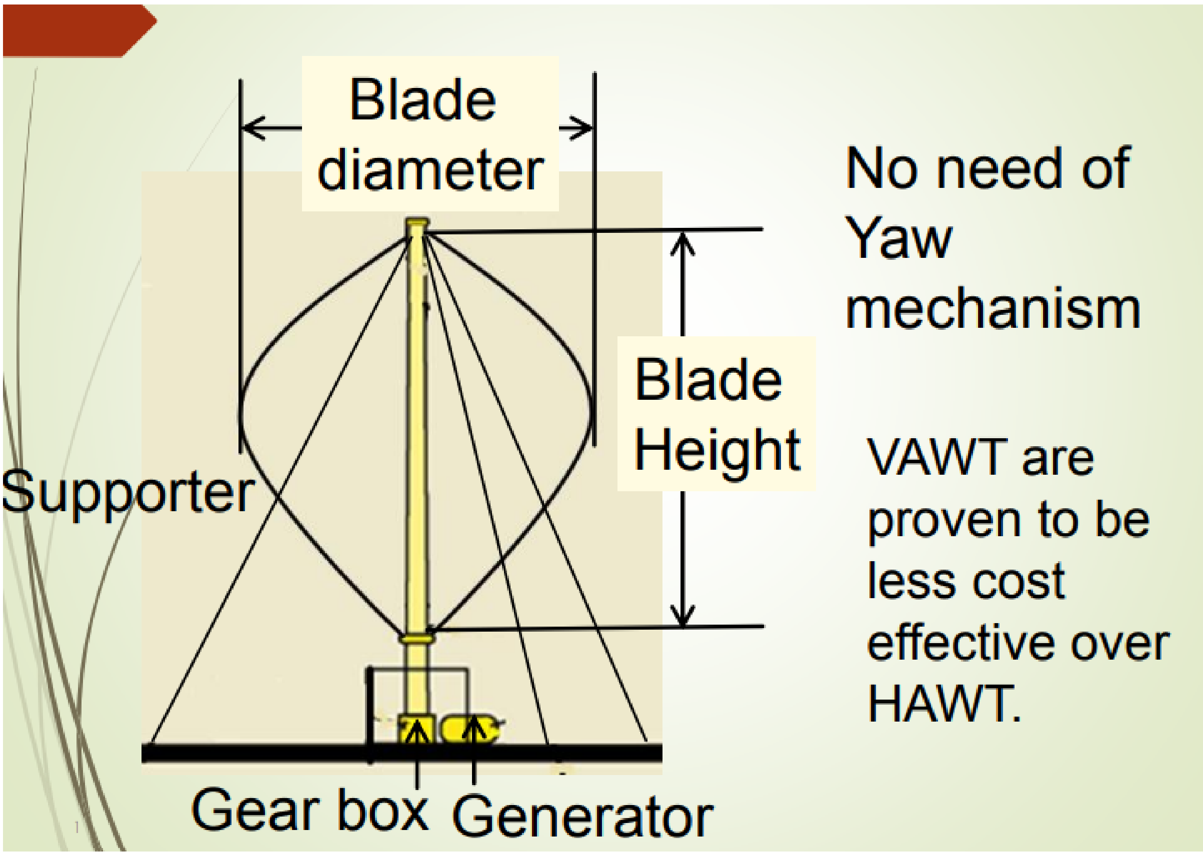
Horizontal Axis Wind Turbine (HAWT)

- The turbine consists of a tower. An enclosure called NACELLE is mounted atop the tower.
- Nacelle houses bearings for turbine shaft, gear box and the generator.

- Turbine blades generally 2 or 3 in number are mounted on the shaft.
- YAW CONTROL is the drive mechanism which orients the nacelle in the direction of the incident wind.



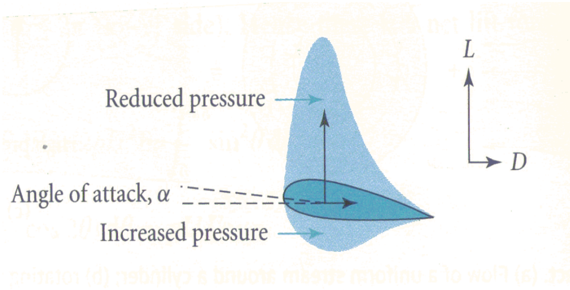
Vertical Axis Wind Turbine (VAWT)



Principle of Operation

Shape of aerofoil for aircraft wings and turbine blades. For small angle of attack, the pressure distribution on the upper side of aerofoil is significantly lower than that of the lower side, resulting in a net lift and drag force on the aerofoil.

- A good blade design is the one which maximizes the lift force and minimizes the drag force.



Pressure distribution over aerofoil for small angle of attack

Tip Speed Ratio (TSR)

Ratio of the speed of rotation of the outer tip of the blade and the speed of the incident wind.

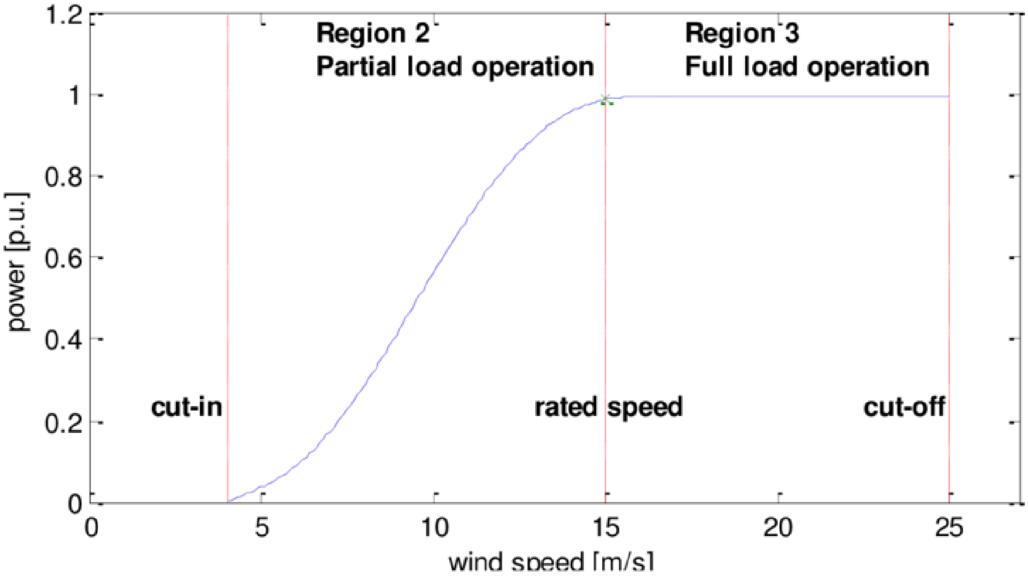
$$TSR = \frac{Speed\ of\ the\ rotation\ of\ the\ outer\ tip\ of\ the\ blade}{Speed\ of\ the\ incident\ wind}$$

- Maximum theoretical efficiency of the rotor is called Betz Limit.
- TSR is a measure of rotations per minute of the rotor.

Capacity Factor

The ratio of the annual energy yield to that which would be produced at the rated power is called capacity factor (CF).

$$\text{Capacity Factor} = \frac{\text{Actual ENERGY Generated (MWh)}}{\text{CAPACITY (MW)} \times \text{TIME Period (h)}}$$



- Below ***cut-in*** turbine not turned on since power generated insufficient to set off generator loss
- Above ***cut-in***, output power increases as cube of wind speed, till ***rated speed***, when the output
  power is same as the rated power, P_r.
- Above ***rated speed***, the pitch of the turbine blades is reduced to shed some of the wind, to prevent the generator from overpowering.
- At ***cut-off***, or furling, the winds are just high and too dangerous, so the turbine shuts down.

Classification of Wind Turbines based on output power

Name	Capacity	Application
Large Turbines	150 kW	connected to the national electricity grid for power production
Intermediate Size Turbines	10 kW-150 kW	in hybrid energy systems: Such as with photovoltaics /hydo/diesel
Small stand alone turbines	<10 kW	for battery charging, water pumping, heating etc

Wind Farms

A wind farm constitutes a group of wind turbines located close at a place. These are used for the production of electric power.

1. Onshore Wind Farms - hilly / mountainous region
    a. done to exploit the topographic acceleration of the wind due to its passage over the ridge.
2. Offshore Wind Farms - at sea > 10 km from land

    Advantages:

    1. Higher average wind speed (and stable wind above open water of sea).
    2. Higher Capacity Factors
    3. Less obtrusive than turbines on land, as their apparent size and noise is mitigated by large distance from habitation.
    4. bigger in size than those located on land because it is easier to transport very large turbine components by sea.

    Disadvantages:

    1. More complex and costly to maintain
    2. More expensive
    3. Corrosion due to saltwater environment

3. Near Shore Wind Farms — within 3 km of a shoreline or within 10km of land
    a. good sites for turbine installation, because of high wind speeds produced by convection due to differential heating of land and sea each day.

Chapter 4a :Solar Power

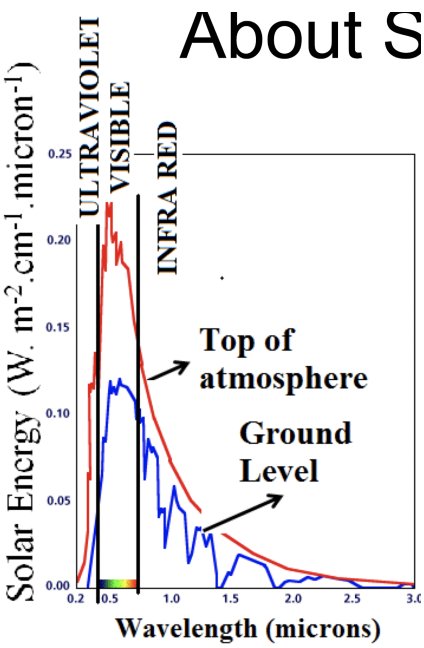
Solar Radiation

Composition

- Ultraviolet (UV) radiation: 9%
- Visible Radiation: 40%
- InfraRed (IR) radiation: 51%

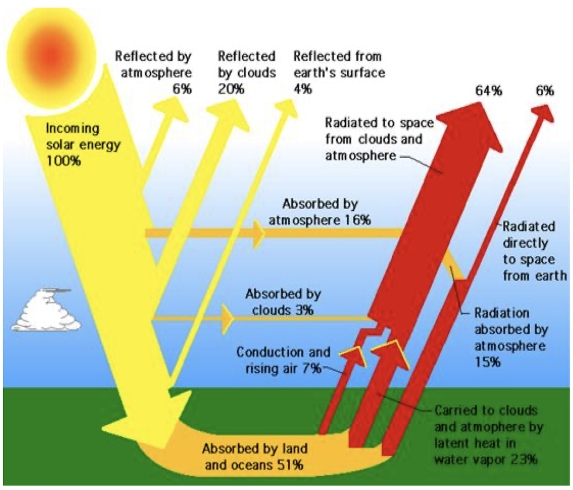
Roughly half of it reaches the surface of the earth

Some of the infrared rays are also absorbed by water vapours, carbon dioxide and methane in the lower atmosphere



Solar Energy Balance for Earth

The relatively constant temperature of earth is the energy balance between the incoming and outgoing radiations.

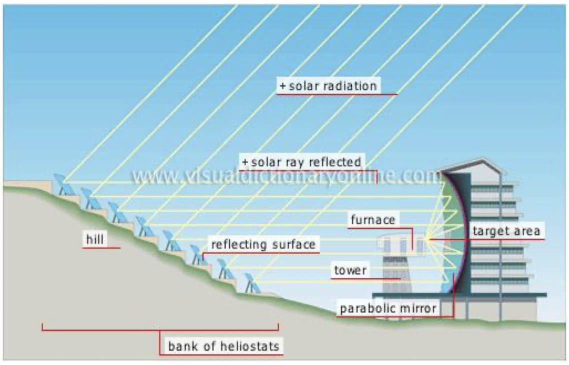


Solar Furnace

Heat produced is clean with no pollutants

Uses for this energy:

- Hydrogen fuel production
- Foundry applications
- High temperature materials testing



Categories of Solar Thermal Devices

1. Solar thermal devices for direct heat applications
2. Concentrating solar power (CSP) thermal devices which use heat for electricity production in a steam turbine
3. Photovoltaic devices that produce electricity directly from solar radiation (PV)

Modern Solar Heating Systems (Active vs Passive)

Active Solar Systems	Passive Solar Systems
The solar heated fluid is circulated by a fan or pump	Uses no external power. Allows the fluid heated by the sun to circulate by natural means
Example: Heating of Swimming Pool water, Domestic water heating Systems	Example: Passive space heating in buildings

Active Solar Systems	Passive Solar Systems
The solar heated fluid is circulated by a fan or pump	Uses no external power. Allows the fluid heated by the sun to circulate by natural means
Example: Heating of Swimming Pool water, Domestic water heating Systems	Example: Passive space heating in buildings

Solar Thermal Devices for Direct Heat

- Power Needed for heating

$$Power\ needed\ for\ heating = P * Efficiency\ of\ Oven * Collector\ Area$$

$$P = Percentage\ of\ insolation\ received * Insolation$$

Solar Water Heating Systems

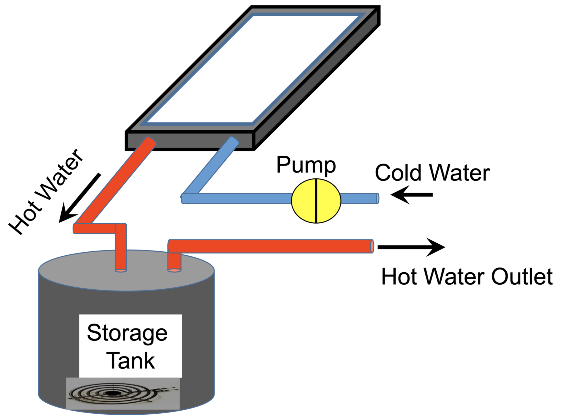
- use the sun's energy to heat water in liquid-based solar collectors
- used along with conventional water heaters
- meet approx. 50% of the water heating requirements in a home
- Solar water heating systems include storage tanks and solar collectors

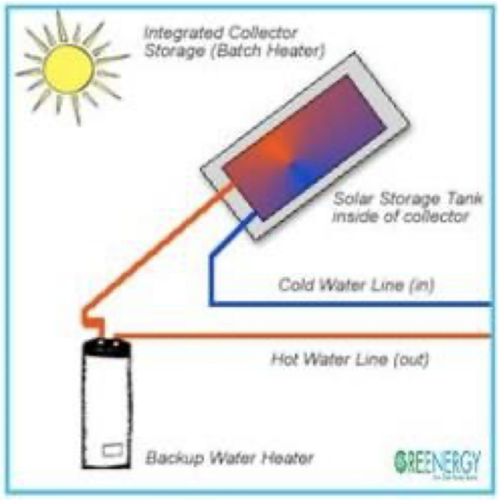
Domestic Water Heater	Swimming Pool Water Heater
Operate at 60-82^{0}C	Operate at 43^{0}C
Most common Water Heating Systems	-

Three Types of solar collectors:

1. Flat Plate Collectors
2. Batch Collectors
3. Evacuated Tube Solar Collectors

Domestic Water Heater



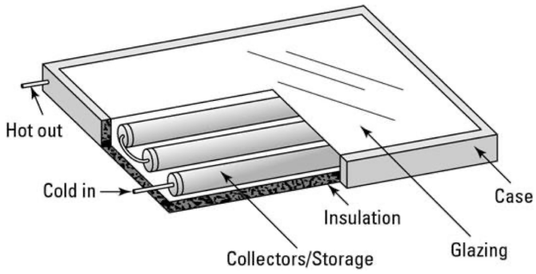


•Batch Collectors

Evacuated Tube Solar Collectors

Flat Plate Solar Collector

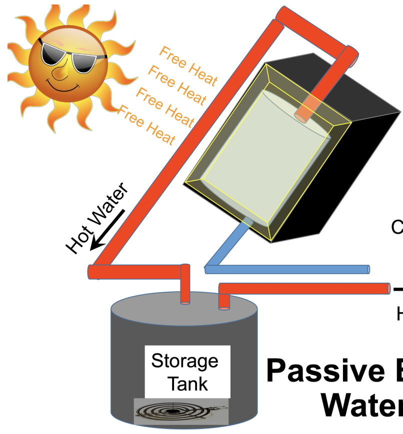
- In an air based collector the circulating fluid is air, whereas in a liquid based collector it is usually water.
- Achievable temperature is 30- 70°C



•Flat Plate Collectors

Passive Batch Solar Water Heater

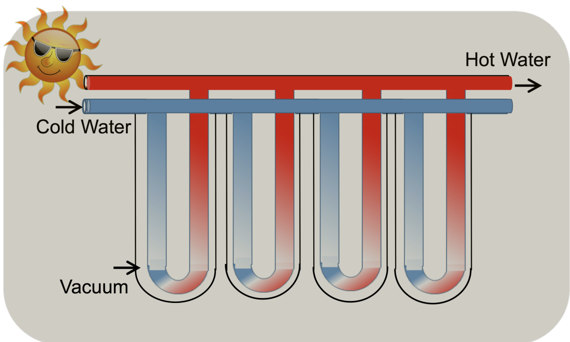
- Choice of materials for surfaces on the tank(s): The surfaces of the tank should have good absorbers of solar infrared radiation and inhibit radiative loss.
- On an area basis, batch collector systems are less costly than glazed flat-plate collectors but energy delivered per year by them is less .

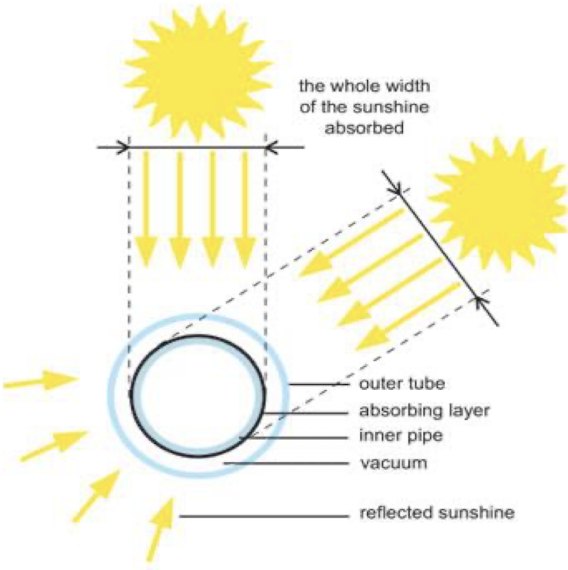


Passive Batch Solar Water Heater

Evacuated Tube Collectors

- This type of solar collector can achieve high temperatures in the range 77°C to 177°C under the clear sky conditions.
- Evacuated-tube collectors are quite expensive, with unit area costs about twice that of flat-plate collectors.
- They can also be an effective alternative to flat-plate collectors for domestic space heating, especially in regions where it is often cloudy.





Passive Solar Space Heating System

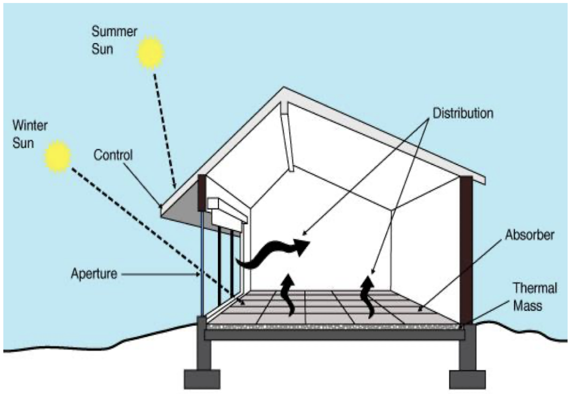
Maximising solar heat gain

1. The solar radiation available at the location of the building
2. Proper orientation of the building
3. The characteristics of the collection areas (their solar transmittance/ absorption and heat transfer)

Minimising heat losses

1. Applying thermal Insulation of high quality
2. Installing multiple-glazed windows
3. Avoding thermal bridges
4. Providing air tightness

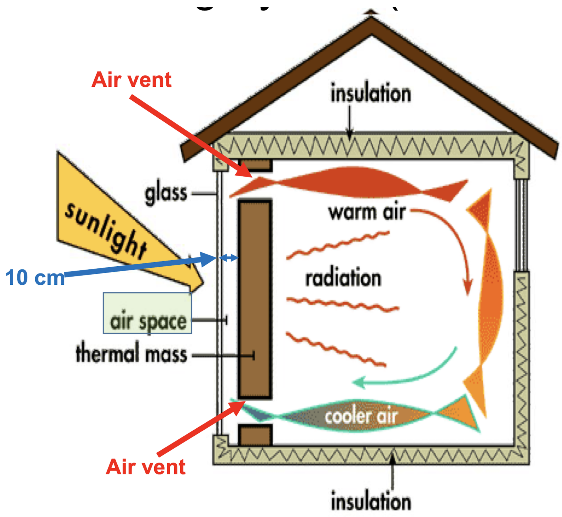
These methods help to reduce heat transmission and air infiltration which are the main avenues for heat transport through the building envelope

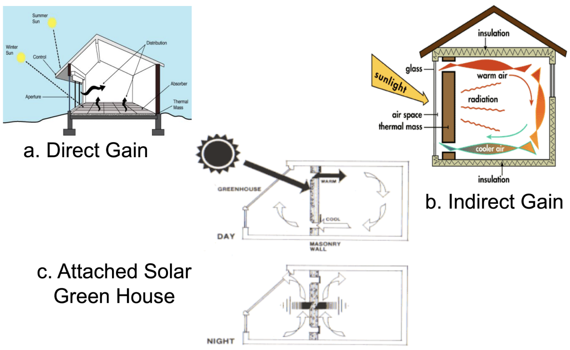


Schematic illustration of direct solar heat gain

3 Types of Passive Solar Space heating System

1. Direct Gain
2. Indirect Gain
    a. Trombe Wall
3. Attached Solar Green House
    a. Serve dual purpose (food production and space heating)
    b. Greenhouse acts as a thermal wall





a. Direct Gain

b. Indirect Gain

c. Attached Solar Green House

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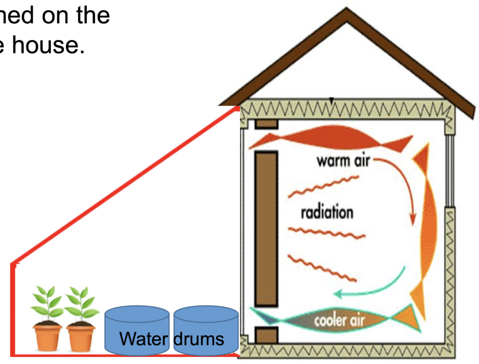


Green house acts as extended thermal wall.

Principles of Passive Cooling

1. Minimising solar heat gain by
    a. Increasing the building mass.
    b. Increasing thermal protection.
    c. Reflective coating (white) on exposed surfaces.
    d. Curtailing solar radiations using shading devices.
    e. Air tightness of the building.
2. Removing Unwanted Heat
    a. Evaporative cooling
    b. Nocturnal ventilation
    c. In hot humid climate, a thermo-active ceiling could be installed (see figure), which would however need a pump.

Estimation of Collector size for space heating

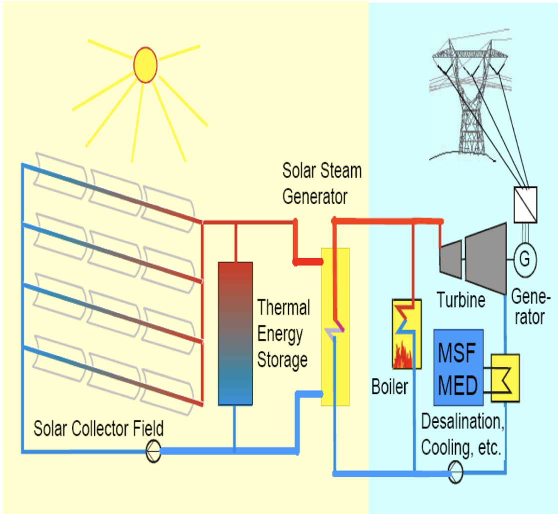
$$Heat\ needed\ for\ 1\ day = Incident\ heat(insolation) * efficiency * Area$$

Electricity Production from Solar Thermal Power Plant

Power plants use curved, mirrored troughs (collectors) which reflects the direct solar radiation onto glass tubes containing a fluid running along the length of the trough and positioned at the focal point of the reflectors.

The fluid (also called heat transfer fluid) becomes very hot. Common fluids are synthetic oil, molten salt and water.

The hot fluid is transported to a turbine where heat is converted into electricity.



Solar Power Tower

capture and focus the sun's thermal energy with thousands of tracking mirrors (called heliostats) in roughly a two square mile field.

Within the receiver the concentrated sunlight heats molten salt to over 550°C

heated molten salt then flows into a thermal storage tank where it is stored, maintaining 98% thermal efficiency, and eventually pumped to a steam generator

The steam drives a standard turbine to generate electricity. This process, also known as the "Rankine cycle" is similar to a standard coal-fired power plant

HELIOSTATES

Chapter 4b: Solar Photovoltaics

$$1\ eV\ (electron\,Volt) = 1.6 \times 10^{-19} J$$

Light exhibits wave nature, with velocity c, wavelength λ and frequency v

$$c = v\lambda$$
$$c = 3 \times 10^{8}\ m/s\ in\ vacuum$$

Light exhibits particle nature, fast moving particles called photos, with Energy, E

$$E = hv$$
$$h\ (Planks\ constant) = 6.63 \times 10^{-34} Js$$

Photovoltaic (PV) systems (solar cells) convert solar energy directly into electricity. Silicon is used, sunlight will create a hole → visible light photo provides the energy for the electron to break loose.

Dopants in Si

Doping is the adding of impurities in small amounts

1. Negative (N) type Si: P, As (Donars)

- Improve conductivity, Group IV elements
- Extra free **electron, mobile** and belong to the body of Si
- As added to Si, only needs 8 electrons and As has 5, but added to Si which has 4 free electrons, will have 9 thus 1 free electron.
- Impurities are added in small amounts, if added in large amount will kill the lattice structure of Si

1. Positive (P) type Si: B, Al, Ga (Acceptors)

- Group III elements
- B (Boron) accepted an electron, acquiring a negative charge
- Absence of electrons, overall doped Si has 1 short electron

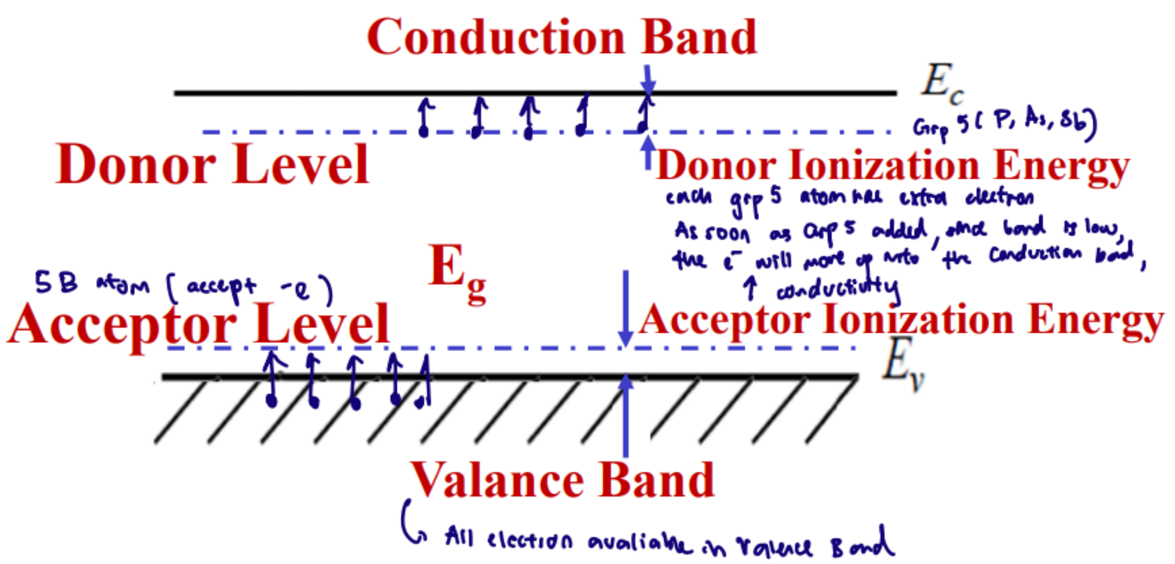
Energy Band Diagram in Solids (Si)

- **Conduction Band:** empty space for electrons to move freely
- **Valence Band:** Outermost filled band in solids, hole in Si created here

- For insulators, Band Gap >> HIGH, unable to conduct high amount of energy to jump from Valence Band to Conduction band.
- For conductors, Band Gap = 0, if electrons are at Conduction Band, it means material can conduct easily.

$$Energy\ of\ photon\ (hf) > E_g$$
$$E = hv = E_g, c = v\lambda$$
$$E_g = \frac{hc}{\lambda}$$

Energy Band Diagram of Doped Si



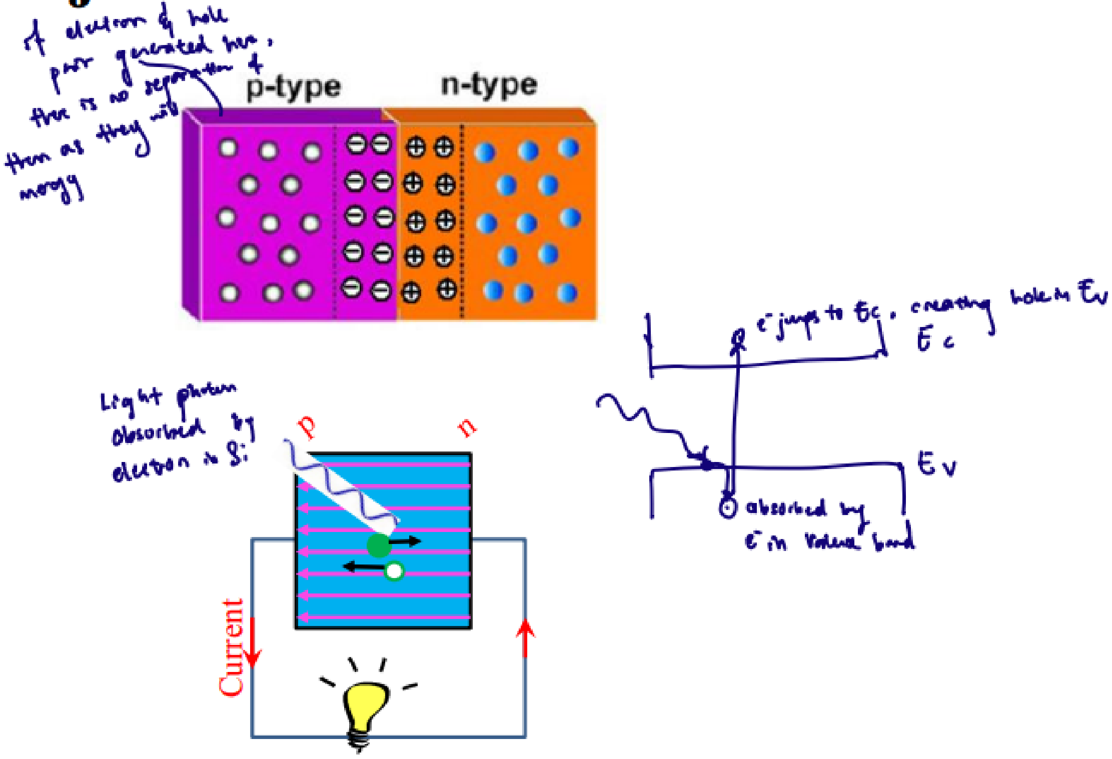
Bandgap energies of selected semiconductors

Material	PbTe	Ge	Si	GaAs	GaP	Diamond
E_g (eV)	0.31	0.67	1.12	1.42	2.25	6.0

p-n junction

The depletion region is needed to allow the **electron to jump from** to p-type Dopant to the n-type Dopant. If the electron-hole is generated elsewhere (not in the depletion region), there is no separation of them, and the hole will be filled up again by the same electron.

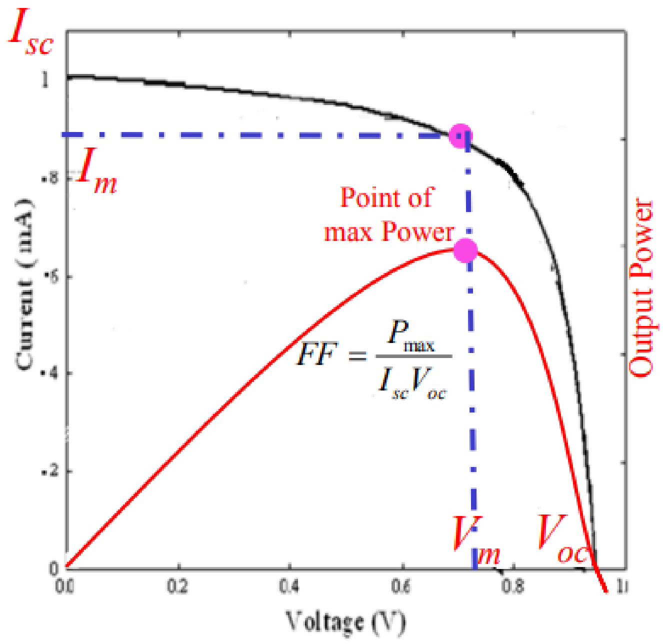
p-n junction: Solar Cell action



I-V and P-V Curve for Solar Cells

Fill Factor (FF): The FF of a solar cell defines how close the I-V characteristics are to a rectangle, good solar cells have FF > 0.7. Typically, FF lies between 0.75-0.85.

$$FF = \frac{P_{max}}{I_{sc} V_{oc}}$$



Output Power P_c is given by:

$$P_c = I_c \times V$$

As V increases P_c increases until V is slightly less that V_{oc}.

No power is generated under short and open circuit

$$P_{max} = V_m I_m = FF V_{oc} I_{sc}$$

Commercially employed material for Solar Cell (Si)

Crystalline & Polycrystalline Silicon

- Advantages:
  - High Efficiency (14-22%)
  - Established technology (The leader)
  - Stable
- Disadvantages:
  - Expensive production
  - Low absorption coefficient
  - Large amount of highly purified feedstock

Amorphous Silicon

- Advantages:
  - High absorption (doesn't need a lot of material)
  - Established technology
  - Ease of integration into buildings
  - Excellent ecological balance
  - Cheaper than the glass, metal, or plastic used for depositing amorphous silicon there on

- Disadvantages:
  - Only moderate stabilized efficiency 7- 10%
  - Instability- It degrades when light hits it

Efficiency of Solar Cells

Conversion Efficiency of a Solar Cell is defined as the ratio of the maximum power output to the incident solar power. Factors that may affect efficiency:

1. Out of 100% Incident solar radiation on a solar cell, photons with **energy less that the band gap is 23%**, so they **cannot produce power**. 30% goes in the form of heat and so **only 47%** is useful or interacting with solar cell.
2. Not all electron hole-pairs produced by incident photons are collected by field across the junction' about **10% recombine**.
3. A potentially large loss (~40%) from the surface of silicon can be reduced by using anti reflecting coatings.

The overall efficiency is the product of the efficiency contribution from each factor. Efficiency depends on band gap, smaller band gap ⇒ increase photo current.

- This decreases maximum output voltage as $eV_{oc} < E_g$
- An optimum band gap is $1.4\ eV$

Economics of Photovoltaics

Cost of solar panels have *decreased* over the years. **Location** also matters, place sunny and have an electricity grid.

Environmental Impacts

1. PV power in operation produces no pollutants and no greenhouse gases.
2. Visually unobtrusive and no moving parts, reduce maintenance / noise polution.
3. Producing, some materials like Cd and As are hazardous, but quantities used are small.
4. Solar energy falling on earth is used, no additional energy needed for operation.

Chapter 5a: Hydro Power

Principle of Hydroelectric Power Plant

Production of electricity by using the gravitational force of falling water

Most widely used form of clean energy (20% of world's electricity)

Potential energy of water → Kinetic energy of water → Rotational Kinetic energy of turbine → Electrical energy

$$Power\ output = \eta \rho g h Q$$
$$\eta = efficiency, \rho = 1000 kg/m^3,$$
$$Q = Volume of water flowing per second (m^3/s)$$

Advantage of Hydroelectric Power Plants

1. Clean, renewable
2. Very low level of greenhouse gases
3. Low operating cost
4. Long plant life ~40 years
5. Available on demand (control water flow)

Different Plants

	Advantage	Disadvantage
Dams		Huge environmental impact Risk of flash flooding (breached dam) Risk of accidents during construction Diversion of water impact stream flow, or cause river dry out Lower amount of dissolved oxygen
Run of the river	No dam Minimised impact on environment	Diversion of water impact stream flow, or cause river dry out Lower amount of dissolved oxygen Hard to find naturally occurring sites
Damless	No environmental impact No construction risk No flash flood risk No flooding large catchment areas No silt accumulation in dam basin No need for fish ladder No additional greenhouse gases	Difficult to find such geological site Not mature

Pumped Storage Hydroelectricity

Use Low-cost off-peak electric to pump water from lower elevation reservoir to a higher elevation

During periods of high electrical demand, stored water is released through turbines

Chapter 5b: Ocean Energy Systems

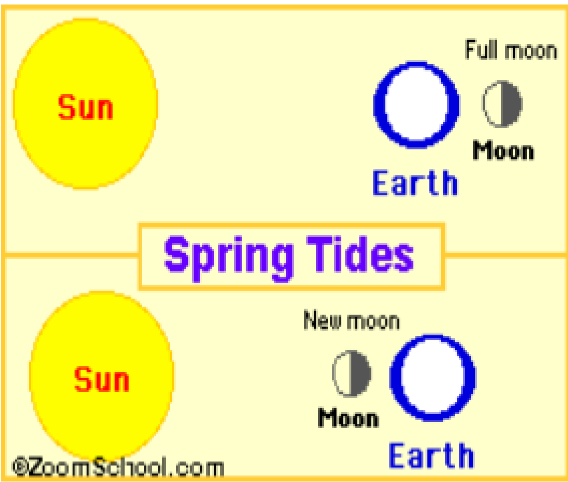
1. **Tidal Energy:** Gravitational fields of the sun and moon are the contributors to formation of tides and the energy contained therein.
2. **Ocean Thermal Energy:** This is the component of energy received by sea directly from the sun.
3. **Ocean Wave Energy:** Wind blowing over the ocean surface drags water with it and produce ocean waves.

Tides

- Low/high tides occur at the same time at 2 places, located at longitudes differing by about 90°
- **Tidal Range:** Difference between height of hide tide and low tide
- **Tidal Period:** Interval between 2 high tides ~ 12 hrs and 25 mins (12 hours for simplicity), 1 day has 2 tidal periods.

Spring Tides

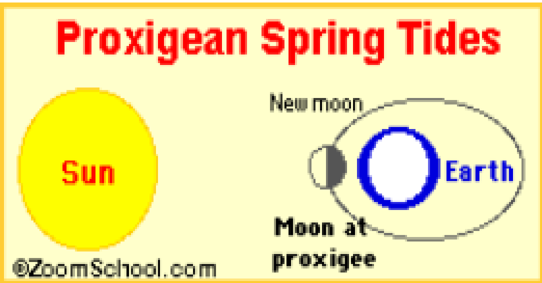
- Especially strong tides, occur when Earth, Sun and Moon are in a straight line.
- Gravitational forces of Moon and Sun jointly contribute to formation of tides.
- Occur during full moon and new moon.



Proxigean Spring Tides

Neap tides

- Rare and unusually high tide. Tide occurs when Moon is both unusually close to Earth (closest perigee is called proxigee) and in the New Moon phases (Moon between Sun and Earth).
- Occurs at the most once every 1.5 years.



- Especially weak tides.
- Occur when gravitational forces of Moon and the Sun are perpendicular to one another (wrt Earth)
- Occur during quarter moons, Tidal height is lower compared to others.

Tidal Power: Tidal Barrages

- High tide, when level of water in the sea is high, sea-water flows into the reservoir of the barrage and rotates the turbine blades and also the shaft which in turn generates electricity.
- Low tide, above process reversed. Sea water stored in barrage allowed to flow out into sea, flowing water turns turbines and generates electricity.
- Sea-water flows in and out of tidal barrage, during high/low tides, turbine rotates continuously to generate electricity.

$$Output\ Power, P = \frac{\rho g A h^2}{2T} \times 2$$
$$= \frac{\rho g A h^2}{T}$$
$$where\ T = Tidal\ Period\ (time\ between\ 2\ successive\ high/low\ tides)$$

Advantages of Tidal Power

- Free, No fuel → No greenhouse gases

Disadvantages of Tidal Power

- Provide power for only about 10 hours each day, when tides moving

- Tides are totally predictable, and produces electricity reliably
- Cheap maintenance
- Offshore turbines not ruinously expensive to build
- Do not cause large environmental impact

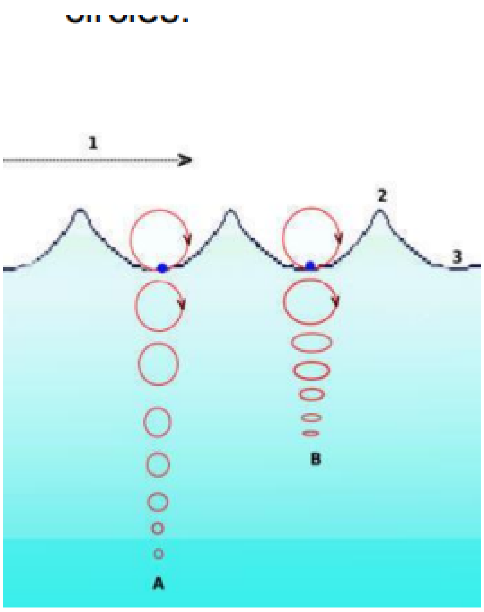
in/out of barrage

- Sites suitable for tidal barrages are limited
- Very expensive to build
- Many birds rely on tide uncovering mud flats for feeding. Fish cannot migrate unless 'fish ladders' are installed.

Ocean Waves

Unequal heating of the earth and sea water due to the solar radiation falling thereon causes the atmospheric air to move from above the sea towards the land. This fast moving air over the sea surface imparts momentum to the top surface layer of the sea water. In this process the water at the
surface is dragged along the wind

- Over deep water, energy in wave moves forward but water does not. Water moves up and down in circles.

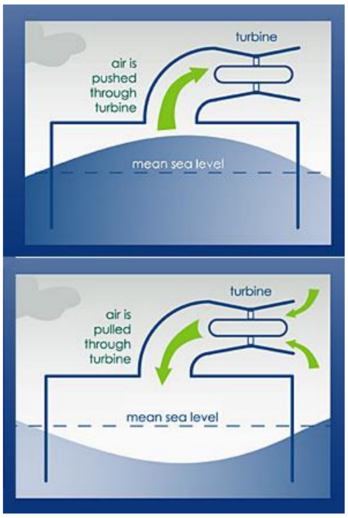


Motion of a particle in an ocean wave.
A - At deep water. The orbital motion of fluid particles decreases rapidly with increasing depth below the surface.
B - At shallow water (ocean floor is now at B). The elliptical movement of a fluid particle flattens with increasing depth.
1 - Direction of propagation of wave.
2 - Wave crest.
3 - Wave trough.

Harnessing Wave Power for Electricity Generation

Oscillating Water Column Devices

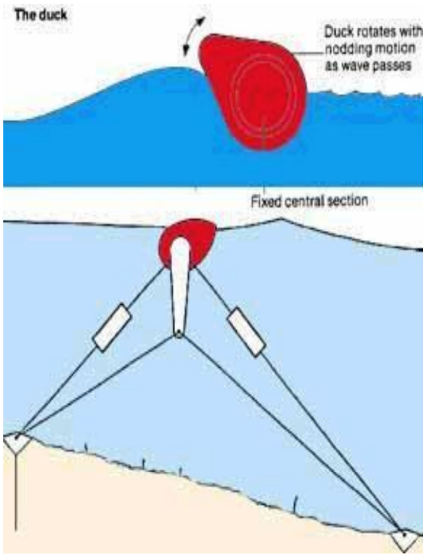
- During the propagation of the wave, its crests and troughs pass alternately over the base of the device. As a result the water is pushed up and down alternately.



- Air Column gets pushed up and down the tube, which turns the turbine.

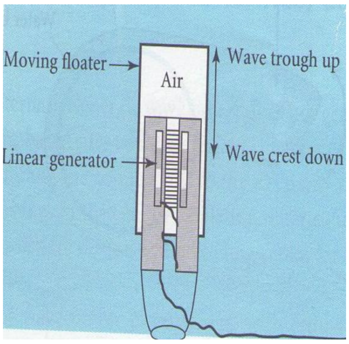
Buoyant Moored Device

- Device floats on the surface of the water or below it. It is moored to the seabed by either a taught or loose mooring system.
- The front edge of the duck matches the wave particle motion.
- The device requires a **<u>water depth of at least 80 metres</u>** and uses a system of weights and floats to give almost **constant tension** in the mooring cables.



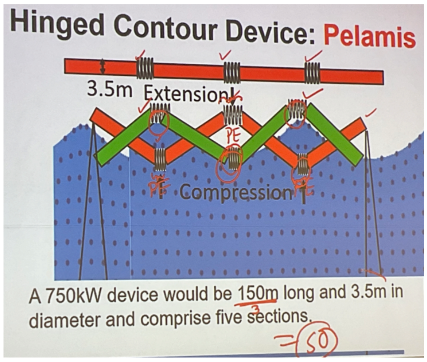
Submerged Devices: Archimedes Wave Swing

- The wave action powers the floater which moves up and down, generating a reciprocating movement.
- When the wave crest approaches, pressure on the top of the floater increases, which pushes mechanism inside the cylinder downwards, compressing the gas within the cylinder to balance the pressure.



- When the wave trough passes over the floater, the reverse process takes place, moving the floater upwards and decompressing the gas inside the cylinder.
- This reciprocating motion generated by the floater is converted into electricity by means of a hydraulic system or a motor-generator set.
- Having only one moving part makes the system is more reliable with less need of maintenance.

Hinged Contour Device: Pelamis



- It is semi submerged serpentine construction consisting of series of cylindrical hinged segments that are pointed towards the incident wave.
- This type of device follows the motion of the waves; it creates power using the motion at the joints. It is commonly moored slackly to hold it in place.

Environmental Impacts, Economics and Prospects of Wave Power

- The global potential for wave power is very large: 1-10 TW
- Opposition to shore-based sites could be an issue in areas of scenic beauty.
- Noise generated by air turbines of oscillating water column is unacceptable.
- The visual impact is much less significant for off-shore devices but providing cables for electricity transmission to the shore adds to the cost.
- Main challenge is to reduce the capital cost of construction of the system to make electricity available at a competitive price.
- Need to withstand extreme weather conditions at sea.

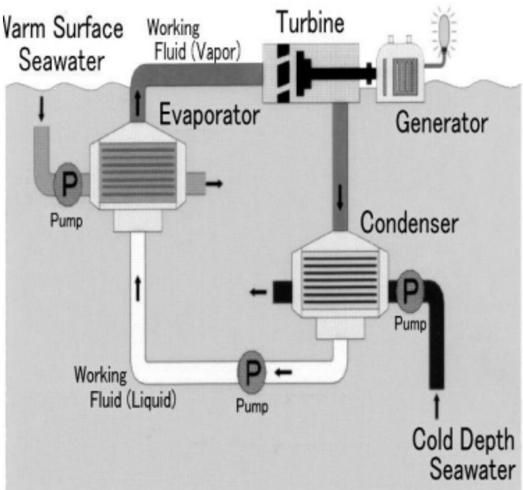
OTEC

OTEC process uses the heat energy stored in the Oceans to generate electricity. OTEC systems work best when the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about **20°C**.

- Earlier OTEC systems had an overall efficiency of only 1 to 3% (the theoretical maximum efficiency lies between 6 and 7%).

Ocean thermal energy conversion systems (*OTEC)* make use of the different high and low temperatures that exists in deep and shallow water to the process of rotation of turbine.

The heat cycle suitable for OTEC is the Rankine Cycle using a low-pressure turbine. The OTEC Systems are of three types: (i) closed-cycle (ii) open-cycle (iii) hybrid cycle.



Principle of OTEC (Closed Rankine cycle)

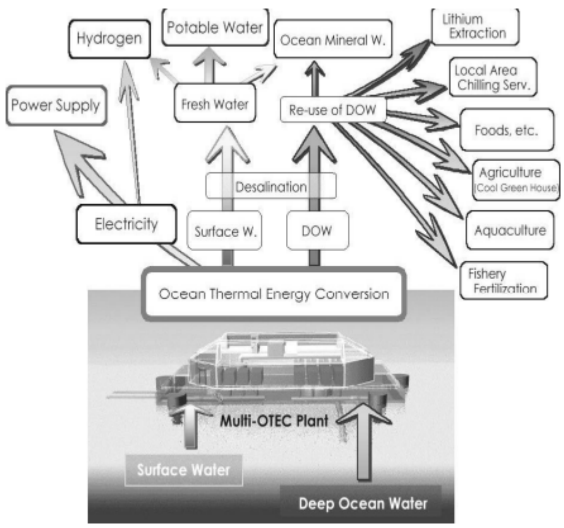
The main components of the systems are : a feed pump, an evaporator, a turbine and a condenser.

Closed cycle: In this system ammonia is used a working fluid. On its passage through the evaporator, ammonia absorbs heat from the hot sea water and gets evaporated.

Then the vaporized ammonia passes over the turbine causes it to rotate and generate electricity.

Apart from generation of electricity, the potential of deep ocean water (DOW) has been explored and has several other applications. Some of the utilizations already in practice are:

- Extracting lithium chloride dissolved in seawater is one of considerable method of industrial lithium production.
- Produces base load electrical energy.
- Produces desalinated water for industrial, agricultural, and



Multiple-OTEC Station

residential uses.

- Helps produce fuels such as hydrogen, ammonia, and methanol.
- Provides air-conditioning for buildings and moderate-temperature refrigeration. The temperature of depth cold water after utilization for OTEC is still low; e.g. the temperature is around 10℃. It is cold enough to use as chilling source of air cool conditioning.

Benefits of OTEC

1. Clean and renewable (solar source energy).
2. Stable throughout a moment, a day and a year.
3. Huge amount but low-density energy.
4. We can assess the value of an ocean thermal energy conversion (OTEC) plant and continued OTEC development by both its economic and noneconomic benefits.
5. Enhances energy independence and energy security.
6. Has potential to mitigate greenhouse gas emissions resulting from burning fossil fuels.

Concerns of OTEC

1. Marine organisms entrainment and impingement through the water current.
2. The effect of chemicals used to reduce/control biofouling buildup inside the seawater pipes and heat exchangers.
3. The effect known as “upwelling”, or rise of the deep cold water to the surface.

Chapter 6: Biomass Energy

Bio Energy Crops

1. Corn
2. Soybeans
3. Sorghum
4. Sugar Cane Bagasse
5. Switchgrass
6. Hybrid Poplar

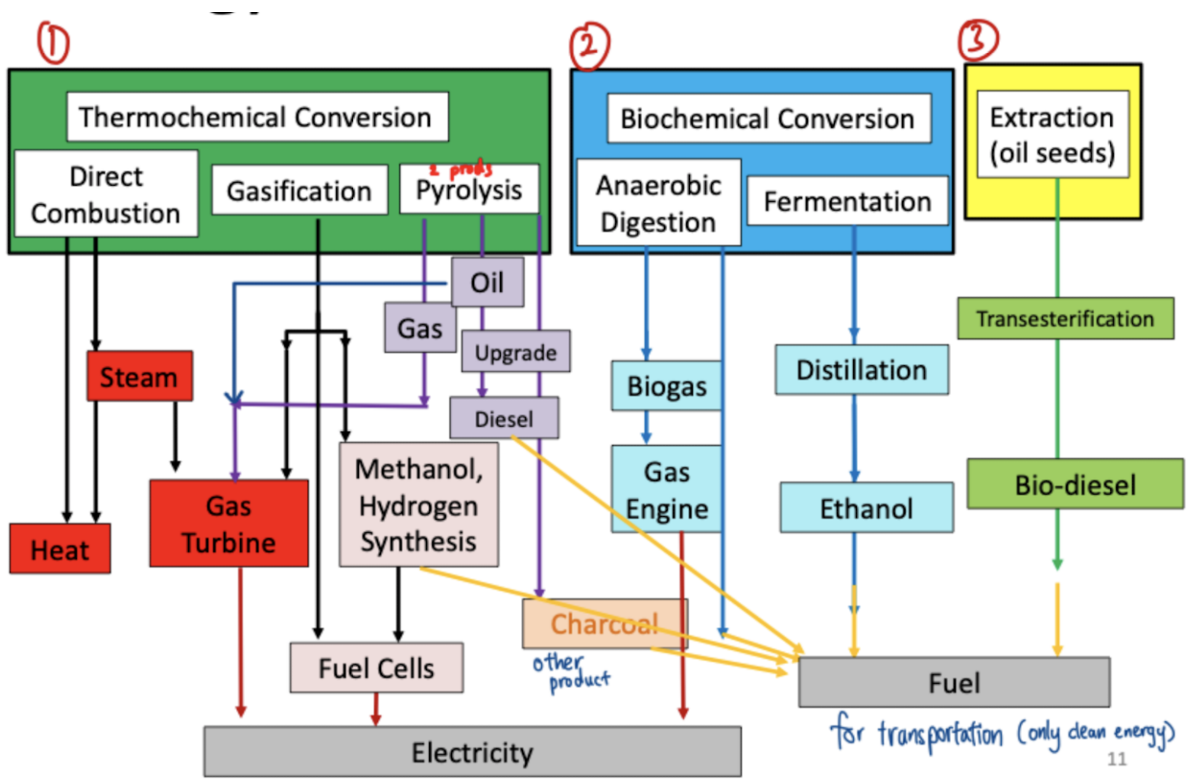
Bio Materials and Crops

1. Corn Stover
2. Wood Chips & Sawdust
3. Municipal Solid Waste

Finding energy stored in biomass

$$1.5 * 10^{14} kg\ of\ carbon$$
$$Mass\ of\ 1\ Carbon\ Atom = \frac{12 * 10^{-3}}{6.023 * 10^{23}} = 2.0 * 10^{-26}$$
$$Number\ of\ Carbon\ atoms = \frac{1.5 * 10^{14}}{2.0 * 10^{-26}} = 7.5 * 10^{39}$$
$$Energy\ stored\ in\ fixing\ 1\ C\ atom = 4.8\ eV$$
$$Total\ Energy\ stored = 4.8 * 7.5 * 10^{39} eV$$

Energy Generation



Gasification

1. Heat in absence of Oxygen around 600 degrees C
    a. Products: Hydrocarbon gases, Hydrogen, CO, CO2, H2O, tar
    b. By Products: Char (carbon), Ash
2. Heat in presence of oxygen at 700-2000 degrees C
    a. Char is gasified by reactions and oxygen, steam and hydroen
    b. Produces Synthetic Gas: CO + H2

Advantage

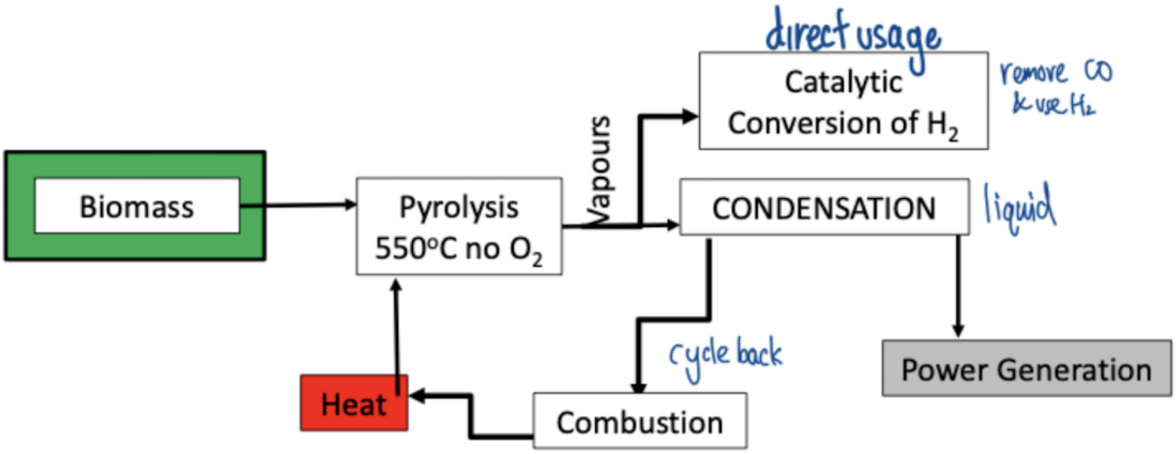
- Gaseous fuels mix with oxygen more easily than liquid fuel
- Syngas therefore inherently burns more efficiently and cleanly than solid biomass
- Improve efficiency of large-scale biomass power facilities

Pyrolysis

Liquify solid biomass through pyrolysis or other thermochemical technologies

1. Biomass heated in absence of air
    a. Forms biomass liquids (bio oils) which are good for transport

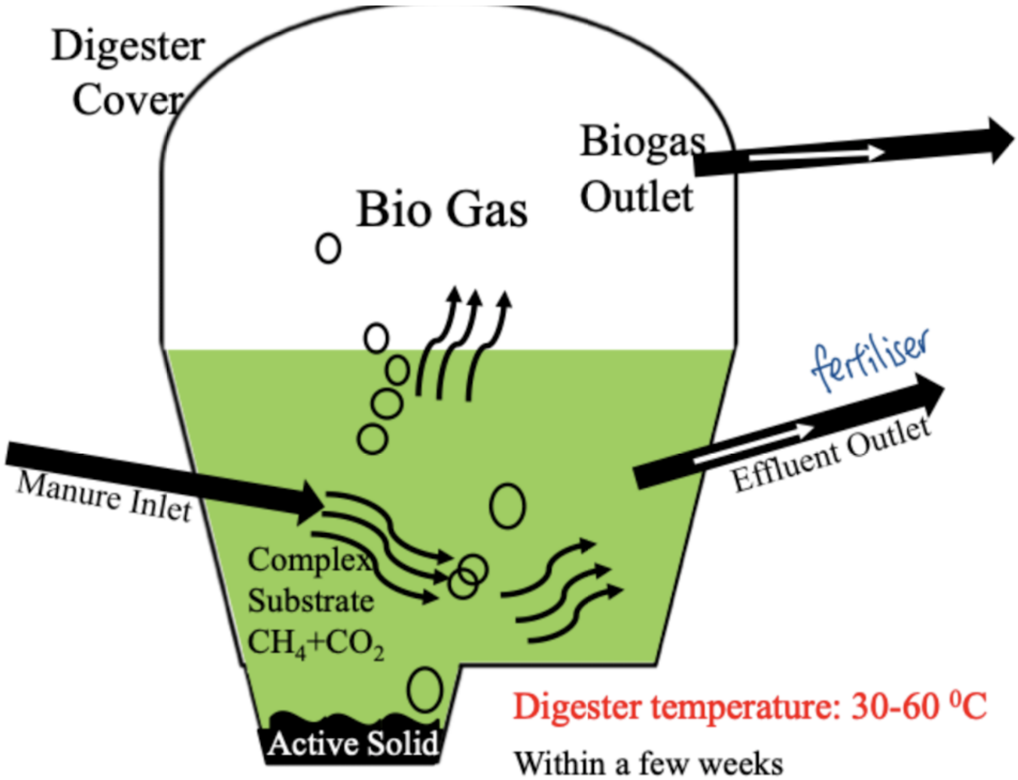
b. Up to 75% of biomass are converted to liquid which are usable in engines turbines and boilers



Anaerobic Digestion

Decomposition of organic matter in the absence of air by bacteria

- Produces gas: methane (65%), carbon dioxide (35%)
- Temperatures kept at 30-60 degrees celcius
- Methane gas can be used for direct heat application, such as operating a boiler or space heater



Bioethanol

Fermentation:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2 + 0.4MJkg^{-1}$$

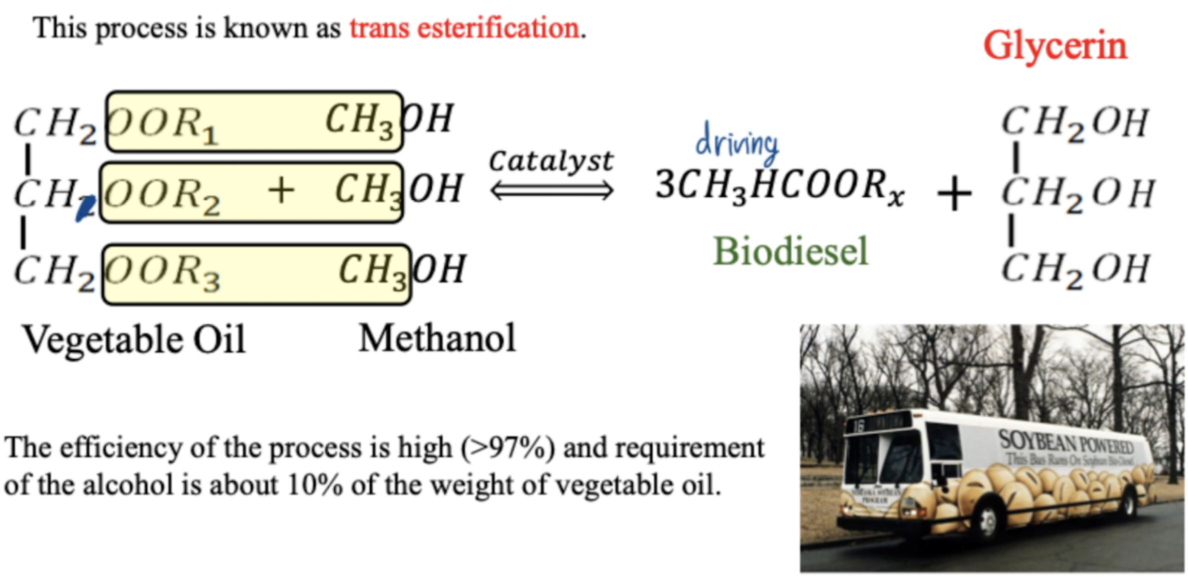
Derived from starch crops such as corn

- Problem: Competition with human consumption
- Solution: Produce cellulosic biomass that is not for human consumption but can be used for synthesis

Biodiesel from plant oils

Trans-esterfication

Reaction of oil with either methanol or ethanol using sodium hydroxide or potassium hydroxide as a catalyst and formation of ethyl or methyl esters



Impact of Biomass

- Biomass is sustainable as long as the land quality is maintained fertile
- Carbon neutral source of energy provided the biocrop is replanted
- Irrigation, fertilisers, harvesting and processing of the biomass consume energy which is derived from fossil fuels, The carbon emissions associated with theses processes are a small fraction of those given off by the fossil fuels producing the same amount of energy.

- Biomass combustion generally produces low emissions. The combustion of wood gives much less SO2 in comparison that emitted by coal. Hence there will be less acid rain.
- Large areas of energy crops may reduce biodiversity.

Economics and potential of biomass

- Sustainable Development: Biomass technologies discourage the use of fossil fuels and help us to adopt sustainable energy production.
- Energy Security: As a domestic energy source, biomass can substantially reduce dependence on imported crude oil. Biomass is more evenly distributed over the earth's surface than other finite energy sources and therefore provides opportunities for local, regional, and national energy self-sufficiency.
- Rural Economic Growth: Producing biomass and using agricultural residues for biomass technologies will stimulate rural development efforts in farming, forestry, and associated service industries by creating new products, markets, and jobs.
- Land Use : The lands must be used in balanced ways, supporting agricultural and forestry production, environmental preservation, human and wildlife habitats, as well as biomass production.
- Combustion and gasification of biomass is the most economical competitive use of biomass, with gasification having greater potential with its use in high temperature gas turbines.

Since the energy density of biocrops is low and the cost of transportation is high, hence small bioplants near the biofarms are more economical.

Future prospects of Biomass tech

- Biomass has the potential to provide 10-20% of the primary energy needs of developed countries and a large percentage in developing countries where there is lot of scope of improvement in Biomass Technology.
- Unlike other renewable technologies, biomass can be stored.
- Biomass can provide energy security and, if used for liquid biofuel production, can reduce dependence on foreign imports.
- Its development aids rural economics and its use locally avoids high transport costs.

Chapter 7: Geothermal Energy

Geothermal energy: Geo+Thermal: Is energy extracted from heat stored in the earth.

Methods of Geothermal Heat Extraction

Hot Springs

- Hot springs are gushes of hot water that are found on the land surface. As molten materials deep in the earth cool down, they give off water vapor and carbon dioxide.
- This hot vapor then find its way upward through the cracks in the rocks, cooling as it goes, until it condenses to become water.
- This water may be pure and clear, but it is rich in mineral salts dissolved from the rocks it has passed through on its way to the surface.

Fumaroles

- Fumaroles are vents from which volcanic gas escapes into the atmosphere.
- Fumaroles may occur along tiny cracks or long fissures, in chaotic clusters or fields, and on the
surfaces of lava flows and thick deposits of pyroclastic flows.
- They may persist for decades or centuries if they are above a persistent heat source (active Magma chamber) or disappear within weeks to months if they occur atop a fresh volcanic deposit that quickly cools.
- The temperatures of volcanic gases escaping from it is 70 0C - 100 0C or more. ⇒ gases are dangerous and a gasmask is often needed. They are always a sign of active volcanism.

Geysers

- A geyser is a type of hot spring that erupts periodically, ejecting a column of hot water
and steam into the air.
- The formation of geysers requires a favourable hydrogeology which exists in only a few places on Earth, and so they are fairly rare phenomena.
- Geyser eruptive activity may change or cease due to ongoing mineral deposition within the

geyser plumbing, exchange of functions with nearby hot springs, earthquake influences, and human intervention.

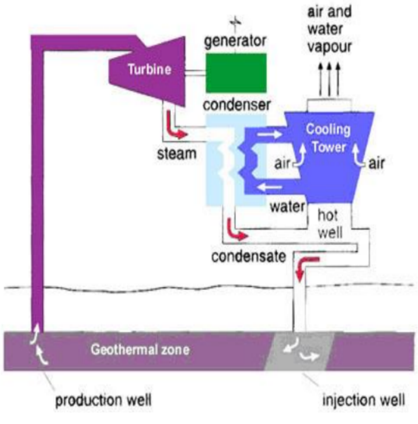
Extracting Geothermal Energy

Source	Technology	TLDR
Dry Steam	Dry Steam Power Plant	Geothermal Steam used to power the turbine entirely. Condensed and returned back into the earth.
Steam + Water	Flash Steam Power Plants	“Flashing” or vapourizing the geothermal fluid into a turbine (those that turns into steam) and condense it back afterwards. The unflashed part of the fluid is then returned back into the earth. (Double flash steam power plants has the unflashed fluid go through the flashing process once more)
Hot Gases	Binary Cycle Power Plant	Used when geothermal resource not hot enough to produce steam/too much impurities to turn to steam. Instead they use a fluid with lower boiling point, and use the geothermal fluid to heat this low B.P fluid to turn the turbine.

Dry Steam Power Plant

The dry steam power plants are suitable where the geothermal steam is not mixed with water.

- Production wells are drilled down to the aquifer and the superheated, pressurised steam (180°-350°C) is **brought to the surface at high speeds**, and passed through a steam turbine
to generate electricity.
- The steam is passed through a condenser to convert it to water. This improves the efficiency of the turbine and avoids the environmental problems associated with the direct release of steam into the atmosphere
- The waste water is then reinjected into the field via reinjection wells Waste heat vented



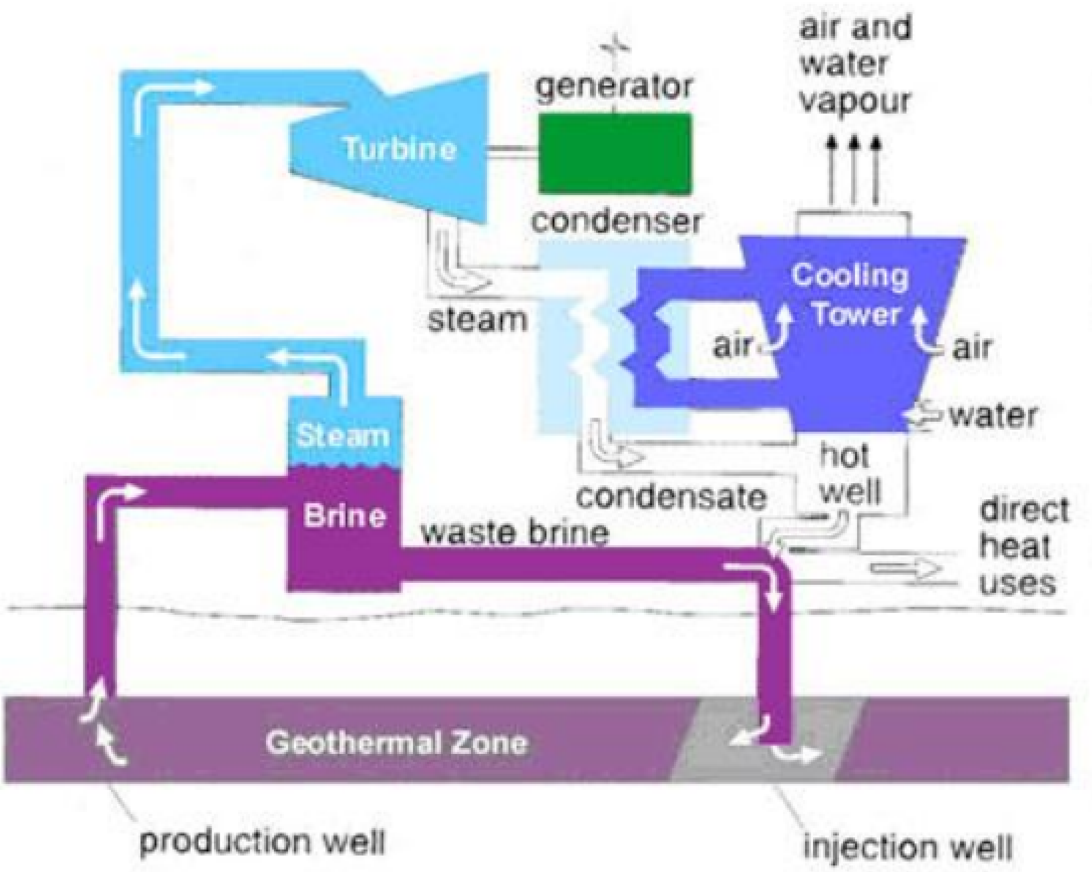
through cooling towers.

- The energy conversion efficiencies are low, around 30% . They are the simplest and most economical technology, and therefore are widespread.

Single Flash Steam Power Plants

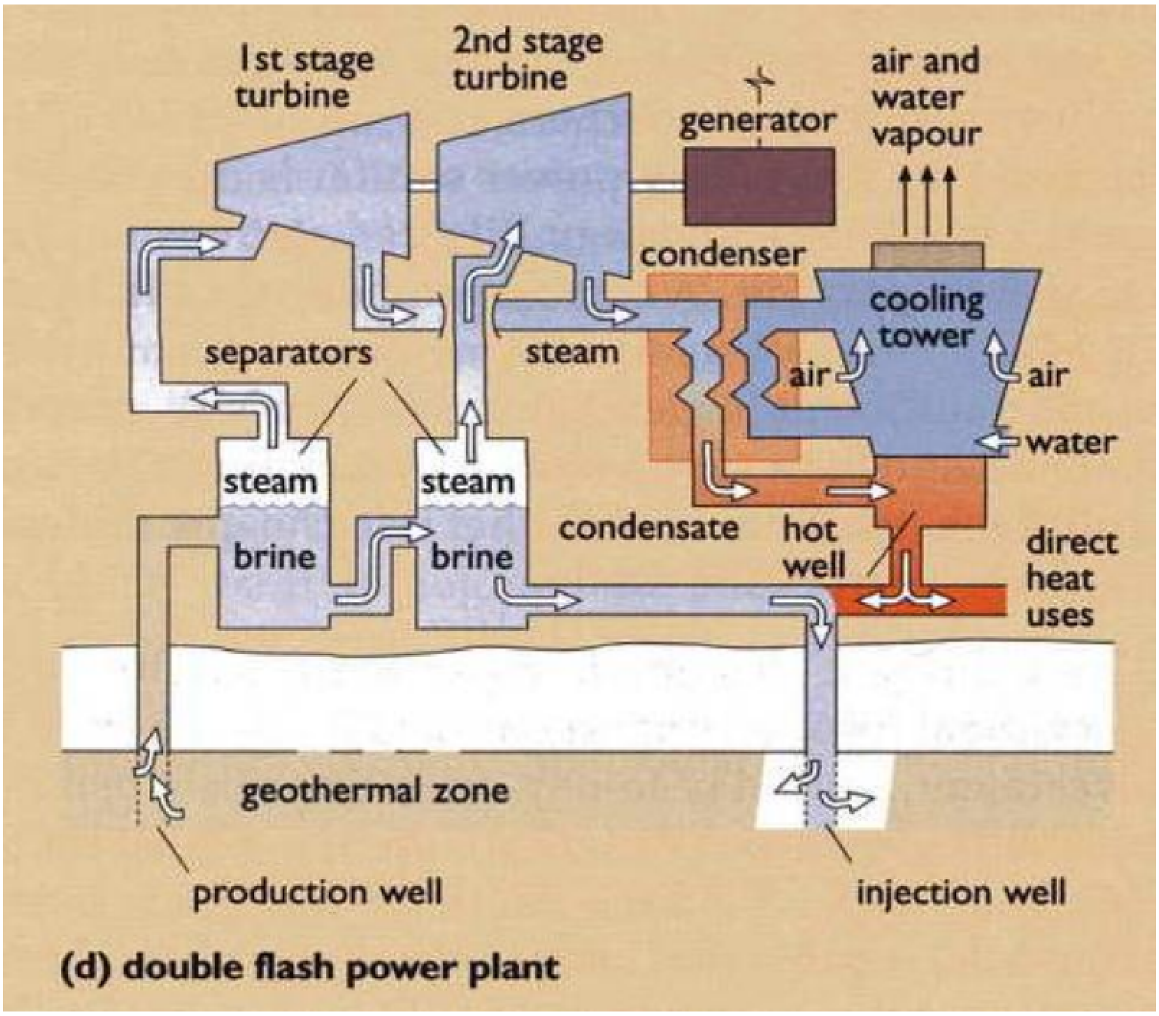
Steam with water extracted from ground. Pressure of mixture drops at surface and more water “flashes” to steam. Steam separated from water and drives a turbine which drives an electric generator. This generates between 5 and 100 MV, using 6-9 tonnes of steam per hour.

- Single flash steam technology is used where the hydrothermal resource is in a liquid form. The fluid is sprayed into a flash tank, causing it to vaporise (or flash) rapidly to steam.
- The steam is then passed through a turbine coupled to a generator as for dry steam plants.
- To prevent the geothermal fluid flashing inside the well, the well is kept under high pressure.
- The **major part** of the geothermal fluid **<u>does not flash</u>**. This fluid is reinjected into the reservoir or used in a local direct heat application.
- Alternatively, if the fluid left in the tank has a sufficiently high temperature, it can be passed into a second tank, where a pressure drop induces further flashing to steam.
- This steam, together with the exhaust from the principal turbine, is used to drive a second turbine or the second stage of the principal turbine to generate additional electricity.



Double Flash Power Plants

Unflashed liquid flows to low-pressure tank – flashes to steam. Steam drives a second-stage turbine – Also uses exhaust from first turbine ⇒ Increases output 20-25% for 5% increase in plant costs

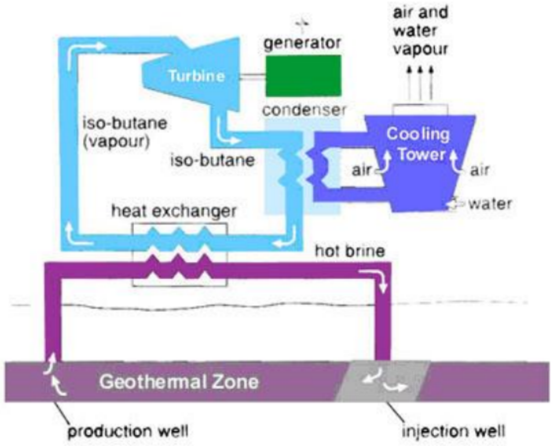


Binary Cycle Power Plants

- Geothermal resource with low temperatures (100° and 150°C) can be used.
- Working liquids with boiling points less than that of water such as iso-butane, iso-pentane are used to form vapour to operate the turbine.
- Vapour used to drive turbine is condensed and recycled continuously.
- Typically **7 to 12** % efficient

Binary cycle power plants are used where the geothermal resource is **not hot enough to efficiently produce steam**, or where the resource contains too many chemical impurities to allow flashing. Further, the fluid remaining in the tank of flash steam plants can also be utilised in binary cycle plants.

In the binary cycle process, the geothermal fluid is passed through a heat exchanger. The secondary fluid , which has a lower boiling point than water (eg isobutane or pentane), is vaporised, and expanded through a turbine to generate electricity. The secondary fluid also known as working fluid is condensed and recycled for another cycle. All of the geothermal fluid is reinjected into the ground in a closed cycle system.



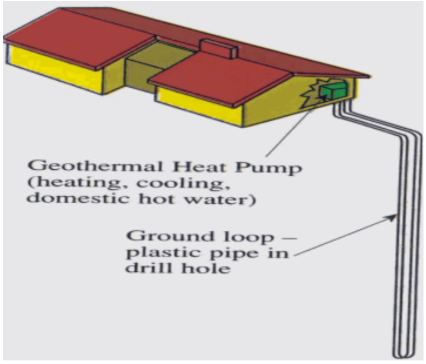
- Binary cycle power plants can achieve
  higher efficiencies than flash steam plants, and they allow the utilisation of
  lower temperature resources.
- Corrosion problems are avoided. BUT
- Binary cycle plants are more expensive, and large pumps are required which consume a significant percentage of the power output of the plants.

Geothermal Heat Pump (GHP)

During the winter, heat is withdrawn from the earth and fed into the building; In the summer, heat is removed from the building and stored under-ground.

- In some GHP systems heat is removed from shallow ground by means of an antifreeze/water solution c**irculating in plastic pipe loops** (either inserted in vertical wells less than 200 m deep which are then backfilled or buried horizontally in the ground).

- Other GHP systems flow of water produced from a shallow borehole through the heat pump, discharges the water either in another well or at surface. The heat pump unit is located inside the building and is coupled either with a low-temperature floor or wall heating net or with a fan delivering hot and cold air.



Impacts of Geothermal Energy

Technological Issues

- Geothermal fluids can be corrosive
    - Contain gases such as hydrogen sulphide
    - Corrosion, scaling
- Requires careful selection of materials and diligent operating procedures
- Typical capacity factors of 85-95%

Environmental Impacts

- Land
    - Vegetation loss
    - Soil erosion
    - Landslides
- Air
    - Slight air heating
    - Local fogging
- Ground
    - Reservoir cooling
    - Seismicity (tremors)
- Water
    - Hydrothermal eruptions
    - Lower water table
    - Subsidence: Sinking of ground to lower level- affects builiding foundations.
- Noise
- **Benign overall**

Renewable?

Heat depleted as ground cools $\Rightarrow$ Earth's core does not replenish heat to crust quickly enough.

Economics of Geothermal Energy

1. **Temperature and depth of resource:** A shallow resource means minimum drilling costs. High temperatures (high enthalpies) mean higher energy capacity.
2. **Type of resource (steam, liquid, mix):** A dry steam resource is generally less expensive to develop as reinjection pipelines, separators and reinjection wells are not required
3. **Available volume of resource**
4. **Chemistry of resource:** A resource with high salinity fluids, high silica concentrations, high gas
content, or acidic fluids can pose technical problems which may be costly to overcome.
5. **Permeability of rock formations:** A highly permeable resource means higher well productivity, and therefore fewer wells required to provide the steam for the power plant.
6. **Size and technology of plant:** As with most types of power plant, large power plants are generally cheaper in terms of $/MW.
7. **Infrastructure (roads, transmission lines) development considerations**
8. Costs of geothermal energy is highly variable from site to site.
    - The cost of drilling boreholes to depths of several kilometers is very high and nature of rock formation and rock temperature are unknown in advance.
    - The initial capital cost is high but the operating cost is low because the fuel is free.

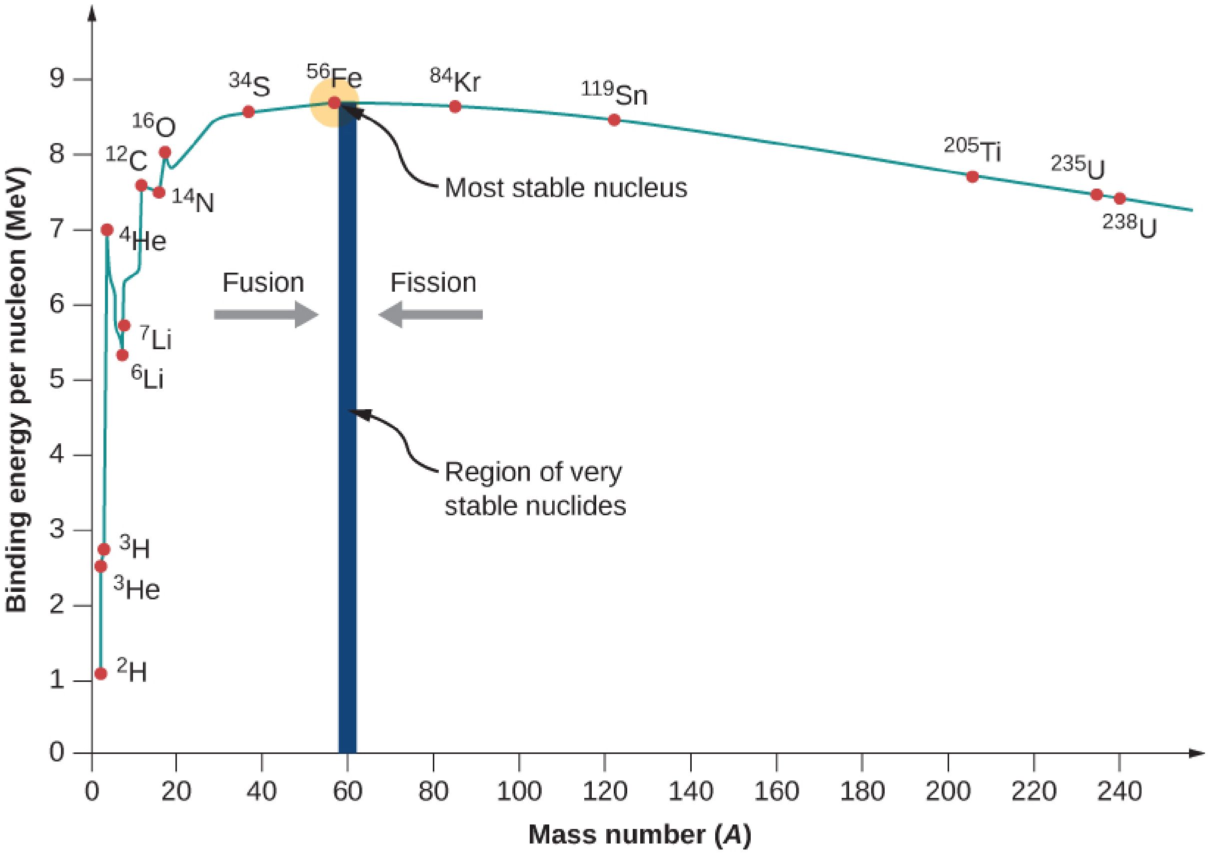
Chapter 8: Nuclear Energy

Binding Energy and Stability

Binding energy: energy released when forming a nucleus, higher BE stronger bond

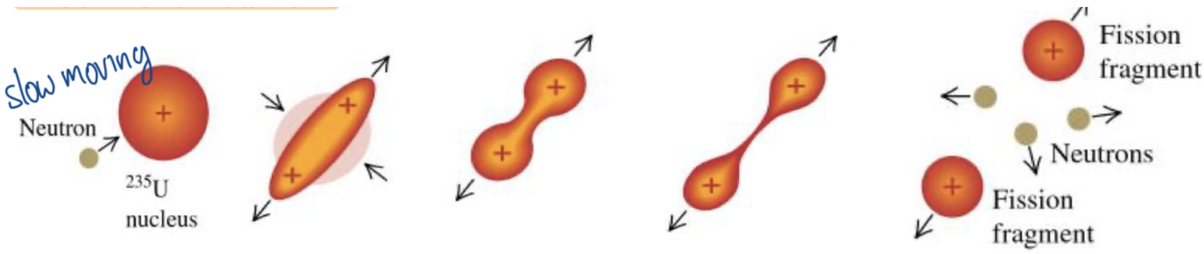
$$E = \triangle mc^2$$

$$\triangle m = Mass\ of\ nucleons(proton + neutron) - Mass\ of\ nucleus$$
$$c = speed\ of\ light\ 3 * 10^8 m/s$$



Nuclear Fission

- Bombardment of Uranium by slow moving neutrons results in splitting of the nucleus into two smaller nuclei alongwith emission of neutrons and huge amount of energy. This process is known as Nuclear Fission.
- The smaller nuclei are of Ba and Kr and each reaction release of three more neutrons.



^{235}U absorbs a neutron

^{236}U* is in a highly excited state and vibrates violently

A neck develop and electric repulsion pushes the two lobes apart.

The two lobes separate forming fission fragments.

Fragments emit neutrons immediately (or a few seconds later)

Chain Reaction

- Natural Uranium has 99.28% of 238 U and 0.72% of 235 U
- In natural uranium, only when neutron energy is less than 5 MeV will neutron-induced fission of Uranium-235 be more likely to occur.

Sustained reaction

1. Uranium 235 proportion should increase: Enrichment or the capture by 238 U should be decreased
2. Addition of nuclei with a low atomic number, called moderators, changes the energy of neutrons which suffer elastic/inelastic collision with moderators and helps in sustaining chain reaction with neutrons with energy as low as 0.05 eV (graphite, light water)

Energy released in fission of uranium

$$Total\ binding\ energy\ (products) - Total\ binding\ energy\ (reactants)$$

Nuclear Fuels

Most reactors use 235U as the fuel for fission as it readily undergoes fission after absorbing a neutron.

- However, concentration of 235U is very low (0.7%)
  - necessary to increase the concentration of (or enrich) 235U
  - makes use of the small mass difference between 235U and 238U, e.g., in a high-speed centrifuge
- Alternatively, a different fuel such as plutonium-239 could be used

- This does not occur naturally and need to be produced in a breeder reactor through the following reaction scheme:

$$^{238}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \longrightarrow ^{239}_{92}\mathrm{U} \xrightarrow{\beta^-} ^{239}_{93}\mathrm{Np} \xrightarrow{\beta^-} ^{239}_{94}\mathrm{Pu}$$

Example

Example: How much energy is released when 1 kg of Uranium enriched to 3% in ^{235}U is consumed in a nuclear reactor.

One mole of Uranium =238 g , so number of uranium nuclei , N_u, in 1kg of Uranium is

$N_u = 1000 \times 6.023 \times 10^{23} / 238 = 2.52 \times 10^{23}$

^{235}U nuclei =3% of $2.52 \times 10^{23} = 0.03 \times 2.52 \times 10^{23}$

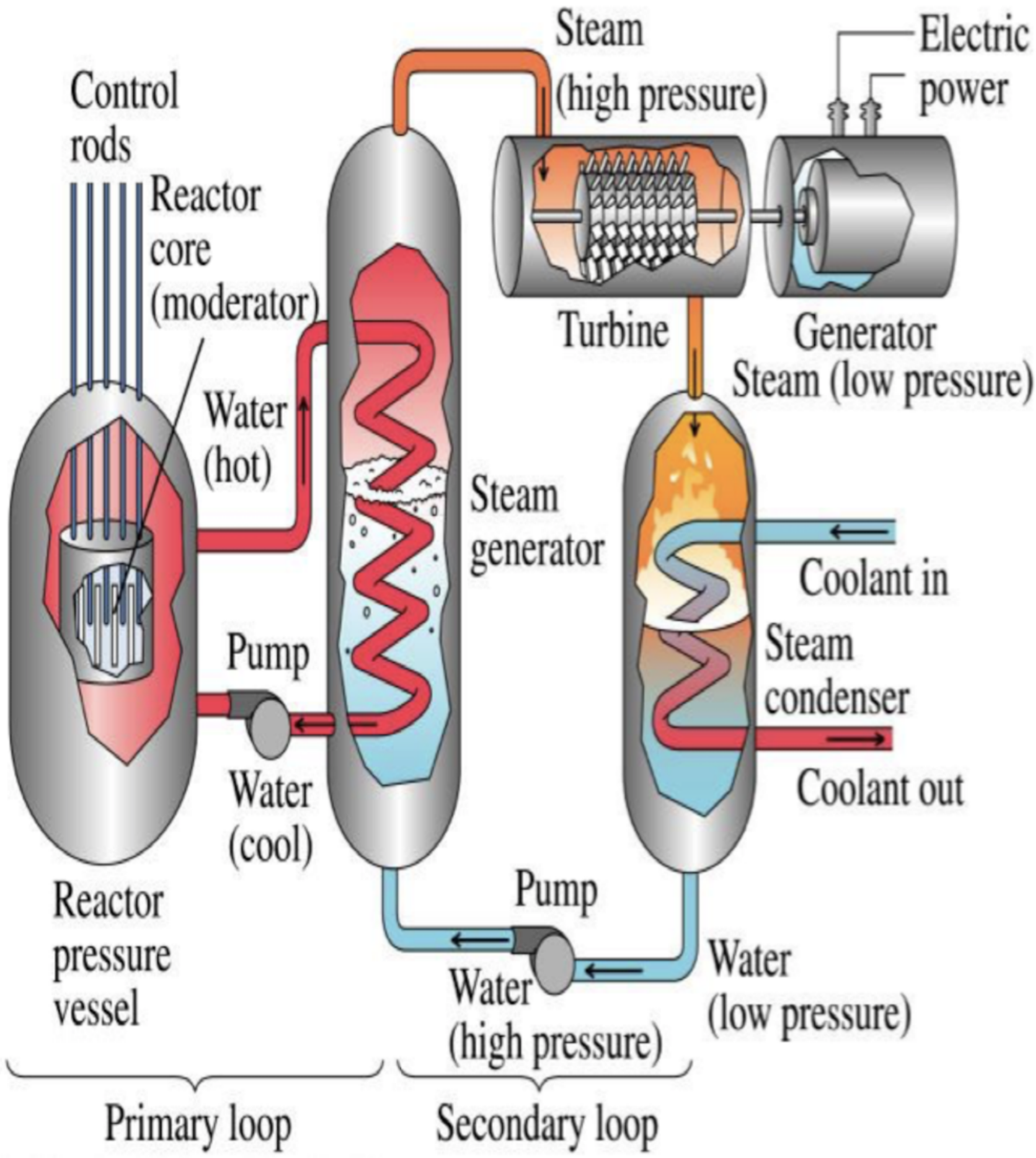
Energy released per fission=200MeV

Total energy released = $0.03 \times 2.52 \times 10^{23} \times 200$ MeV= $0.03 \times 2.52 \times 10^{23} \times 1.6 \times 10^{-19}$ = 2420 GJ

Thermal Nuclear Reactor

- Fuel Rods
- Chemically Inert Fluid: To immerse fuels rods in and also heated
    - water, CO_2, helium
- Moderator: Slows the speed of neutrons
    - Carbon, helium or heavy water
- Control Rods: separates fuels rods. The higher they are the greater the rate of reaction
- Heat Exchangers: To get heat from chemically inert fluid while still keeping it isolated because radioactive
- Primary Loop: transfer heat from reaction

- Secondary Loop: For turning the turbine



Reactor Control

1. Add a chemical containing a nucleus with a large neutron absorption property
    a. chemical containing a nucleus with a large neutron absorption property
2. Burnable poisons. Examples are Gd_2O_3 or Er_2O_3 and are included in fuel rods.

Fission Products

- Long lived actinides arising through successive neutron capture reaction on uranium.
- When amount of fissile material in fuel rod is insufficient to maintain the controlled chain reaction, the rod is removed and the remaining fissile material is extracted chemically.
- It is reutilised in new fuel and the waste products are separated for storage.
- The presence of these actinides means that the waste must be stored safely for many thousand years.

Radiation Effects

- Causes ionisation, which breaks molecules apart and gives rise to free radicals, which can damage cells
    - scale of effect depends on the energy deposited per unit mass of tissue, the dose of the radiation , and on the type of radiation.
- Charged particles, such as α-particles cause relatively more damage than γ-rays or electrons depositing the same energy since their energy loss per unit length is higher.

Safety of Nuclear Power

Only 4 incidents

1. 1952 UK
2. 1979 Pennsylvania
3. 1986 Chernobyl
4. 2014 Japan

It is safe

Economics of Nuclear Power

- New reactor designs with both passive and active safety features will reduce this accident probability.
- Large capital costs
- Operation costs is low (highly automated)

- Compact system
- No CO_2

Environmental impact

- Main environmental considerations are related to location of nuclear reactors. These include, the seismology, risk of flooding, meteorology, geology and population distribution in the area of reactor.
- effects of thermal discharge to the environment and in particular the storage and disposal of nuclear waste.
    - The spent fuel is first stored on site for several years to allow the intense short-lived activity to decay. There it is kept in storage pools to remove the heat and prevent the radiation.
    - spent fuel is reprocessed to recover the Uranium and plutonium. The residue is immobilised by incorporating in borosilicate glass.
    - This spent fuel can then be placed in a corrosion-resistant can and stored in an underground repository.

Nuclear Fusion research is going well

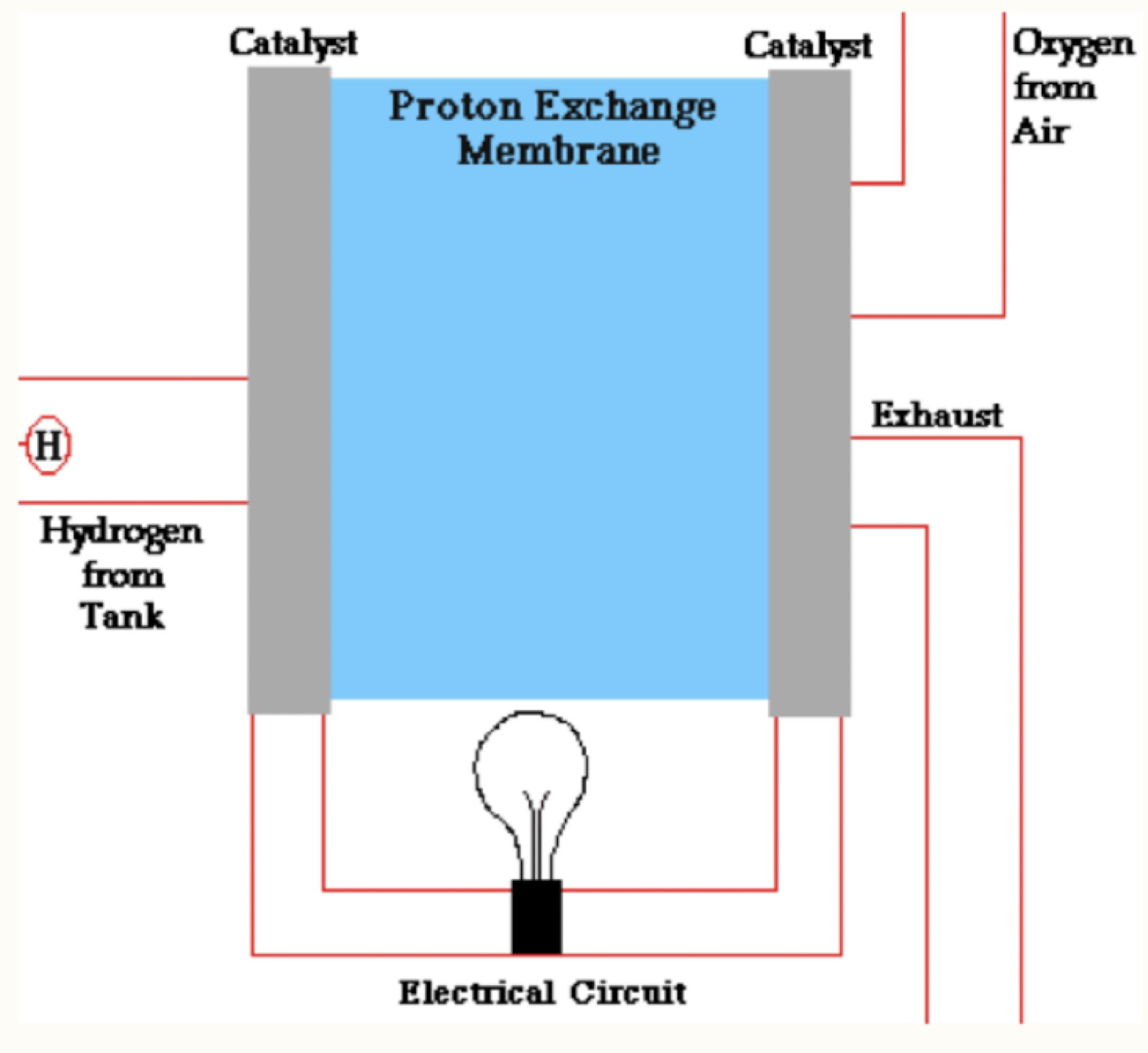
New breakthrough

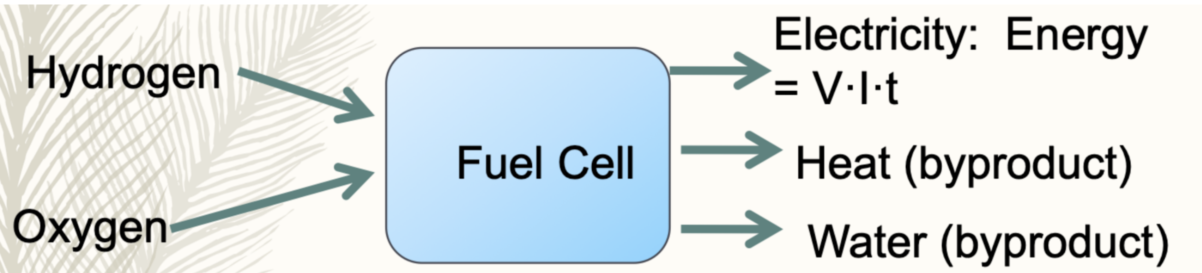
Chapter 9: Fuel Cells

Design of Fuel Cell

A typical fuel cell produces a voltage from **<u>0.6 V to 0.7 V</u>** at full rated load.

1. Each type of fuel cell consists of 3 parts : (1) An anode (2) An electrolyte, and (3) A Cathode.
2. The most common fuel used in the cells is hydrogen
3. The anode catalyst is usually made up of very fine platinum powder. The anode catalyst, accelerates up the dissociation of the fuel into electrons and ions.
4. The cathode catalyst is often made up of nickel which converts the ions into the waste chemicals like water or carbon dioxide.



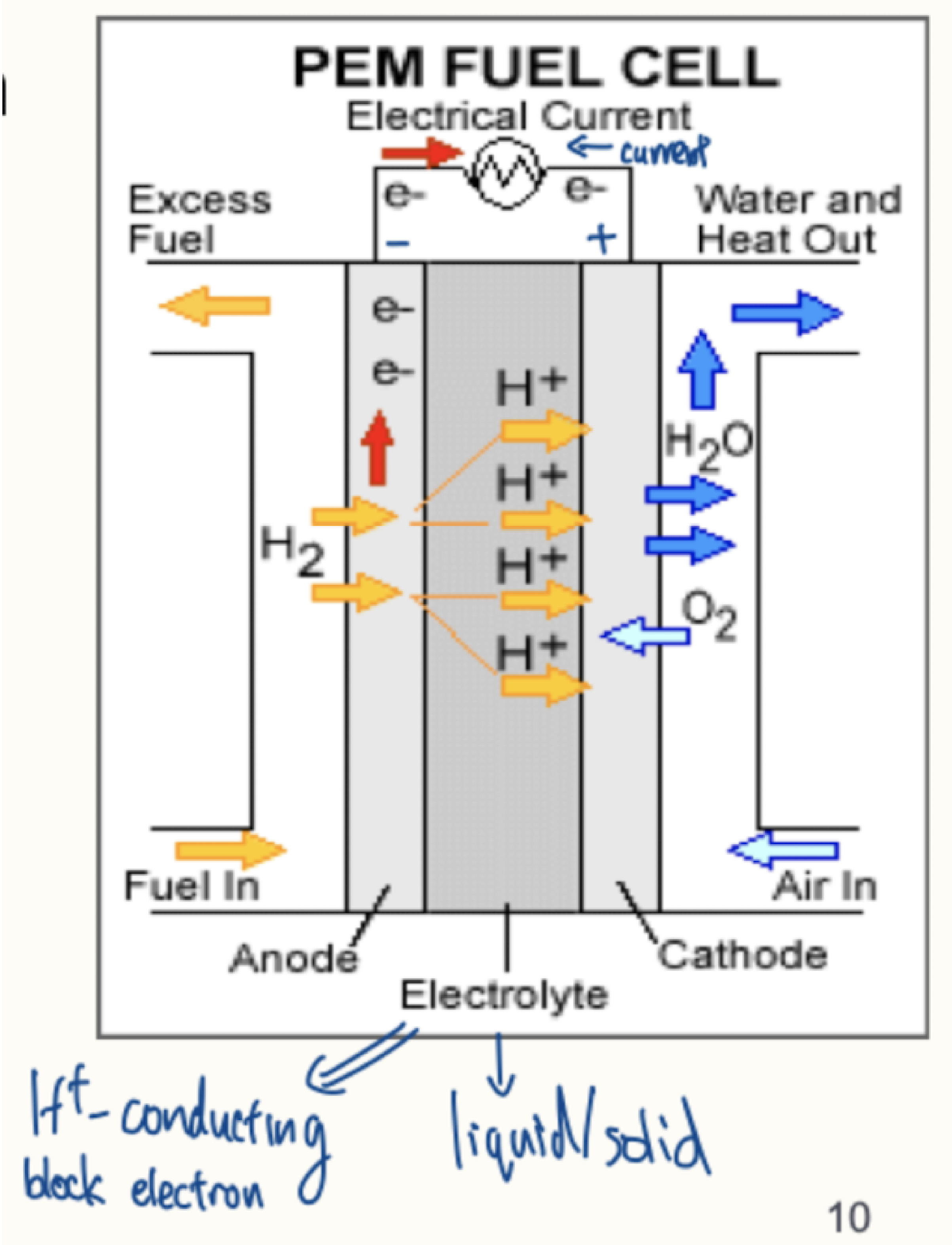


Types of Fuel Cells

	Design	Properties	Application

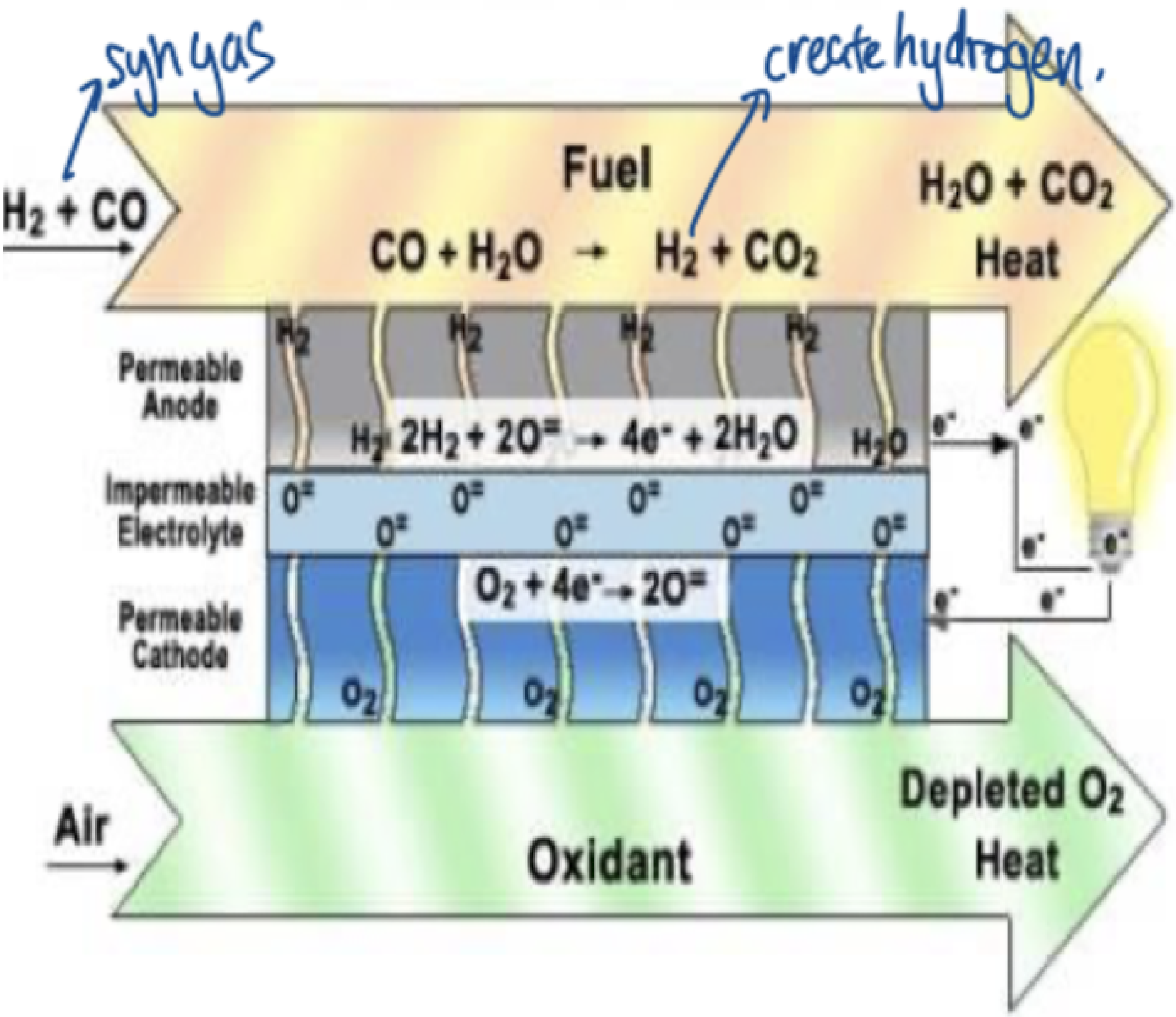
	Design	Properties	Application
Polymer Electrolyte Membrane Fuel Cell	Solid Polymer as an electrolyte and porous carbon electrode	High power density Low weight and volume Noble-metal catalyst Low operating temp (80 degrees	Transportation Hydrogen storage is a problem (not enough)
Solid Oxide Fuel Cells	porous ceramic-oxide electrodes and electrolyte Electrolyte: YSZ Cathode: Calcium or Strontium substituted Lanthanum manganite Anode: Nickel-YSZ	Since all ceramic-oxide, the electrolyte, anode and cathode bond well	Planar or tubular design
Alkaline Fuel Cell			
Phosphoric Acid Fuel Cells			
Molten Carbonate Fuel Cells			

PEMFC



Solid Fuel Oxide

Solid Oxide Fuel Cell



Sources of Hydrogen

Source	Production Technology
Natural gas	Reforming
Coal	Gasification
Biomass	Gasification Syn gas remov CO
Water	Splitting fuel cell but opposite

Hydrogen from Natural Gas (Steam Methane Reforming)

Endothermic conversion of methane and water vapour into hydrogen and carbon monoxide

- 700 to 850 °C

$$CH_4 + H_2O + \text{heat} \rightarrow CO + 3H_2 \qquad (1)$$

$$CO + H_2O \rightarrow CO_2 + \underset{\text{store}}{H_2} + \text{heat} \qquad (2)$$

Hydrogen from Natural Gas (Partial Oxidation of Natural Gas)

Partial combustion of methane with oxygen gas yields carbon monoxide and hydrogen

$$CH_4 + \overset{\text{limit } O_2}{1/2O_2} \rightarrow CO + \overset{\text{store}}{2H_2} + \text{heat}$$

Hydrogen from Natural Gas (Autothermal Reforming)

Combination of both steam reforming (Eqn. 1) and partial oxidation (Eqn. 3)

The outlet temperature from the reactor is in the range of 950 to 1100 °C, and the gas pressure can be as high as 100 bar.

Hydrogen from Coal (Gasification)

This is the main method used now

- carbon is converted to carbon monoxide and hydrogen.

$$C(s) + H_2O + \text{heat} \rightarrow CO + H_2$$

Hydrogen production from coal is commercially mature, but it is more complex than the production of hydrogen from natural gas. The cost of the hydrogen produced is also higher.

Hydrogen from splitting of water

1. Water electrolysis
    a. water splits into hydrogen and oxygen through the application of electrical energy
2. Photo-electrolysis
3. Photo-biological production
4. High-temperature water decomposition

Hydrogen Storage

Properties of H2

- Small difference between melting and boiling point
- Very low boiling point (hard to liquify)

	State	Description	Advantage / Disadvantage
Storage Tank	Gas	Common practice	+ Light weight + Well-tested - Large physical volume
Microsphere	Gas	H2 stored in microspheres using high heat and pressure	+ inherently safe + Portability + low container cost - Low achievable volumetric density - Slowly leak hydrogen - need to supply heat to use
Cryogenic Liquid	Liquid	Cooled to -253 degrees C	+ High storage density can be reached at relatively low temp - only 20 wt.% H2 of this can be achieved - 30-40% of the energy is lost when LH2 is produced.

	State	Description	Advantage / Disadvantage
Rechargeable Hydrides	Solid	Chemisorption 8 wt.% H2	+ Lower volume + Lower pressure (greater energy efficiency) + Higher purity H2 output + Solid is safest
Carbon and other high surface area materials	Solid	Physisorption useful only at cryogenic temps up to 6 wt.% H2	

Batteries

A battery is a device that converts chemical energy to electrical energy.

- The amount of energy per unit mass or volume (Watt. hours/kg or Watt. hours/litre) that a battery can deliver depends significantly on the cell's voltage and capacity, which are dependent on the chemistry of the system.
- Another important parameter is power which depends partly on the battery's engineering but crucially on the used chemicals in that battery.

Primary Batteries

Used once only because its active material (chemicals) is consumed in a single discharge via an irreversible electrochemical reaction. ⇒

- low price, easy to carry
- light-weight, exhibit high energy density at low to moderate discharge,
- require minimum maintenance and are easy to use.

Primary	Merits and/or applications
Zinc-carbon battery	Midium cost, used in light drain application.
Zinc-chloride battery	Similar to zinc-carbon but slightly longer life.
Alkaline/manganese battery	Long life, widely used in both light-drain and heavy-drain application.
Silver oxide battery	Commonly used in hearing aids, watches, and calculators

Primary	Merits and/or applications
Lithium-Thionyl Chloride battery	Industrial applications, including computers, electric meters and other devices which contain volatile memory circuits and act as a carryover voltage to maintain the memory in the event of main power failure. These are relatively expensive.
Mercury battery	Digital watches, radiocommunications, and portable electronic instruments. Manufactured only for specialist applications due to toxic nature of mercury.
Thermal battery	High-temperature reserve

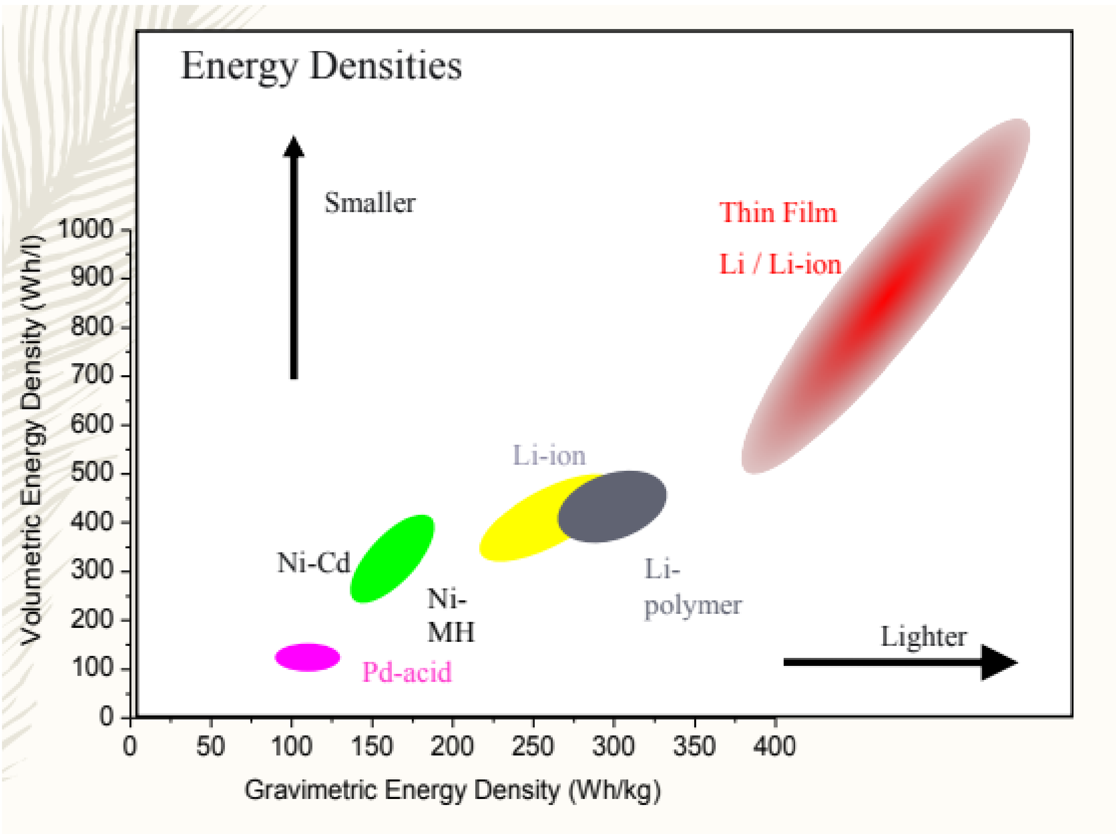
Secondary Batteries (Rechargeable)

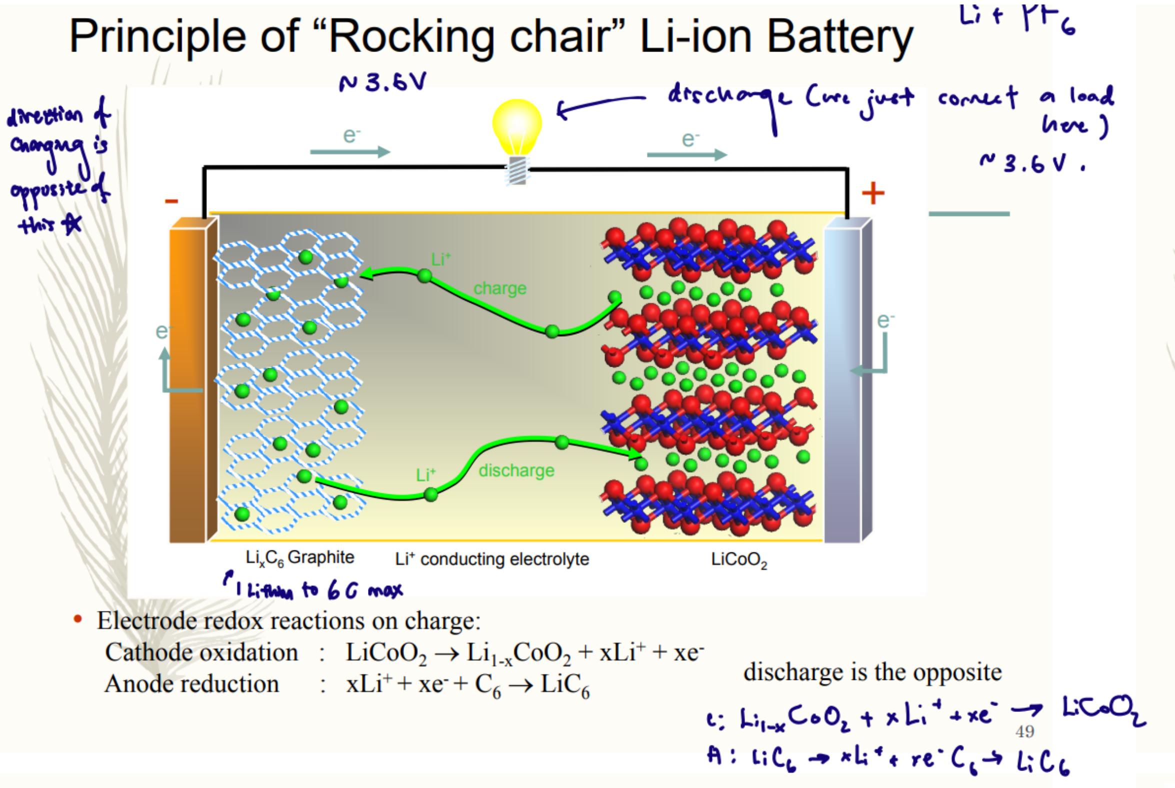
Can be re-charged by applying the electrical current, which reverses the chemical reactions that occur during its use and regenerate its active material for further use. These batteries are also known as storage batteries or accumulators

- eco-friendly alternative to primary batteries $\Rightarrow$ less metal pollution
- Reclamation companies recycle batteries to reduce number of batteries going into land fills
- Primary batteries created many environmental problems $\rightarrow$ toxic metal pollution

Battery Spec	Key Parameter
Light Weight	High Gravimatric Energy Density (Wh/KG)
Small Size	High Volumetric Energy Density (Wh/l)
High Power Output	High Voltage $\times$ Current
Recharge conditions and Limits	Strict for Battery Protection

Battery Name	Output Voltage and Charging Cycles	Cost	Energy density and Memory Effect	Self Discharge	Toxicity
Nickel Cadmium (Ni-Cd)	1.2 V 400 Cycles	Inexpensive – Simple charging	Low energy density – Memory effect	High self discharge (20% month)	Toxic
Nickel Metal Hydride (Ni-MH)	1.2 V 600 Cycles	Simple charging	Reduced memory effect	High self discharge (30% month)	Less-toxic
Silver Zinc (AgZn)	1.5 V 300 Cycles	Very difficult to recharge	Low energy density		
Lithium Ion (Li-ion) based	3.5 V 2000+ Cycles	Expensive More complex charging	Higher energy density – No memory effect	Low Self discharge	Lower toxicity





Principle of Operation of LIBs

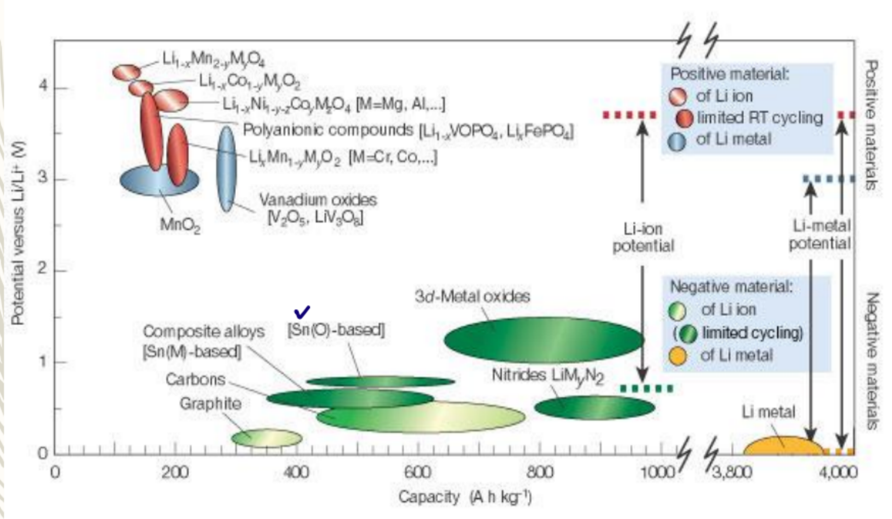
Rechargeable LIBs involve a reversible insertion/extraction of Li ions (guest species) in to/from a host electrode material during discharge/charge.

- The Li intake/uptake process happening with a flow of ions through the electrolyte is accompanied by a redox (reduction/oxidation) reaction of the host matrix assisted with a flow of electrons through the external circuit.
- In the commercial LIBs, Li-containing metal oxides (LiCoO2, LiNiO2, LiMn2O4 , and LiFePO4) are employed as cathodes (positive electrode).
- Graphitic carbons (MCMB: mesocarbon microbeads) or amorphous SnCo-C composite are used as anodes (negative electrode).
- The electrolyte allows the flow of Li-ions between the electrodes but prevents the electron flow. Due to the reversible motion of Li-ions between cathode and anode through electrolyte, the LIBs are also known as rocking chair, swing and shuttle-cock batteries.

Electrode Materials Tested for Li Ion Battery

cathode

Anode



Voltage vs. capacity (mAh/g) of electrode materials for LIB. The output voltage values for Li-ion cells or those with Li-metal anodes are represented.

Lithium has very high reactivity & cannot stand cycling

Advantages of LIB

- Wide variety of shape/sizes to fit into devices they power
- Lighter than other energy-equivalent secondary batteries
- High open circuit voltage compared to aqueous batteries → Increase amount of power that can be transferred at lower current
- No memory effect → reduction in longevity of rechargeable battery cycle due to incomplete discharge previously
- Self-discharge rate ~ 5-10% per month compared to over 30% in common nickel metal hydride batteries

Disadvantages

- **Shelf life:** Over time cell's capacity diminishes. Increase in internal resistance reduces the cell's ability to delivery current. Older batteries do not charge as much as new ones.
- **Internal Resistance:** Higher compared to other nickel-based metal hydrides / nickel-cadmium. Its internal resistance increases with both cycling and age. Rising internal resistance causes the voltage at the terminals to drop under load, reduces the maximum current drawn.