NPTEL

Department of Mechanical Engineering, SSIEMS, Parbhani-431401

Course Summary:

1. Usage of energy around the world- Nation, per capita, by sector
2. Impact on Environment
3. Solar energy
4. Wind energy
5. OTEC
6. Geothermal energy
7. Biomass
8. Battery
9. Fuel cells supercapacitors
10. Flywheels
11. Magnetohydrodynamic power generation

INDEX

Renewable energy Technologies

- Renewable energy technologies is an umbrella term that stands for energy production using a renewable energy source like solar, wind, OTEC, biomass and geothermal heat
- Renewable energy technologies are developing progressively with the battlement of efficiency.
- The growing energy demand and the depleting fossil fuels allow the flourishment of renewable energy
- Renewable energy systems can be installed at a small level called off-gird system
- Renewable systems are socially and economically accepted by the people

Scales of quantities:

Femto	10^{-15}	Femtosecond laser
Pico	10^{-12}	Picoampere current source
Nano	10^{-9}	Nanomaterials
Micro	10^{-6}	Microstructure
Milli	10^{-3}	Millimeter
Kilo	10^{3}	Kilogram
Mega	10^{6}	Megapixels
Giga	10^{9}	Gigabyte RAM
Tera	10^{12}	Terabyte Hard disk
Peta	10^{15}	Petaflops in Supercomputers
Exa	10^{18}	World annual energy usage
Zetta	10^{21}	7 Zettabytes data in 2020
Yotta	10^{24}	1 Ym ~ 100 million light yea

Energy usage by Humans: Estimate of Impact on Atmosphere

Energy usage of by humans:

Currently, our civilization consumer around 17.7 Terawatts of power taken from all sources of energy, namely oil, coal, natural gas and alternate energies such as solar, wind, hydropower etc.

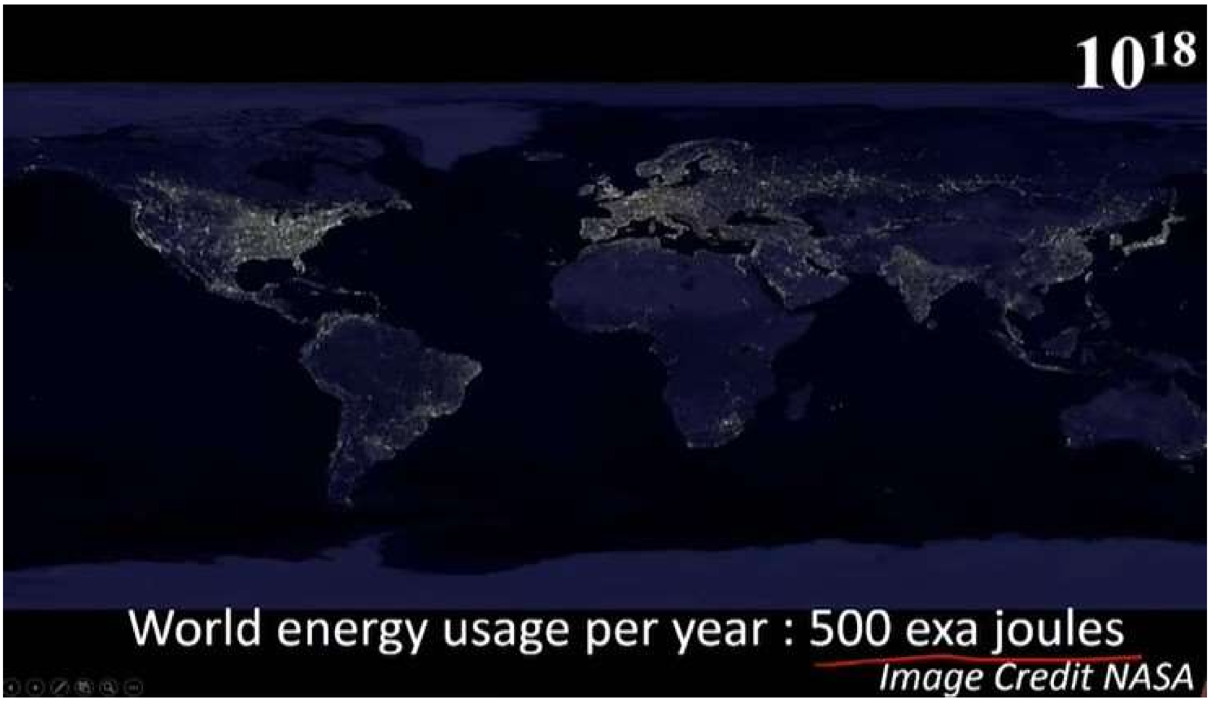
Impact on the atmosphere of energy usage by humans:

The environmental problems directly related to energy production and consumption include air pollution, climate change, water pollution, thermal pollution and solid waste disposal.

The emission of air pollutants from fossil fuel combustion is the major cause of urban air pollution.

Burning fossil fuels to produce electricity or heat is responsible for roughly half of global warming pollution.

Tacking on industry in general, including producing cement, steel, plastics and chemicals, accounts for 78% of greenhouse gases.



Major constituents of dry air, by volume

Name	Formula	Volume in %
Nitrogen	N_2	78.084
Oxygen	O_2	20.946
Argon	Ar	0.9340
Carbon dioxide	CO_2	0.04
Neon	Ne	0.001818
Helium	He	0.000524
Methane	CH_4	0.000179

Not included in above dry atmosphere:

Water vapour	H_2O	0.001%–5%

Water vapour is about 0.25% by mass over full atmosphere

Water vapour strongly varies locally

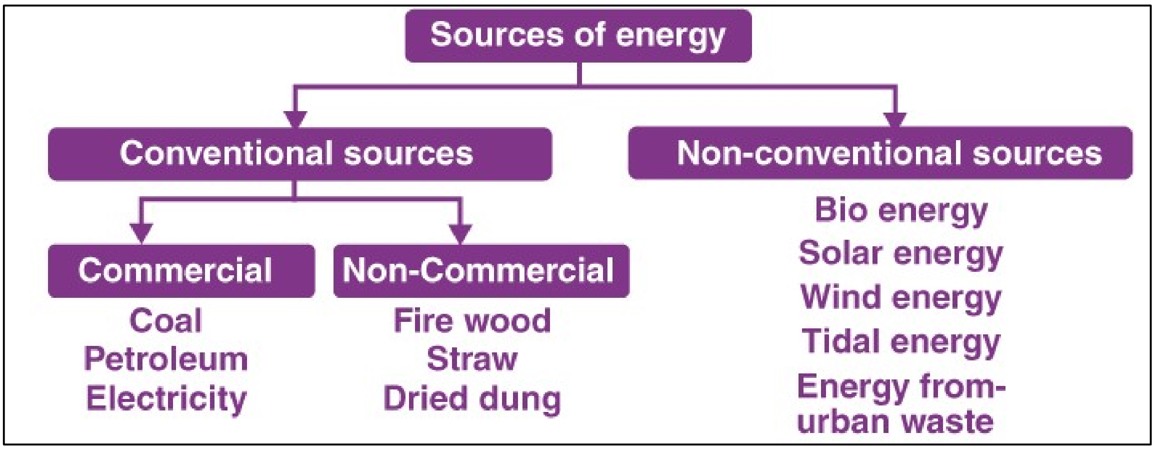
Layers of the atmosphere:

Exosphere:	700 to 10,000 km
Thermosphere:	80 to 700 km
Mesosphere:	50 to 80 km
Stratosphere:	12 to 50 km
Troposphere:	0 to 12 km

Approximately 80% of mass of Earth's atmosphere is in the Troposphere

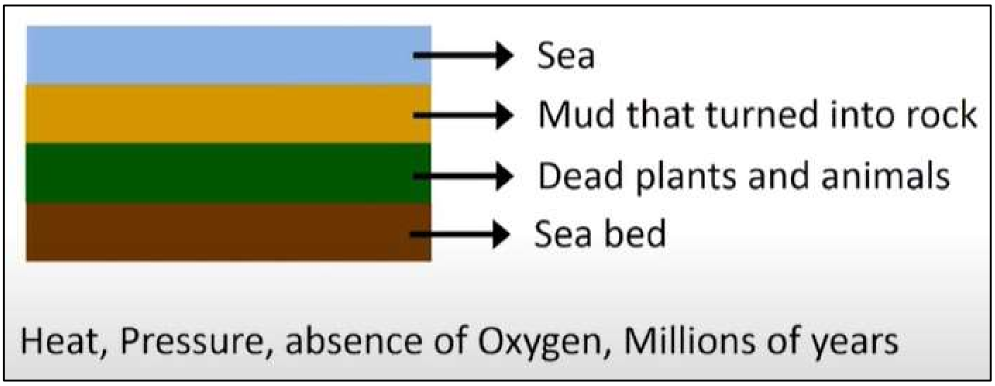
Composition of Crude oil by weight:

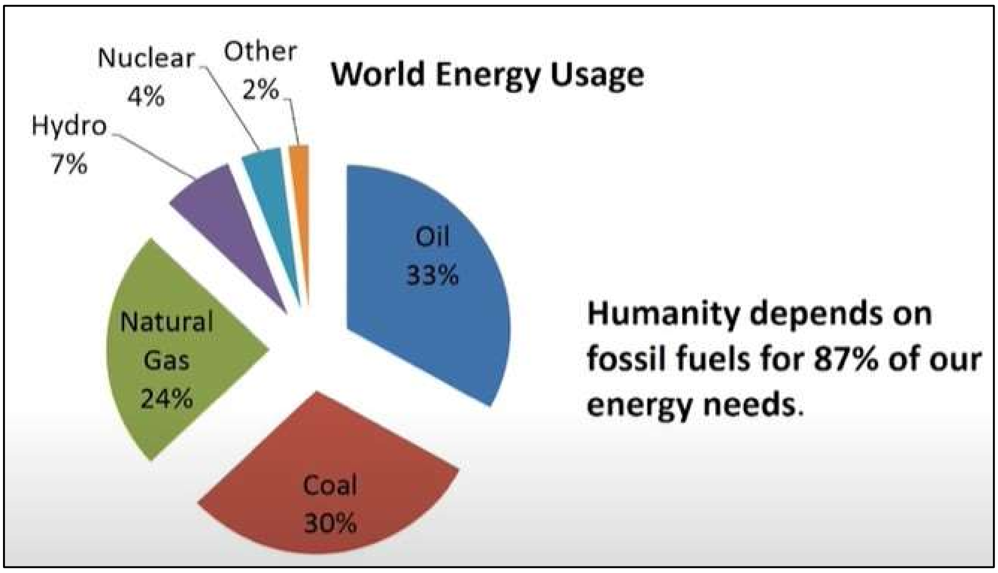
Element	Percentage by weight
Carbon	83 to 85%
Hydrogen	10 to 14%
Nitrogen	0.1 to 2%
Oxygen	0.05 to 1.5%
Sulfur	0.05 to 6.0%
Metals	< 0.1%



Conventional sources of energy

Crude oil 50-100 US $ per Barrel





Conventional Energy Resource means an energy resource that is non-renewable in nature, such as natural gas, coal, oil, and uranium, or electricity that is produced with energy resources that are not renewable energy resources.

Types of Conventional Sources of Energy:

Coal

Coal is the most abundant conventional source of energy which could last for at least 200 years. It is a black-brown sedimentary rock. Formation of coal occurs when the remains of plants convert into lignite and then into anthracite. This involves a long process that takes place over a long period of time. Coal helps for various proposes such as heating of the house, as fuel for boilers and steam engines and for generation of electricity by thermal plants. It constitutes about 70% of total commercial energy consumption in the country.

Oil

Out of all the conventional sources of energy, oil is used abundantly all over. Considering, oil is one of the most important conventional sources of energy in India, the resources for same are even smaller. The extraction of oil from deposits is known as **oil resources.**

Petroleum and Natural Gas

Petroleum is the mixture of hydrocarbons like alkanes and cycloalkanes. In crude form black liquid is known as petroleum and the formation of a natural gas occurs when the gas comes in contact with petroleum layer. Natural gas is a mixture of 50-90% of Methane, Ethane, Propane, Butane, and Hydrogen sulphide. After refining and purifying crude petroleum, it is available as petrol, diesel, lubricating oil, plastic etc. Natural gas is also making a significant contribution to the household sector. It causes less air pollution as compared to other fossil fuel.

Fuel Woods

Rural people use the fuelwood for their day to day cooking which comes from natural forests and plantations. The availability of fuelwood has become difficult due to rapid deforestation. We can avoid this problem by planting more trees on degraded forest land, culturable wasteland, barren land grazing land.

Thermal Power Plant

Power stations burn a large number of fossil fuels to heat up water, to produce steam, which further runs the turbine to generate electricity. Transmission of electricity is more efficient than, transporting coal or petroleum over the same distance. It is called as the thermal plant because fuel is burnt to produce heat energy which is converted into electrical energy.

Nuclear energy

A small amount of radioactive substance can produce a lot of energy through the nuclear substances all over the world. In order to obtain nuclear energy, nuclear reactions are essential and there are about 300 nuclear reactions. Nuclear energy is one of the most environmentally friendly conventional sources of energy as it produces fewer greenhouse gas emissions during the production of electricity in comparison to sources like coal power plants.

Advantages of Conventional Sources of Energy

1. Highly efficient

The conventional sources of energy are highly efficient, and for this reason, it is used for home as well as commercial purposes. Take examples of conventional sources of energy like coal, natural gas, and oil, and compare them with renewable sources of energy like wind or solar energy

2. Well-known source

We know how to use conventional sources of energy, as it is with us for centuries now. Unlike new renewable energy source technology, you don’t have to learn to use them in the right way. Consider fuel woods, they come from natural forests and plantations. And, they are used by people in rural areas in their daily life for various purposes. One such purpose is cooking

3. Abundant

We have the conventional sources of energy available with us in abundance. So, it is easily available throughout the year. If you look at renewable sources of energy, you will realize that they are dependent. Consider solar energy, it is dependent on the sun, and wind energy is dependent on the wind. There is no such dependence when it comes to conventional sources of energy

4. Cost-effective

We know how conventional sources of energy are available in abundance and have been with us for the longest time, so it comes naturally they are very cost-effective. Many reserves of conventional energy sources have been discovered in the last centuries making them readily available for consumption

5. Convenient

Since conventional sources of energy are found across the globe, they can be moved conveniently across the borders. Furthermore, they are quite simple to use. Some people find it difficult to use new machines or other sources of energy, so they stick to using traditional sources that are conventional sources of energy. In addition to usage, these sources are quite easy to store, making them a favorable option among the masses

Disadvantages of Conventional Sources of Energy

1. Makes dependent

We discussed how we have been using conventional energy sources all this time. We are very much dependent on it and because of this, switching to renewable energy sources is becoming difficult. It takes centuries for these sources to form, and we have seen a rise in our consumption rate

2. Causes health problems

When conventional sources of energy are burnt, they emit gases that cause health problems. The most common type of problem observed is respiratory problems. The burning of conventional energy sources pollutes air, water, as well as land. The people who are involved in the mining process are at higher risks. Mining for coals while operating heavy machinery is a dangerous job

3. Creates hazardous byproducts

With conventional sources of energy, there are a number of byproducts that create problems. When coal is burnt, the by-product fly ash is formed. It puts the workers of coal power plants at risk, along with the residents who live nearby the coal ash disposal sites. When fuel woods are burnt, it releases smoke that contains carbon dioxide, water, and other harmful chemicals

4. Depletes soon

You might have come across campaigns where people are encouraged to switch to renewable sources of energy. The reason behind running such campaigns and similar initiatives is to create awareness among people regarding the depletion of conventional sources of energy

5. Harms environment

We discussed, in brief, the release of harmful byproducts in the environment, putting millions of lives at risk. Especially when there are accidents where oil-tankers and cargo ships contents are spilled in the water bodies, the consequences are deadly. It puts the health of animals at risk. In addition to this, the humans coming in contact are affected negatively.

Non-conventional energy resources

Natural resources like wind, tides, solar, biomass etc generate energy which is known is "Non-conventional energy resources"

These are pollution free and hence we can use these to produce a clean form of energy without any wastage.

Types of Non-convention sources

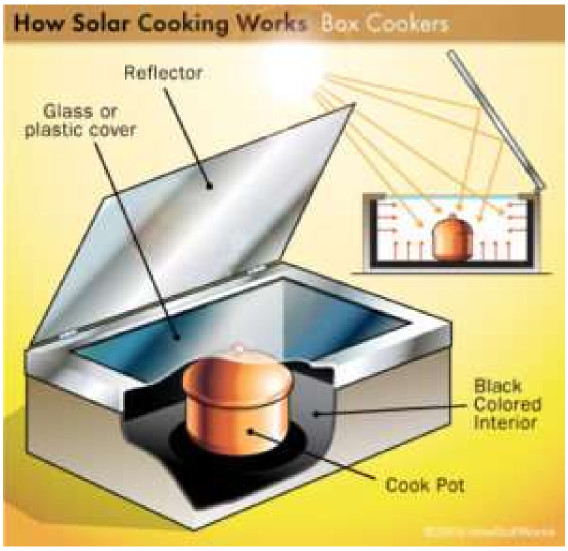
- Solar Energy
- Wind Energy
- Tidal Energy
- Geothermal Energy
- Biomass

Solar Energy

Solar energy is harnessed by converting solar energy directly into electrical energy in solar plants. Photosynthesis process carries out this process of conversion of solar energy. In photosynthesis, green plants absorb solar energy and convert it into chemical energy. Solar energy is an essential energy of all non-conventional sources but its usage amount is very less. It is the most important non-conventional source of energy and it gives non-polluting environment-friendly output and is available in abundant.

Uses of Solar energy

- A solar cooker directs the solar heat into secondary reflector inside the kitchen, which focuses the heat to the bottom of the cooking vessel. It has a covering of a glass plate. They are applicable widely in areas of the developing world where deforestation is an issue, and financial resources to purchase fuel are not much.
- Solar heaters also use solar energy to heat water instead of using gas or electricity.
- Solar cells also use solar power to generate electricity from the sun.

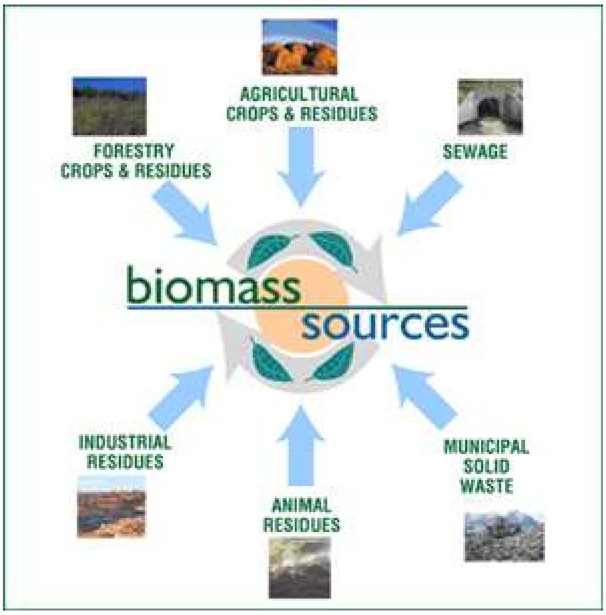


Wind energy

Wind energy describes the process by which wind is used to generate electricity. As the wind increases, power output increases up to the maximum output of the particular turbine. Wind farms prefer areas, where winds are stronger and constant. These are generally located at high altitudes. Wind turbines use wind to make electricity. There is no pollution because no fossil fuels are burnt to generate electricity. One of India's largest windmill farm is in Kanyakumari which generates 380mW of electricity.

Biomass energy

Biomass is the organic matter that originates from plants, animals, wood, sewage. These substances burn to produce heat energy which then generates electricity. The chemical composition of biomass varies in different species but generally, biomass consists of 25% of lignin, 75% of carbohydrates or sugar. Biomass energy is also applicable for cooking, lighting, and generation of electricity. The residue left after the removal of biogas is a good source of manure. Biomass is an important energy source contributing to more than 14% of the global energy supply.



Tidal energy

Tidal power is a form of hydropower that converts the energy of tides into electricity. In areas where the sea experiences waves and tides, we can generate electricity using tidal power. India may take up "ocean thermal level conversion" by which it will be able to generate 50,000mW of electricity to meet the power requirements.

Geothermal energy

Geothermal energy is the heat energy that we get from hot rocks present in the earth’s crust. So Geothermal wells release greenhouse gases trapped within the earth and but these emissions are much lower per energy unit than the fossil fuels. This energy generally involves low running costs since it saves 80% on fossil fuels. Due to this, there is an increase in the use of geothermal energy. It helps in reducing global warming and does not create pollution.

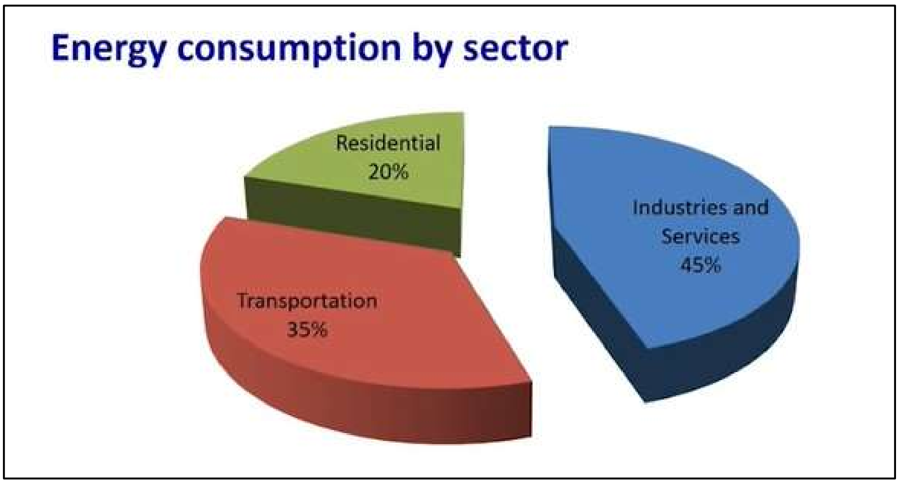
Advantages of Non-conventional energy resources:

- They are renewable in nature
- Cause little or no pollution as compared to the conventional energy resources
- Low maintenance cost
- Cost saving option in the long run
- Leads to job creation
- It is technology

Disadvantages of Non-conventional energy resources:

- Initial setup cost is higher
- Energy cannot be extract 24/7, year round, because some day will be windier than others, on some day sun will shine brighter
- Energy has to be stored
- Geographic locations can be challenging

Energy consumption



Energy poverty:

17% lack access to electricity

38% lack access to clean cooking facilities

95% of these people live in subsaharan Africa

80% of these are in Rural areas

Top 5 Nations based on total energy consumption sector wise distribution(annual)

1. China
2. United states
3. India
4. Russian federation
5. Japan

Top 5 Nations based on total energy production (annual)

1. China
2. United states
3. Russia
4. Saudi Arabia
5. India

Top 5 Nations energy consuming buildings

1. Mercantile and service
2. Office
3. Education
4. Healthcare/Hospitals
5. Lodging

Details of energy usage in each sector:

Industrial sector:

Oil refining, Metallurgical process, Glass manufacture

- Process heating:- raising temperature of components during manufacturing
- Refining crude oil:- separation of products
- Boiler heating:- To generate steam

Primary :- Natural gas and oil

Secondary :- Electricity

Commercial sector energy usuge:

Space heating	36%
Lighting	20%
Cooling	8%
Ventilation	7%
Water heating	8%
Refrigeration	6%
Cooking	3%
Computers	2%
Office equipment	1%
Other	8%

Agriculture sector:

Energy is consumed directly by agriculture with the use of machinery (e.g. cultivation of fields with tractors) and heating of livestock stables and greenhouse.

Agriculture also uses energy indirectly, for the production of agrochemicals farm machinery and buildings.

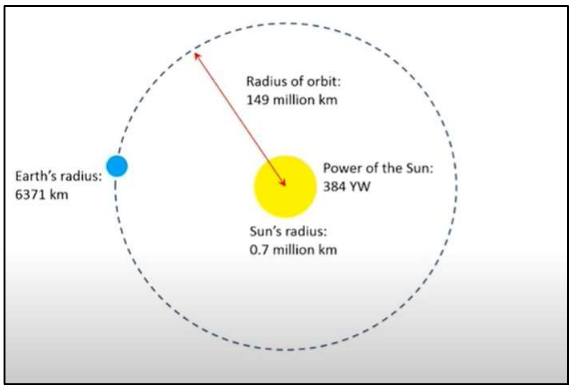
Consequences of energy consumption

- The environmental problems directly related to energy production and consumption include air pollution, climate change, water pollution, and solid waste disposal
- The emission of air pollutants from fossil fuel combustion is the major cause of urban air pollution
- The reasons for increasing energy consumption include economic development, riding population and technological developments
- Burning fossil fuels is also the main contributor to the emission of greenhouse gases
- Coal mining can also pollute water
- Solid waste is also a by-product of some forms of energy usage

Solar energy: The sun to earth transaction

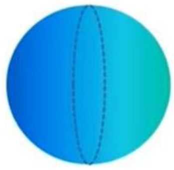
Surface of the Sun ~ 5500 °C
Core of the Sun, several million °C

Sun gives out 384 Yotta Watts
$= 384 \times 10^{24}$ W
$= 3.84 \times 10^{26}$ W



Power received from the Sun, by Earth:

$= 1.27 \times 10^{14} \times 1377 = 1.755 \times 10^{17}$ W or J/s



Energy received from the Sun, by Earth each year:

$= 1.755 \times 10^{17} \times 60 \times 60 \times 24 \times 365$

$= 5.5 \times 10^{24}$ J

= 5.5 million Exa Joules per year

Humankind uses:	Earth receives from the Sun:
= 500 Exa Joules per year	5.5 million Exa Joules per year

This is received in :

$500 / 5.5 \times 10^{6} = 9 \times 10^{-5}$ years = 0.033 days = 0.79 hours

Since 30% of the incident energy is reflected back, on the surface of the Earth, the energy used by humankind each year is received in :

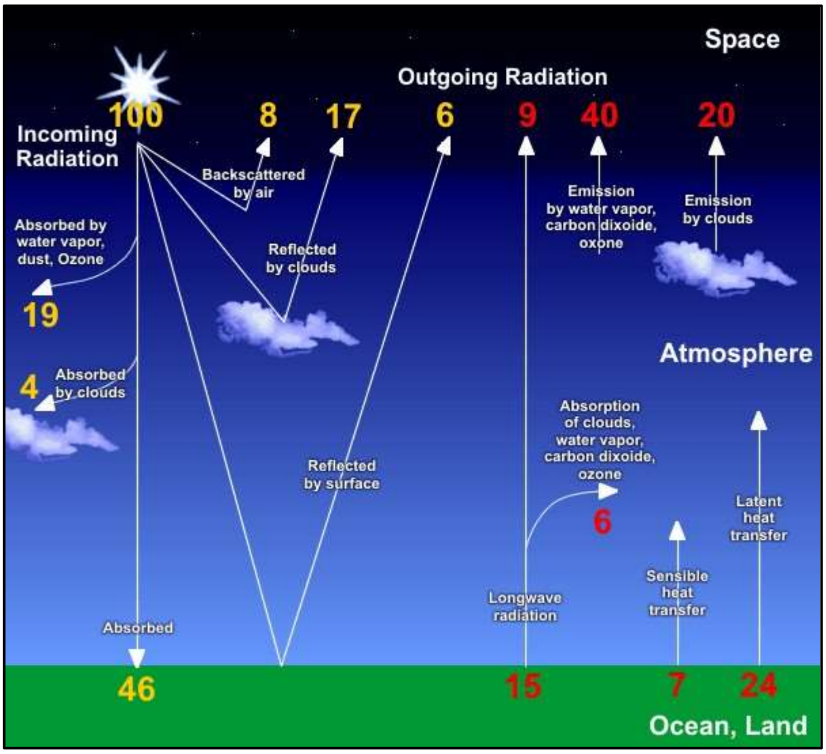
= 0.79/0.70 ~ **1 hour**

Conclusions:

1) Earth receives nearly 5.5 million exa joules of energy from the Sun each year
2) The entire energy used by humankind each year, is received on the surface of the earth, from the sun, each hour!

The Solar Energy Budget

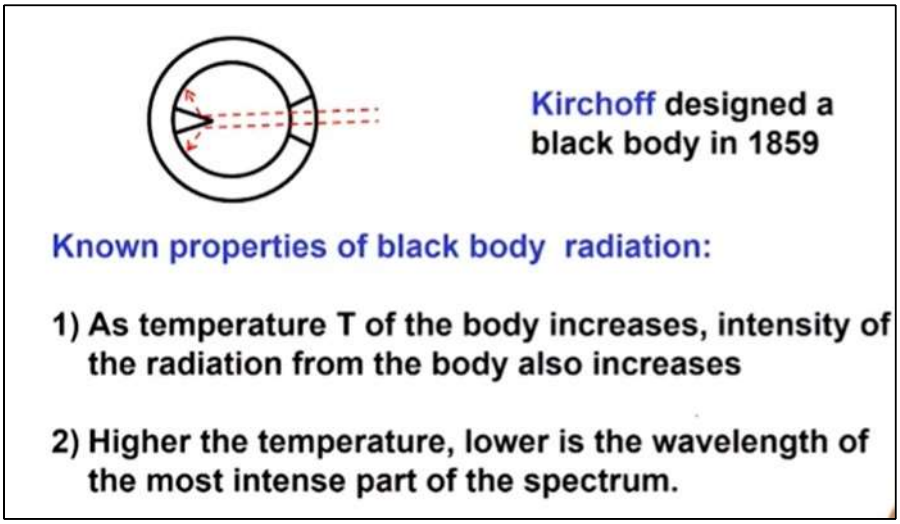
- Earth's energy budget accounts for the balance between the energy that earth's receives from sun and the energy earth losses back into outer space.
- The total energy from the sun that reaches the upper atmosphere is approximately 54.4×10^{20} kJ per year. Nearly all of this is either reflected for radiated back into space. The picture below from the National Oceanic and Atmospheric Administration shows the solar energy budget.
- Solar energy warms the land, ocean, and the atmosphere. A very small amount of the solar energy reaching the Earth is converted into electricity through photovoltaic cells. These are devices that use silicon or other materials to convert sunlight directly into electricity.

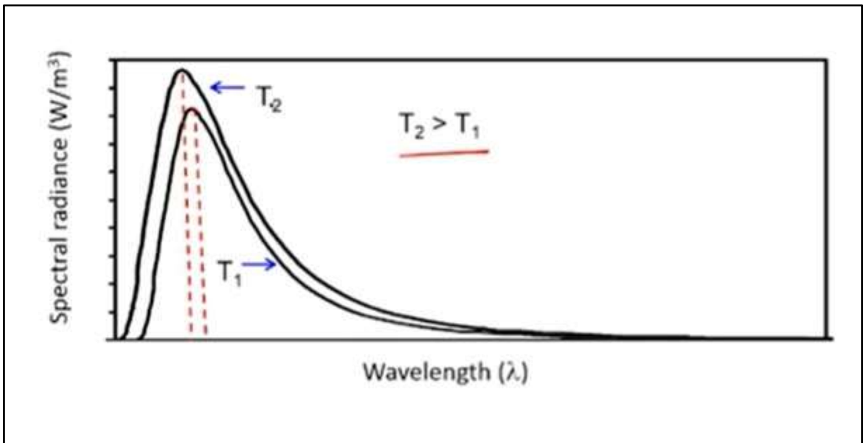


Conclusions:

1) Solar energy is absorbed and released through a wide range of phenomena on earth
2) Geographical location and seasons are important aspects impacting solar energy received by specific locations
3) Time of the day is an important parameter impacting the intensity of solar energy received

Electromagnetic Radiation: The solar spectrum





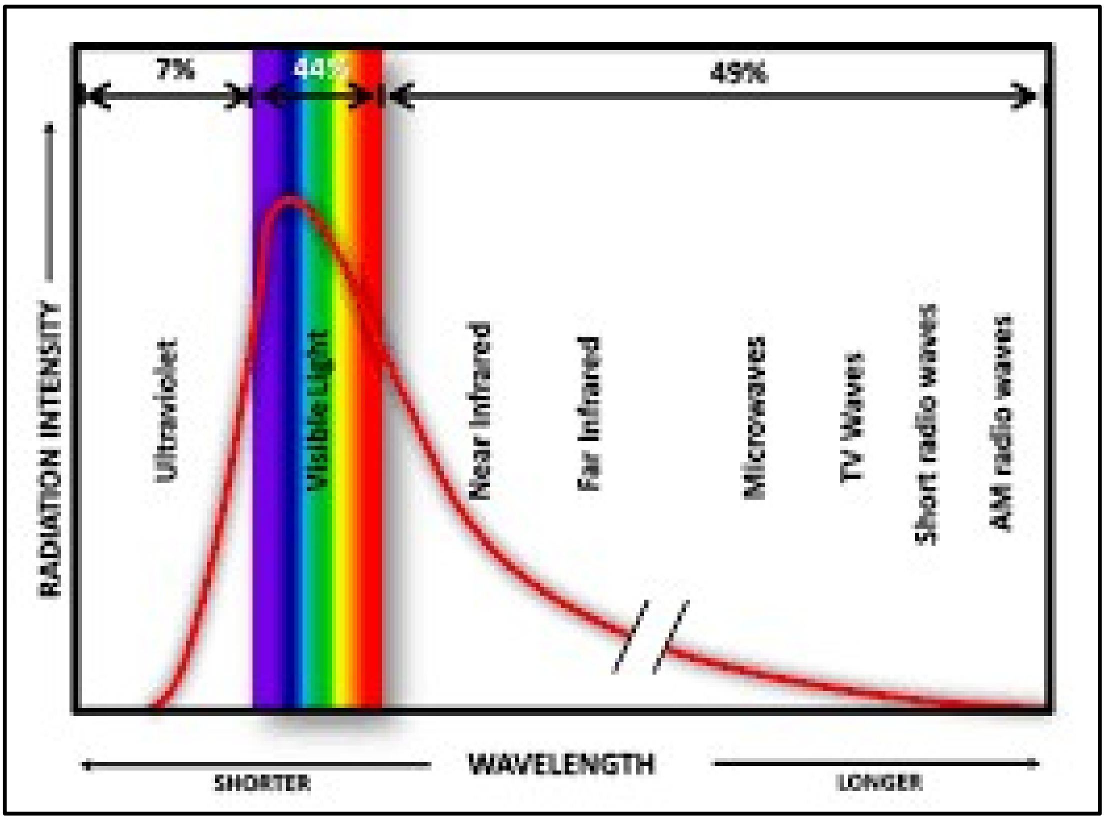
Black body Radiation

Black Body Radiation:

- Solar energy spectrum is consistent with black body radiation
- Visible spectrum a very small fraction of electromagnetic radiation
- All of the energy from the sun that reaches the earth arrives as solar radiation, part of a large collection of energy called the electromagnetic radiation spectrum
- Solar radiation includes visible light ultraviolet light, infrared, radio waves, X-rays and gamma rays

The 4 types of sun's radiation include:

1. Infrared rays
2. Visible rays
3. Ultraviolet light
4. Radio waves



Conclusions:

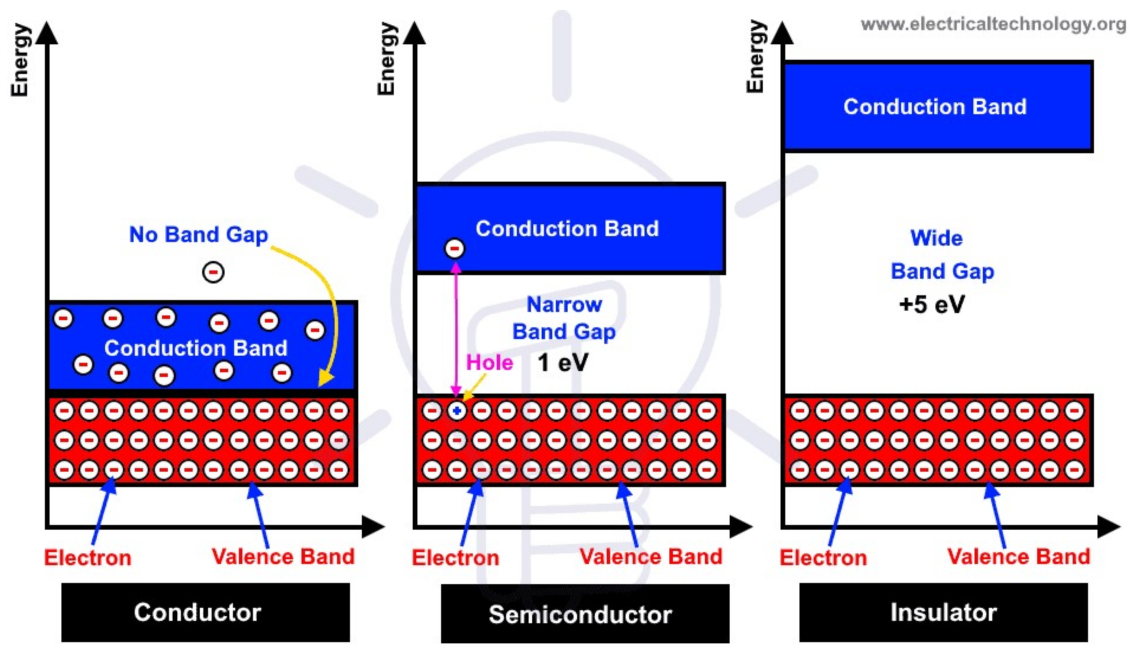
1) Solar energy spectrum is consistent with black body radiation
2) Visible spectrum a very small fraction of electromagnetic radiation
3) Chlorophyll ideally suited for absorbing visible spectrum

Solar energy :- Semiconductor

Valence Band and Conduction Band

Here are some of the differences between a valence band and conduction band.

Conduction Band	Valence Band
Higher energy level band	Energy band formed by a series of energy levels containing valence electrons
Partially filled by the electrons.	Always filled with electrons
High Energy State	Low Energy State
Above the Fermi level	Below of Fermi level
Electrons move into the conduction band when the atom is excited	Electrons will move out of the conduction band when the atom is excited
Current flows due to such electrons.	The highest energy level which can be occupied by an electron in the valence band at 0 K is called the Fermi level.



S.No	Conductors	Semiconductors	Insulators
1	Easily conducts the electrical current.	Conducts the electric current less than conductor and greater than insulator.	Does not conduct any current.
2	Has only one valence electron in its outermost orbit.	Has four valence electron in its outermost orbit.	Has eight valence electron in its outermost orbit.
3	Conductor formed using metallic bonding.	Semiconductors are formed due to covalent bonding.	Insulators are formed due to ionic bonding.
4	Valence and conduction bands are overlapped.	Valence and conduction bands are separated by forbidden energy gap of 1.1eV.	Valence and conduction bands are separated by forbidden energy gap of 6 to 10eV.
5	Resistance is very small	Resistance is high	Resistance is very high
6	It has positive temperature coefficient	It has negative temperature coefficient	It has negative temperature coefficient
7	Ex: copper,aluminium,etc	Ex: silicon, germanium, etc	Ex: Mica, Paper, etc

Solar Energy :- The p-n junction

A p-n junction separates the electron and hole carriers in a solar cell to create a voltage and useful work.

What is P-N Junction?

Definition: *A P-N junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.*

Formation of P-N Junction

As we know, if we use different semiconductor materials to make a P-N junction, there will be a grain boundary that would inhibit the movement of electrons from one side to the other by scattering the electrons and holes and thus, we use the process of doping. We will understand the process of doping with the help of this example. Let us consider a thin p-type silicon semiconductor sheet. If we add a small amount of pentavalent impurity to this, a part of the p-type Si will get converted to n-type silicon. This sheet will now contain both the p-type region and the n-type region and a junction between these two regions. The processes that follow after forming a P-N junction are of two types – diffusion and drift. There is a difference in the concentration of holes and electrons at the two sides of a junction. The holes from the p-side diffuse to the n-side and the electrons from the n-side diffuse to the p-side. These give rise to a diffusion current across the junction.

Biasing Conditions for the P-N Junction Diode

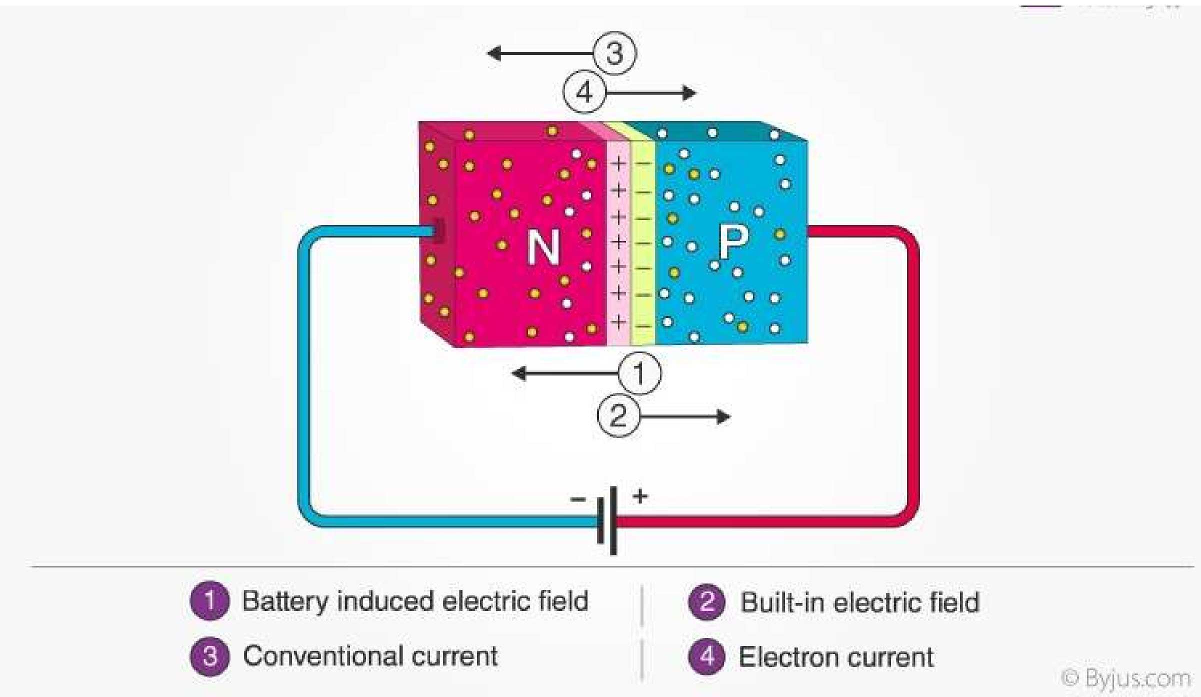
There are two operating regions in the P-N junction diode:

- P-type
- N-type

There are three biasing conditions for the P-N junction diode, and this is based on the voltage applied:

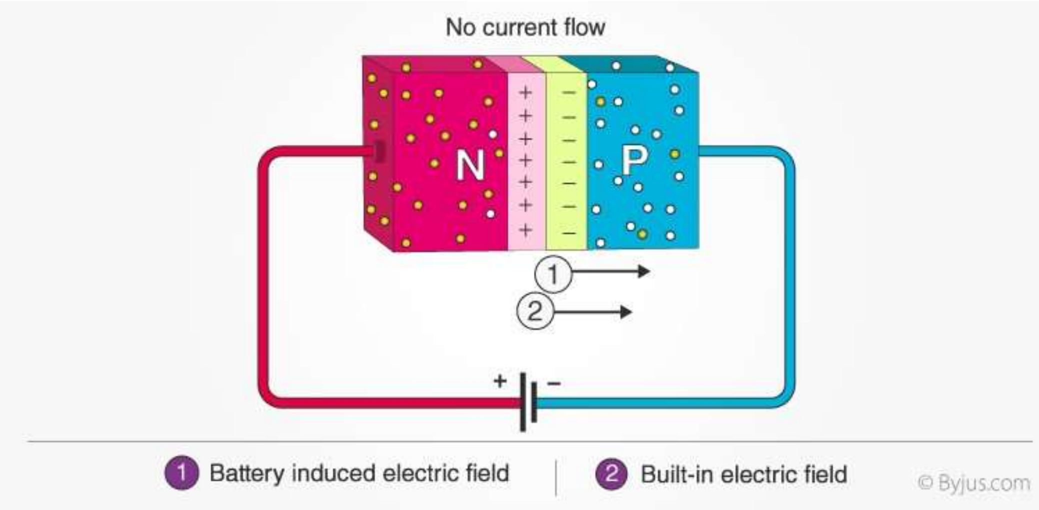
- Zero bias: There is no external voltage applied to the P-N junction diode.
- Forward bias: The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type.
- Reverse bias: The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

Forward Bias



When the p-type is connected to the battery's positive terminal and the n-type to the negative terminal, then the P-N junction is said to be forward-biased

Reverse Bias



When the p-type is connected to the battery's negative terminal and the n-type is connected to the positive side, the P-N junction is reverse biased

P-N Junction Formula

The formula used in the P-N junction depends upon the built-in potential difference created by the electric field is given as:

$$E_0 = V_T ln[\frac{N_D.N_A}{n_i^2}]$$

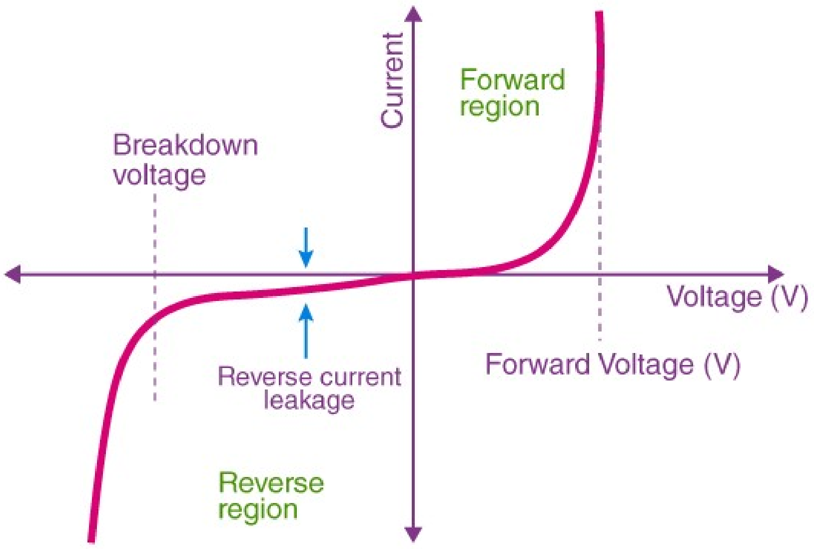
Where,

- E_0 is the zero bias junction voltage
- V_T is the thermal voltage of 26mV at room temperature
- N_D and N_A are the impurity concentrations
- n_i is the intrinsic concentration.

How does current flow in PN junction diode?

The flow of electrons from the n-side towards the p-side of the junction takes place when there is an increase in the voltage. Similarly, the flow of holes from the p-side towards the n-side of the junction takes place along with the increase in the voltage. This results in the concentration gradient between both sides of the terminals. Due to the concentration gradient formation, charge carriers will flow from higher concentration regions to lower concentration regions. The movement of charge carriers inside the P-N junction is the reason behind the current flow in the circuit.

V-I Characteristics of P-N Junction Diode



VI characteristics of P-N junction diodes is a curve between the voltage and current through the circuit. Voltage is taken along the x-axis while the current is taken along the y-axis. The above graph is the V-I characteristics curve of the P-N junction diode. With the help of the curve, we can understand that there are three regions in which the diode works, and they are:

- Zero bias

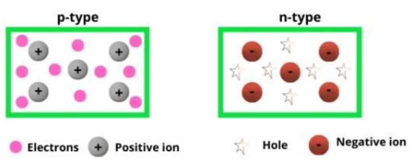
- Forward bias
- Reverse bias

Applications of P-N Junction Diode

- P-N junction diode can be used as a photodiode as the diode is sensitive to the light when the configuration of the diode is reverse-biased.
- It can be used as a solar cell.
- When the diode is forward-biased, it can be used in LED lighting applications.
- It is used as rectifier in many electric circuits and as a voltage-controlled oscillator in varactors.

Difference between the P and N type semiconductors

Sl No	P-type Semi conductor	N-type semi conductor
1	P-type semiconductor is formed due to the dopping of III group elements i.e. Boron, Aluminium, Thallium.	N-type semi conductor is formed due to dopping of Nitrogen, Phosporus, Arsenic, Antimony, Bismoth.
2	These are also known as Trivalent semi conductors.	These are also known pentavalent semiconductor.
3	P-type semiconductors is positive type semiconductor it means it deficiency of 1 electron is required.	N-type semiconductor is negative type semi-conductor it means excess of 1 electron is required.
4	In P-type semiconductor majority charge carries are holes and minority charge carries are electrons.	In N-type semiconductor majority charge carries are electrons and minority charge carries are hole.
5	A hole indicates a missing electron. In this no. of holes is more than the no. of electrons.	In N-type semiconductor the no. of holes is less than the no. of free electron.



Solar Cell :- solar cell characteristics and usage

Characteristics:-

Solar cells convert power of sunlight into electric power.

The power of sun is given in terms of the solar constant, the power spectrum and power losses in earth atmosphere expressed by the so-called air mass.

The basic characteristics of a solar cell are the short-circuit current (I_{SC}), the open-circuit voltage (V_{OC}), the fill factor (FF) and the solar energy conversion efficiency (η). The influence of both the diode saturation current density and of I_{SC} on V_{OC}, FF and η is analyzed for ideal solar cells.

Uses of Solar Cell

Biogas Solar cells are portable, durable and the maintenance cost is low. It was discovered in the year 1950 and its first use was in communication satellite Let's see some Solar cell applications for different purposes:

1. Transportation
2. Solar cells in calculators
3. Solar cell panels
4. Solar cell advantages

1. Solar Cell for Transportation

Solar energy is used in cars. This solar power is created by photovoltaic cells. This electricity is transferred to the storage battery or powers the motor. Ed Passerini was the first person to build a solar car. The first powered car was created in the year 1977

2. Solar Cells in Calculators

Solar-powered calculators use photovoltaic cells. These calculators work with solar energy. The light from sun gives power for the operation of calculators. Solar calculators work very well in outdoor light

3. Solar Cell Panels

On the rooftop, solar panels are kept. It is used as a solar heater which heats the water. This water can be used for bathing. Also, another use it helps in generating power. People can store this energy in the backup battery and can use during power cut issues. Or people can store this energy and use it to generate electricity in their house and save money by reducing the electricity bill

4. Solar Cell Advantages

Solar energy is a renewable form of energy. Saves money as it reduces the electricity bill. Maintaining is simple and affordable so the maintenance cost is also low. It is one of the best alternatives for non-renewable energy.

Solar Cell Construction & Working Principle

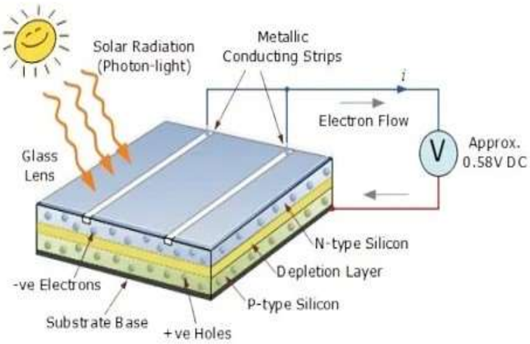
Solar cell is a device or a structure that converts the solar energy i.e. the energy obtained from the sun, directly into the electrical energy. The basic principle behind the function of solar cell is based on photovoltaic effect.

Solar cell is also termed as photo galvanic cell. The electricity supplied by the solar cell is DC electricity / current which is same like provided by batteries but a little bit different in the sense the battery is providing constant voltage.

In another way of defining the solar cell it is a solid state electrical device that converts energy of light directly into electricity by **Photoelectric Effect**.

Construction of Solar Cell

Mainly Solar cell is constructed using the crystalline Silicon that consists of a n-type semiconductor. This is the first or upper layer also known as emitter layer. The second layer is p-type semiconductor layer known as base layer. Both the layers are sandwiched and hence there is formation of p-n junction between them. The surface is coated with anti-reflection coating to avoid the loss of incident light energy due to reflection.



Working of Solar Cell

As soon as the solar cell is exposed to sunlight, the solar energy which is present in the form of light photons is absorbed by semi conductor materials. Due to this absorbed energy, the phenomena of photovoltaic occurs and electrons are liberated and produce the external DC current. The DC current is converted into 240-volt AC current using an inverter for different applications.

Photovoltaic cells are made of special materials called semiconductors such as silicon. An atom of silicon has 14 electrons, arranged in three different shells. The outer shell has 4 electrons. Therefore a silicon atom will always look for ways to fill up its last shell, and to do this, it will share electrons with four nearby atoms.

Now we use phosphorus (with 5 electrons in its outer shell). Therefore when it combines with silicon, one electron remains free. When energy is added to pure silicon it can cause few electrons to break free of their bonds and leave their atoms. These are called free carriers, which move randomly around the crystalline lattice looking for holes to fall into and carrying an electrical current.

However, they are very few and are not very useful. But impure silicon with phosphorous atoms takes a lot less energy to knock loose of "extra" electrons because they are not tied up in a bond with any neighboring atoms. As a result, we have a lot more free carriers than we would have in pure silicon to become N-type silicon.

Advantages of Solar Energy	Disadvantages of Solar Energy
Renewable Energy Source	Cost
Reduces Electricity Bills	Weather Dependent
Diverse Applications	Solar Energy Storage is Expensive
Low Maintenance Costs	Uses a Lot of Space
Technology Development	Associated with Pollution

Wind Energy Overview

Wind energy describes the process by which wind is used to generate electricity.

Wind turbines convert the kinetic energy in the wind into mechanical power.

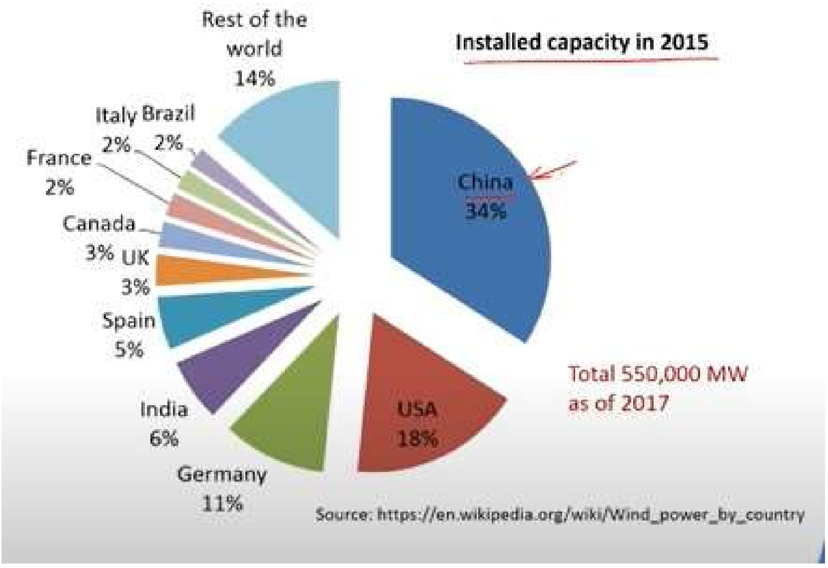
A generator can convert mechanical power into electricity. Mechanical power can also be utilized directly for specific tasks such as pumping water.

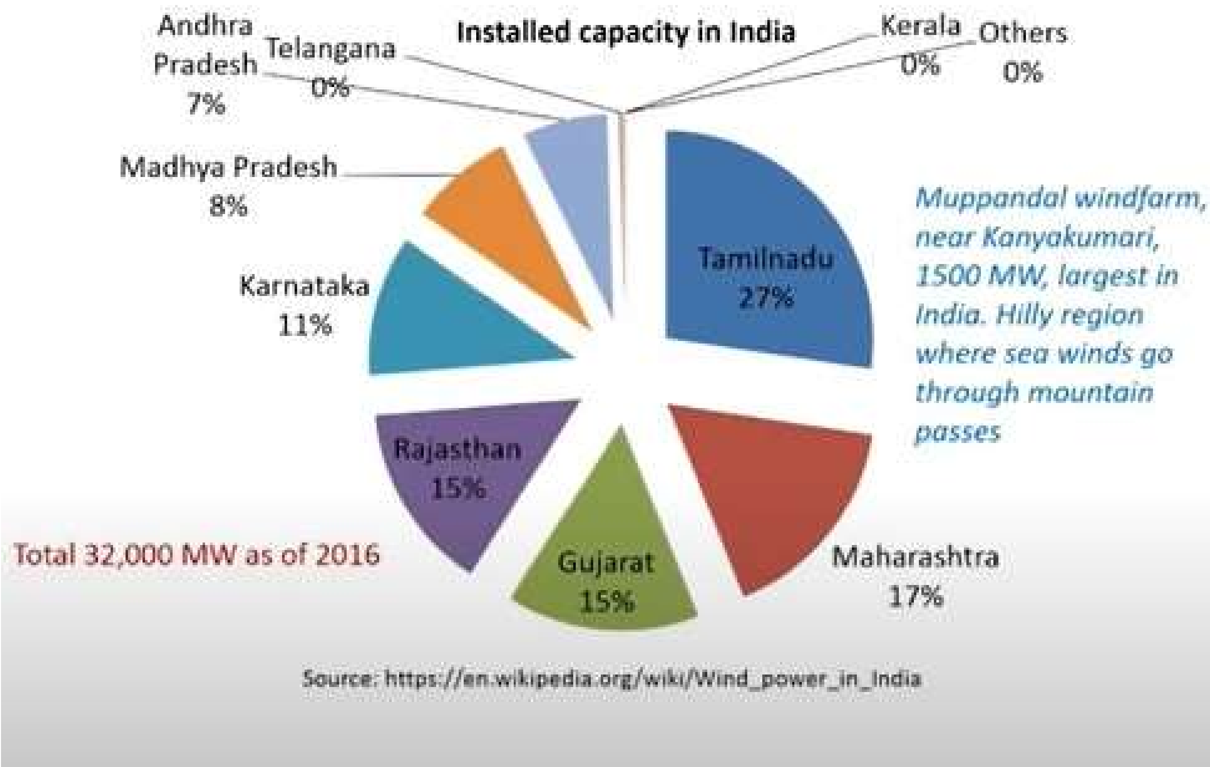
Historical usage of windmills

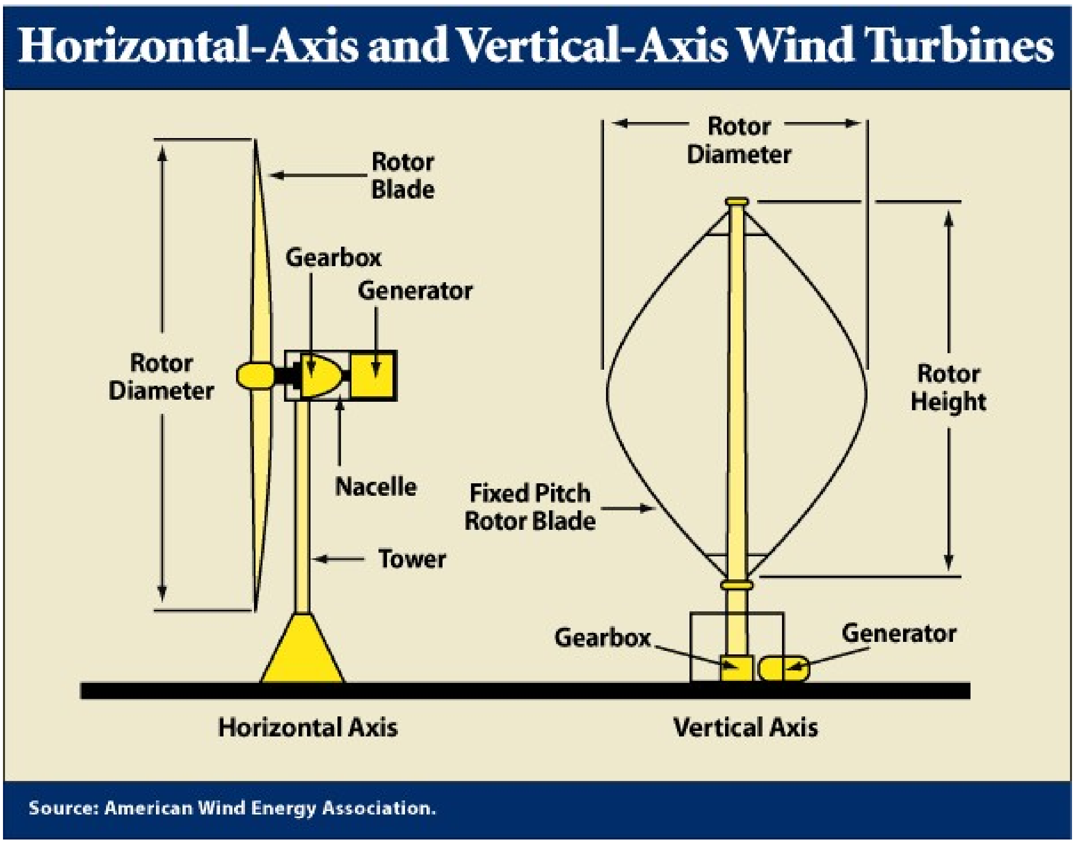
1. Grinding grains
2. Pumping water
3. Generating electricity

Requirements

1. At least 16 km/hr winds
2. Low likelihood of bursts of wind
3. Access to transmission capacity


Installed capacity in 2015
Rest of the world 14%
Italy 2%
Brazil 2%
France 2%
Canada 3%
UK 3%
Spain 5%
India 6%
Germany 11%
USA 18%
China 34%
Total 550,000 MW as of 2017
Source: https://en.wikipedia.org/wiki/Wind_power_by_country


Installed capacity in India
Andhra Pradesh 7%
Telangana 0%
Kerala 0%
Others 0%
Madhya Pradesh 8%
Karnataka 11%
Tamilnadu 27%
Muppandal windfarm, near Kanyakumari, 1500 MW, largest in India. Hilly region where sea winds go through mountain passes
Rajasthan 15%
Gujarat 15%
Maharashtra 17%
Total 32,000 MW as of 2016
Source: https://en.wikipedia.org/wiki/Wind_power_in_India



Types of windmills

Horizontal axis wind turbines

- Tall towers enable accessing stronger winds
- Blades capture wind energy throughout rotation
- Strong and huge towers required
- Complexity during construction
- Need to be turned to face the wind

Vertical axis wind turbines

- Generates power independent of wind direction
- Low cost
- Strong tower not needed since generator is on the ground
- Low efficiency (only one blade works at a time)

- May need wires to support
- More turbulent flow near ground

Energy calculations:

$$Kinetic\ Energy\ (KE) = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2}\rho V v^2 = \frac{1}{2}\rho A l v^2$$

$$Power = \frac{dE}{dt} = \frac{1}{2}\rho A \frac{dl}{dt} v^2 = \frac{1}{2}\rho A v^3$$

Performance Characteristics:

Tip speed ratio:- Ratio of rotational speed of blade to wind speed. Maximum of 10 for lift type blades

Cut in speed:- Minimum wind speed at which the blades will turn. 10 km/hr to 16 km/hr

Rated speed:- The wind speed at which the windmill generated its rated power. Usually it levels off in power beyond this speed. Around 40 km/hr

Cut out speed:- Usually at wind speeds above 70 km/hr, the windmill is stopped to prevent damage

Blade types:

Drag type:- Greater torque, lower rotational speed. Better suited for mechanical work

Lift type:- Higher rotational speed. Better suited for power generation

Theoretical Limit

Betz law (1920)

- Wind fully stopped by windmill
- Wind unaffected by windmill

$$\frac{16}{27} = 0.59$$

Practical efficiencies obtained:- 10% - 30% of energy originally available in wind

Wind energy efficiency

Wind turbines are 20% to 40% efficient at converting wind into energy. The typical life span of a wind turbine is 20 years, with routine maintenance required every six months.

What is the maximum efficiency of a wind turbine?

~59%

The theoretical maximum efficiency of a turbine is ~59%, also known as the Betz Limit. Most turbines extract ~50% of the energy from the wind that passes through the rotor area.

Winds energy: Parts and Materials

Materials used in a windmill:

Rotor: Glass fiber reinforced plastics. Require high strength and fatigue resistance

Nacelle: Yaw drives, blade pitch change, coolants, brakes, bearings, shafts, controllers, steel, aluminum.

Gearbox: Epicycle gears. May get eliminated

Generator: Permanent magnets, copper

Tower: Prestressed concrete, steel

Rotor blades:

- Steel
- Aluminum and composites
- Light weight
- Fatigue resistance
- Strength- Loading
- Stiffness- Integrity of shape
- Environment- Lightning, Humidity, Temperature
- Blade recycling

Tower:

- Wind shear variation with altitude
- Doubling the height increases wind speed by 10%
- Doubling the height, requires four times the diameter
- Material choice impacts transportation and construction cost
- Conical tubular steel towers
- Concrete increases life and better for taller towers
- Wood

Hub:

- Blades directly bolted onto hub
- Blades bolted to pitch bearing which is bolted to the hub

Gearbox:

- Connects the shaft from the blades to the generator
- Low RPM of blades to high RPM of generator
- Gearless designs considered. More magnets required for desired frequency. Neodymium (rare earth) required goes up by a factor of 10. Heavier.

Modern wind turbines have several parts and these are integrated in a design that places specific requirements on some of the parts.

Based on function, a wide range of materials are used for the parts of a modern wind turbine.

<u>Wind energy Design considerations</u>

<u>To differentiate between lift and drag designs of wind turbines</u>

To understand the significance of the number of blades in a windmill

The number of blades of a wind turbine affects its efficiency and power generation. A wind turbine blade is an important component of a clean energy system because of its ability to capture energy from the wind.

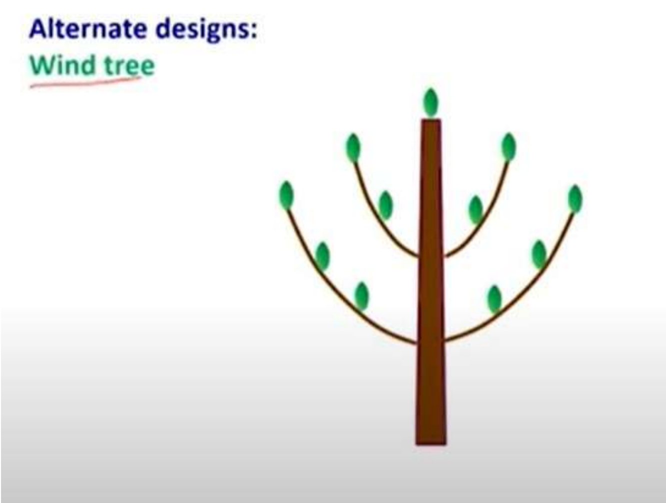
The power that a wind turbine extracts from the wind is directly proportional to the swept area of the blades; consequently, the blades have a direct effect on power generation.

The number and configuration of the blades is very important because it affects the speed and efficiency of turbine. Unfortunately, as the number of blades increases, so does the slipstream effect. Too few a number of blades results in poor efficiency and thus inadequate performance.

Too large a number of blades increases weight and production cost. The correct number of blades is important to fit the generator performance curve to optimize overall turbine performance and efficiency.

Therefore, with three blades, the angular momentum stays constant because when one blade is up, the other two are pointing at an angle. So the turbine can rotate into the wind smoothly.

To examine alternate designs for wind energy capture



Conclusions:

- Lift base design more efficient than drag based design

- For power generation, RPM is important, and even one blade may be sufficient. For other mechanical purposes, torque is important and multiple blades may be desirable

- Interesting alternate designs are available for wind energy capture

Advantages of Wind Energy

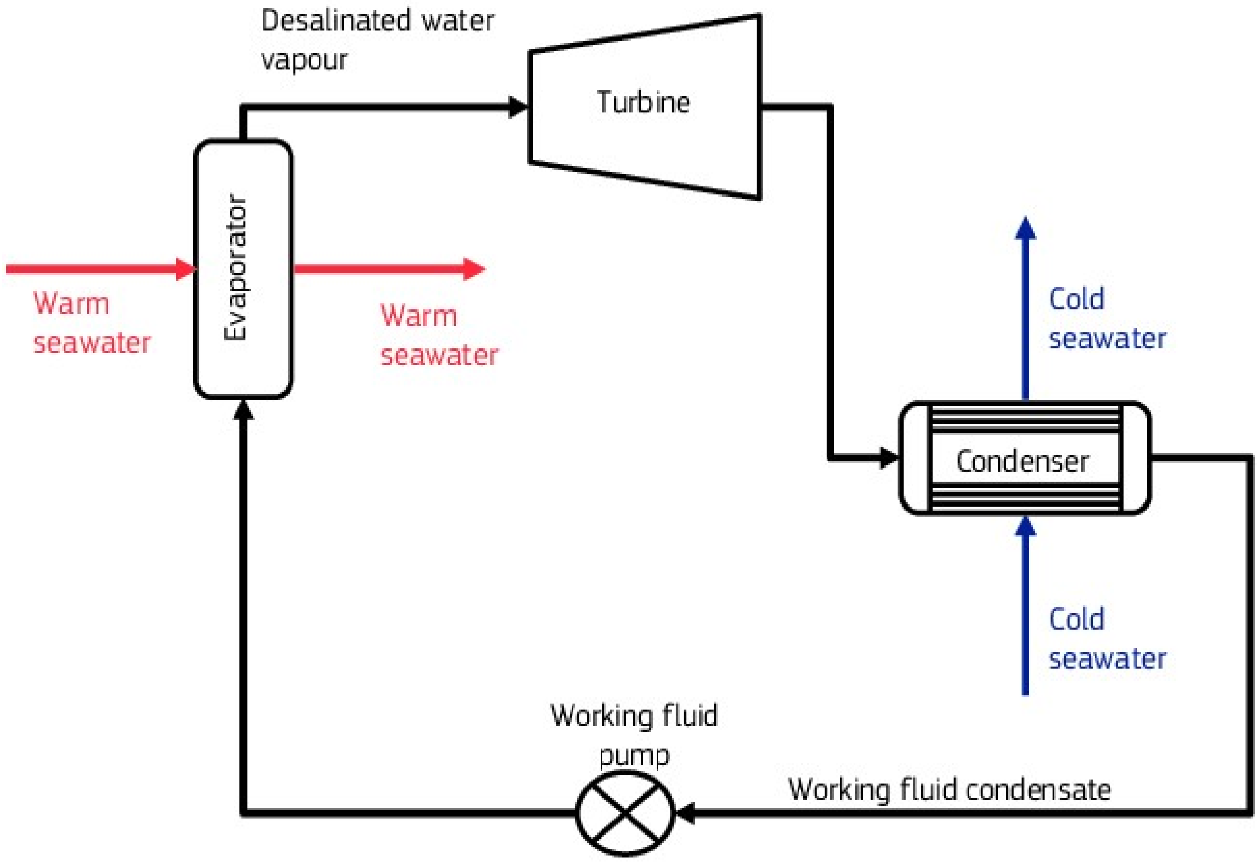
1) Free for use
2) One of the Cleanest Forms of Energy
3) Advances in Technology
4) Doesn't Disrupt Farmland Operations
5) Reduces Our Dependence of Fossil Fuels

Disadvantages of Wind Energy

1) Dangerous to Some Wildlife
2) Wind turbines can be quite noisy
3) Expensive Upfront Cost
4) Unreliable/Unpredictable

Ocean Thermal Energy Conversion (OTEC)

Ocean thermal energy conversion (OTEC) is a process or technology for producing energy by harnessing the temperature differences (thermal gradients) between ocean surface waters and deep ocean waters. Energy from the sun heats the surface water of the ocean.



Principle of OTEC:

- Temperature difference between warm water at the surface and colder water approximately 1 km below the surface is used to run a heat engine and energy is extracted from the same
- Temperature difference can be of the order of 15°C to 25°C

Thermal profile of sea water:

- First 20 m absorbs sunlight, Surface freezing at poles to 36° C in the Persian Gulf
- Water turbulent and mixed for a few hundred meters
- Boundary of a few hundred meters between mixed layer and undisturbed water below, called Thermocline
- 90% of sea water below thermocline, temperature around 3°C

Challenges working under sea:

- Marina Trench, 11 km deep, visited by 3 people
- Moon, nearly 3,84,400km, visited by 12 people

Close Cycle: Warm sea water evaporates at low pressure, runs turbine, condensed by cold sea water. Desalinated water becomes available

Closed cycle: Low boiling point liquid, ammonia, -33°C. Warm water makes it evaporate and run turbine, cold water condenses it afterwards

Conclusions:

- ➢ OTEC is available to tap in almost all coastal regions
- ➢ Can be setup off-shore as well
- ➢ Efficiencies are low
- ➢ Stability of structures in the presence of water currents is a factor to address

Advantages of Ocean Thermal Energy

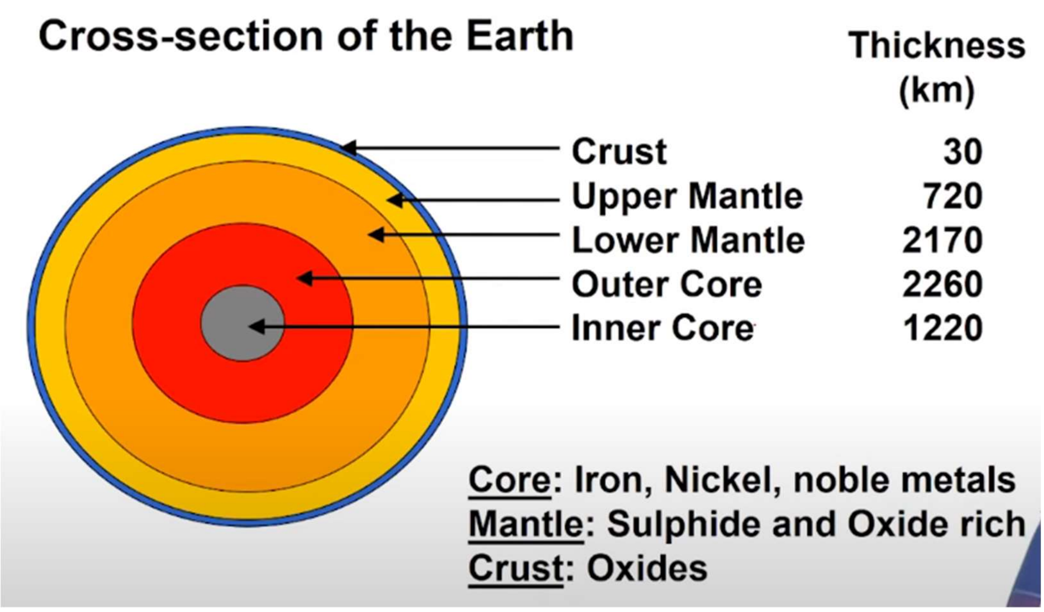
- Renewable Energy
- Clean energy
- Reliable
- Environmental friendly
- Low Maintenance
- Independent of Disadvantages of Ocean Thermal Energy

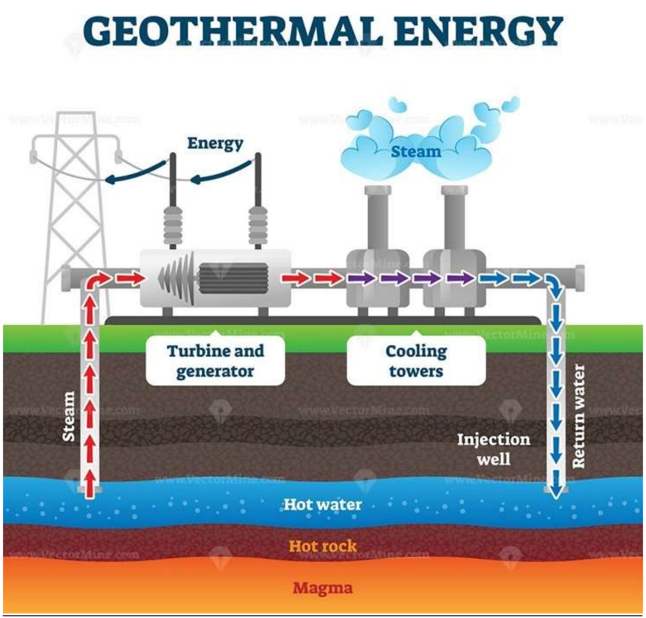
Disadvantages of Ocean Thermal Energy

- The locality of Production
- High Commercing Cost
- Interfere with navigation
- Slight temperature difference
- Large size turbines with expensive liquid
- Harmful on Marine life

Geothermal Energy

Geothermal energy is **heat within the earth**. The word geothermal comes from the Greek words geo (earth) and therme (heat). Geothermal energy is a renewable energy source because heat is continuously produced inside the earth. People use geothermal heat for bathing, to heat buildings, and to generate electricity.





How is it Used?

It has been used in some countries for thousands of years for cooking and in heating systems. The underground geothermal reservoirs of steam and heated water can be used for electricity generation and other heating and cooling applications.

One example of heating and cooling is where a geothermal heat pump is installed around 10 feet underground. These pipes are filled with water or an antifreeze solution. The water is pumped around the closed loop of pipes. These ground source heat pump systems help to cool buildings in summer and maintain warmth in summer. This occurs by absorbing the earth's heat as the water circulates back into the building.

Geothermal water has been used to help grow plants in greenhouses, for district heating in homes and businesses. It can also be piped under roads to melt snow.

How is Geothermal Energy Produced?

Wells of up to a mile deep or more are drilled into underground reservoirs to tap into the geothermal resources. These resources can be exploited from naturally occurring heat, rock and water permeability or through enhanced geothermal systems, which enhance or create geothermal resources through a process called hydraulic stimulation. These geothermal resources, whether natural or enhanced, drive turbines linked to electricity generators.

The first recorded instance of geothermal heat being used for producing electricity was in Larderello, Italy in 1904. Yet, geothermal heat has been used for bathing since the Palaeolithic Age. Monkeys in Japan have also been shown to use heated water from hot springs to keep warm during winter months in mountainous regions.

How Does Geothermal Energy Work?

Geothermal power plants come in three different designs; dry steam, flash and binary:

- The oldest type is dry steam, which takes steam directly from fractures in the ground to drive a turbine.
- Flash plants pull high pressure hot water from underground and mix it with cooler low pressure water. This, in turn, creates steam that is used to drive a turbine.
- Binary plants use hot water passed through a secondary fluid that has a lower boiling point than water. The secondary fluid is turned into vapour which drives a turbine. Most future geothermal power plants are expected to be binary plants.

The United States is the world's largest producer. They also have the largest geothermal development in the world, situated at The Geysers north of San Francisco, California. Despite the name, there are no geysers there and the energy used is all steam rather than hot water.

The first power generation well was sunk in 1924, with more wells drilled in the 1950s and further development taking place from the 1970s on.

Other nations, such as Iceland, are well placed to exploit geothermal resources, which they have done since 1907. With 25 active volcanoes and 600 hot springs, 25% of Iceland's energy comes from five geothermal power plants.

Advantages of Geothermal Energy

- This energy source is more environmentally friendly than conventional fuel sources.
- A source of renewable energy.
- The number of exploitable geothermal resources will increase with ongoing research and development in the industry.
- A sustainable source of energy as its always available unlike wind and solar.
- A reliable source as its easier to predict the power output from a geothermal plant with a high degree of accuracy.
- No fuel is required.
- Increase in exploration meaning that new technologies are being created to improve the energy process.
- Pollution levels are much lower compared to fossil fuels.

Disadvantages of Geothermal Energy

- The largest single disadvantage of geothermal energy is that it is location specific.
- Gases are released into the atmosphere during digging.
- Geothermal energy runs the risk of triggering earthquakes.
- Expensive resource to tap into, with high upfront costs ranging from around $2-$7 million for a plant with a 1 megawatt capacity.
- Energy fluid needs to be pumped back into the underground reservoirs faster than it is depleted. Management is required to maintain sustainability.

Biomass

Biomass is organic, meaning it is made of material that comes from living organisms, such as plants and animals.

The most common biomass materials used for energy are plants, wood, and waste.

These are called biomass feedstocks. Biomass energy can also be a non-renewable energy source.

Biomass Agriculture:

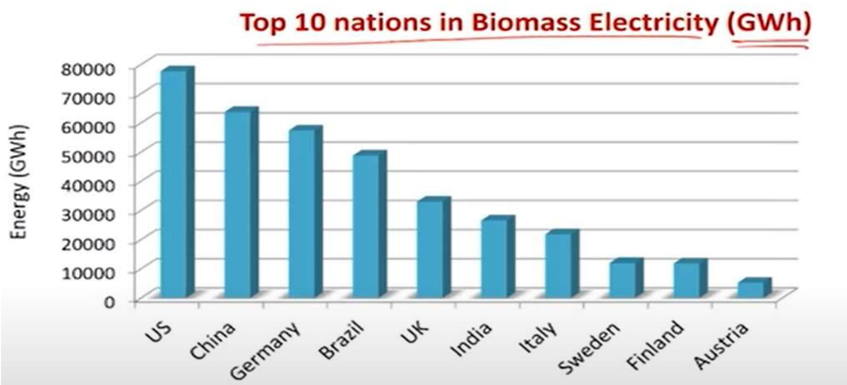
Farmers grow corn for producing ethanol

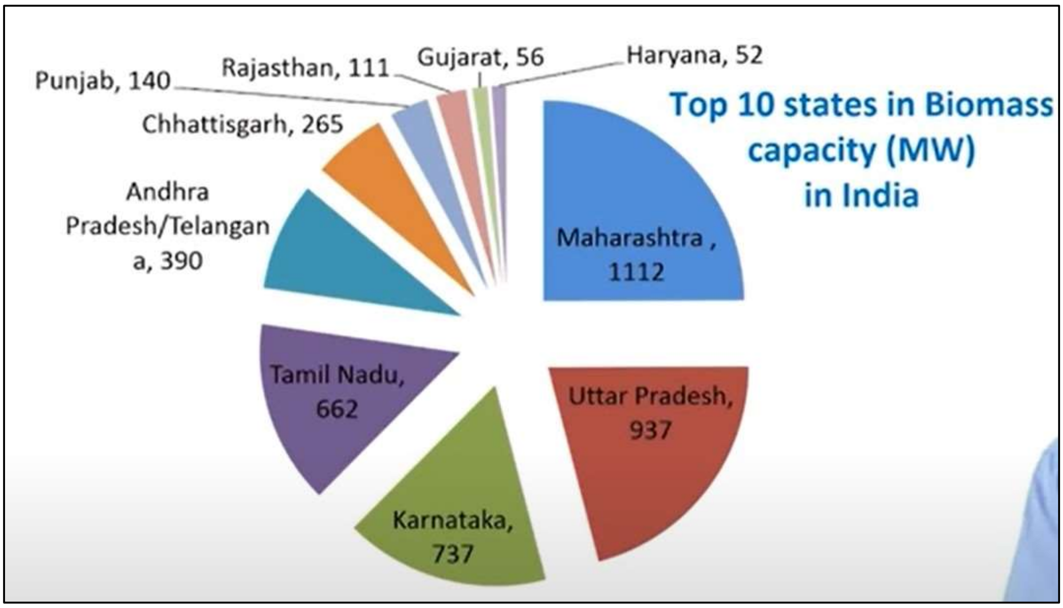
- Alternate source of income
- Competition with food resources

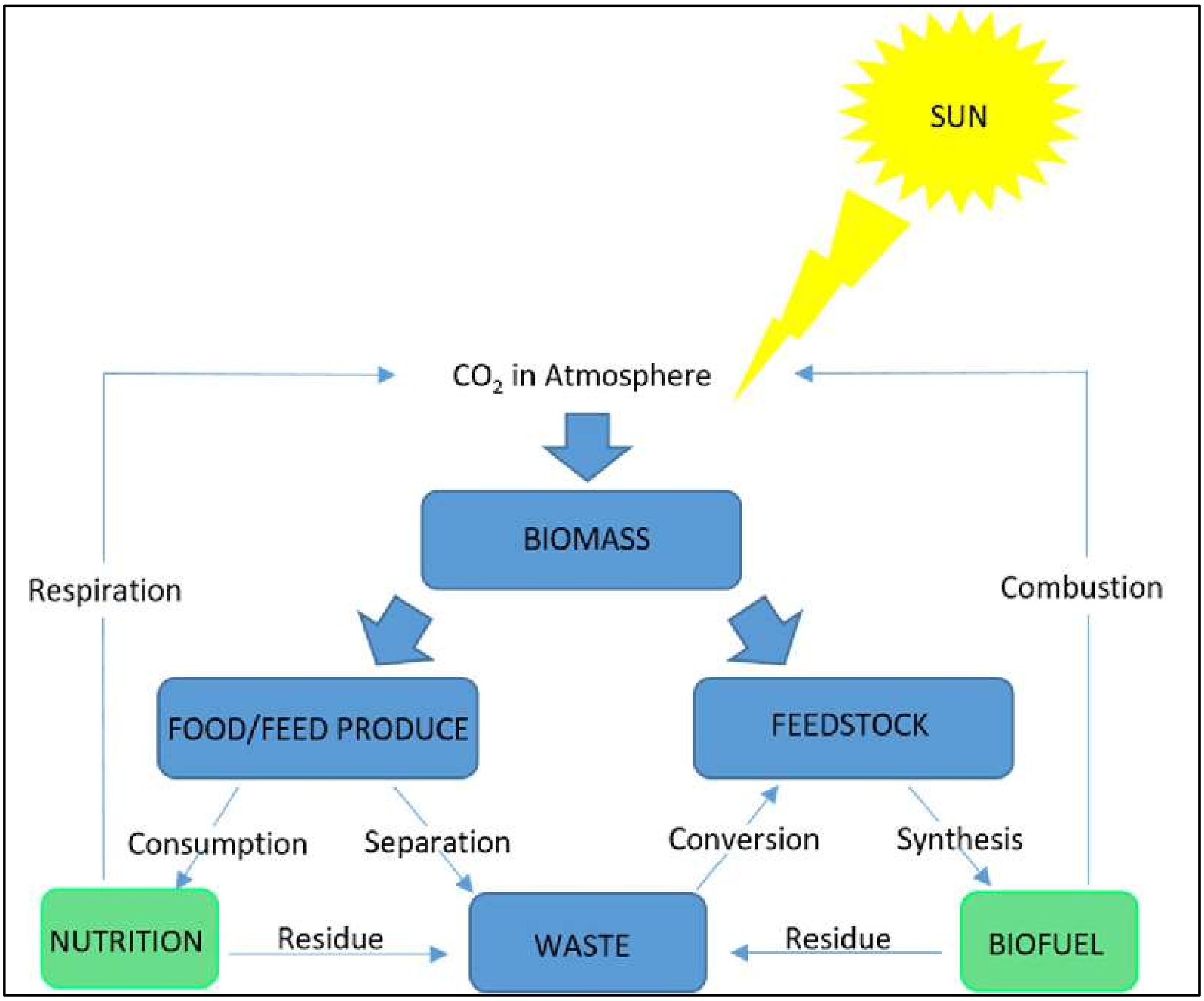
Bio-wastes

Substitutions:

- Coal- Direct combustion of wood
- Coal- Charcoal (wood heated in absence of air), removes volatiles, twice the energy content per unit mass
- Petrol- Ethanol by fermentation of corn/sugarcane (anaerobic)
- Diesel- Biodiesel, from vegetable oils such as soybean oil
- Natural gas- Biogas, from organic wastes (anaerobic)




Top 10 states in Biomass capacity (MW) in India
Maharashtra , 1112
Uttar Pradesh, 937
Karnataka, 737
Tamil Nadu, 662
Andhra Pradesh/Telangana, 390
Chhattisgarh, 265
Punjab, 140
Rajasthan, 111
Gujarat, 56
Haryana, 52


SUN
CO2 in Atmosphere
BIOMASS
Respiration
Combustion
FOOD/FEED PRODUCE
FEEDSTOCK
Consumption
Separation
Conversion
Synthesis
NUTRITION
Residue
WASTE
Residue
BIOFUEL

Converting biomass to energy

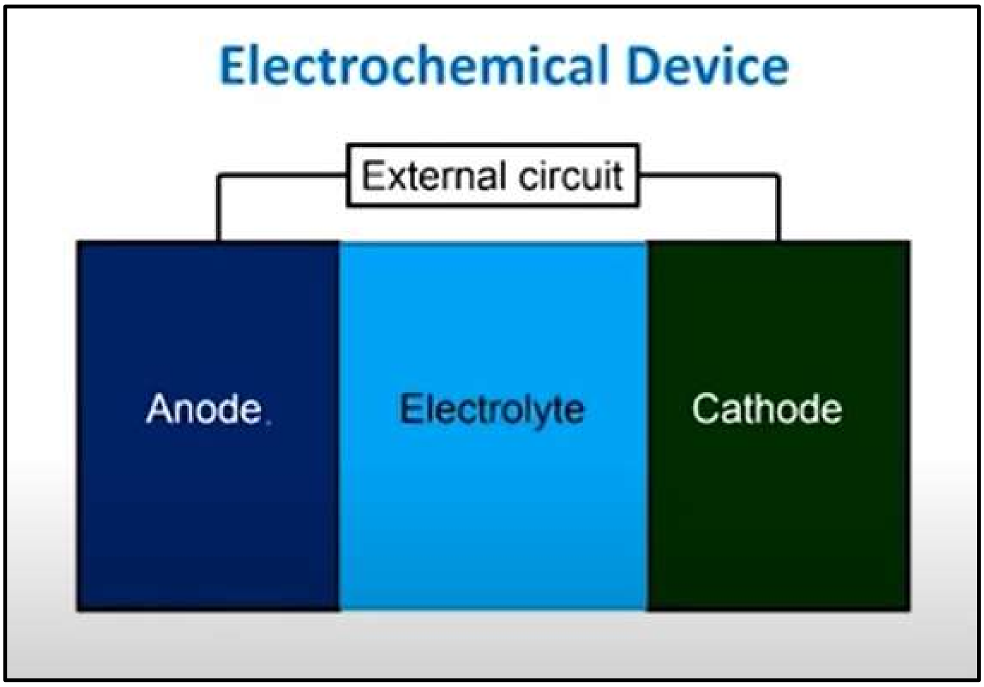
Biomass is converted to energy through various processes, including:

- Direct combustion (burning) to produce heat
- Thermochemical conversion to produce solid, gaseous, and liquid fuels
- Chemical conversion to produce liquid fuels
- Biological conversion to produce liquid and gaseous fuels

Advantages of Biomass Energy	Disadvantages of Biomass Energy
It is Renewable	It's Not Completely Clean
Carbon Neutrality	High Costs In Comparison To Other Alternatives
Less Dependency On Fossil Fuels	Possible Deforestation
It Is Versatile	Space
Availability	It Requires Water
Low Cost In Comparison To Fossil Fuels	It Has Inefficiencies
It Reduces Waste	It's Under Development
Domestic Production	

Battery basics

1. Electrochemical device
    - Electrode phase
    - Electrolyte phase
    - Charge transfer
2. Energy storage device



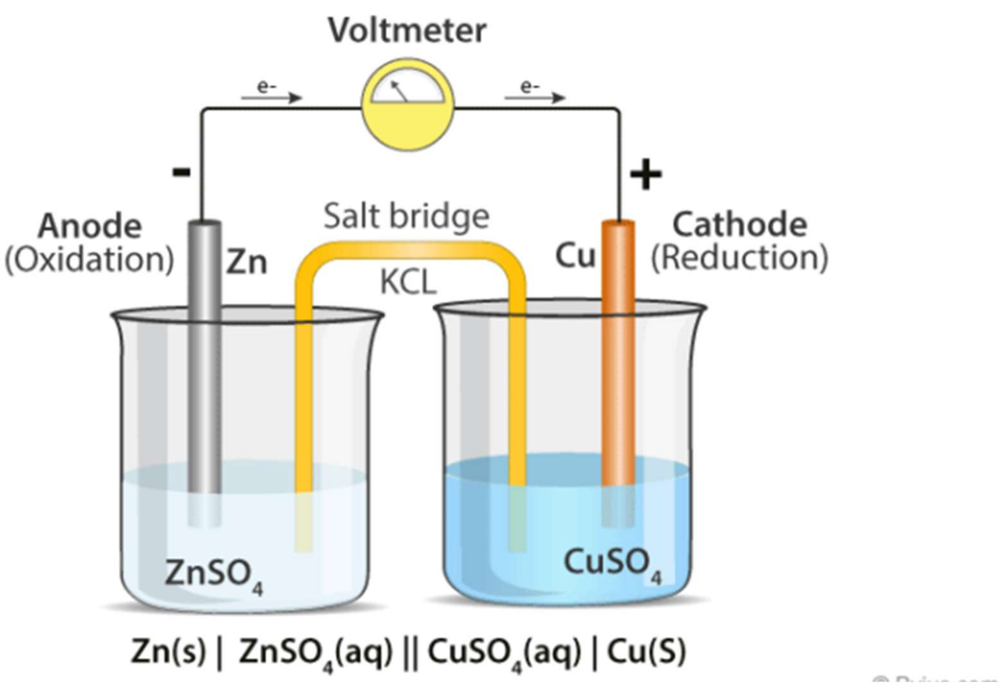
Anode	Oxidation	Loss of electrons
Cathode	Reduction	Gain of electrons

What is an Electrochemical Cell?

An electrochemical cell is a device that can generate electrical energy from the chemical reactions occurring in it, or use the electrical energy supplied to it to facilitate chemical reactions in it. These devices are capable of converting chemical energy into electrical energy, or vice versa. A common example of an electrochemical cell is a standard 1.5-volt cell which is used to power many electrical appliances such as TV remotes and clocks.

Such cells capable of generating an electric current from the chemical reactions occurring in them care called Galvanic cells or Voltaic cells. Alternatively, the cells which cause chemical reactions to occur in them when an electric current is passed through them are called electrolytic cells.

A diagram detailing the different parts of an electrochemical cell is provided below.



Electrochemical Cell

Electrochemical cells generally consist of a cathode and an anode. The key features of the cathode and the anode are tabulated below.

Cathode	Anode
Denoted by a positive sign since electrons are consumed here	Denoted by a negative sign since electrons are liberated here
A reduction reaction occurs in the cathode of an electrochemical cell	An oxidation reaction occurs here
Electrons move into the cathode	Electrons move out of the anode

General convention dictates that the cathode must be represented on the right-hand side whereas the anode is represented on the left-hand side while denoting an electrochemical cell.

Half-Cells and Cell Potential

- Electrochemical Cells are made up of two half-cells, each consisting of an electrode which is dipped in an electrolyte. The same electrolyte can be used for both half cells.
- These half cells are connected by a salt bridge which provides the platform for ionic contact between them without allowing them to mix with each other. An example of a salt bridge is a filter paper which is dipped in a potassium nitrate or sodium chloride solution.
- One of the half cells of the electrochemical cell loses electrons due to oxidation and the other gains electrons in a reduction process. It can be noted that an equilibrium reaction occurs in both the half cells, and once the equilibrium is reached, the net voltage becomes 0 and the cell stops producing electricity.
- The tendency of an electrode which is in contact with an electrolyte to lose or gain electrons is described by its electrode

potential. The values of these potentials can be used to predict the overall cell potential. Generally, the electrode potentials are measured with the help of the standard hydrogen electrode as a reference electrode (an electrode of known potential).

Primary and Secondary Cells

- Primary cells are basically use-and-throw galvanic cells. The electrochemical reactions that take place in these cells are irreversible in nature. Hence, the reactants are consumed for the generation of electrical energy and the cell stops producing an electric current once the reactants are completely depleted.
- Secondary cells (also known as rechargeable batteries) are electrochemical cells in which the cell has a reversible reaction, i.e. the cell can function as a Galvanic cell as well as an Electrolytic cell.
- Most of the primary batteries (multiple cells connected in series, parallel, or a combination of the two) are considered wasteful and environmentally harmful devices. This is because they require about 50 times the energy they contain in their manufacturing process. They also contain many toxic metals and are considered to be hazardous waste.

Types of Electrochemical Cells

The two primary types of electrochemical cells are

1. Galvanic cells (also known as Voltaic cells)
2. Electrolytic cells

The key differences between Galvanic cells and electrolytic cells are tabulated below.

Galvanic Cell / Voltaic Cell	Electrolytic Cell
Chemical energy is transformed into electrical energy in these electrochemical cells.	Electrical energy is transformed into chemical energy in these cells.
The redox reactions that take place in these cells are spontaneous in nature.	An input of energy is required for the redox reactions to proceed in these cells, i.e. the reactions are non-spontaneous.
In these electrochemical cells, the anode is negatively charged and the cathode is positively charged.	These cells feature a positively charged anode and a negatively charged cathode.
The electrons originate from the species that undergoes oxidation.	Electrons originate from an external source (such as a battery).

Applications of Electrochemical Cells

- Electrolytic cells are used in the electrorefining of many non-ferrous metals. They are also used in the electrowinning of these metals.
- The production of high-purity lead, zinc, aluminium, and copper involves the use of electrolytic cells.
- Metallic sodium can be extracted from molten sodium chloride by placing it in an electrolytic cell and passing an electric current through it.
- Many commercially important batteries (such as the lead-acid battery) are made up of Galvanic cells.
- Fuel cells are an important class of electrochemical cells that serve as a source of clean energy in several remote locations.

Energy Storage Device:

Fuel and oxidant are stored within the device

Energy Conversion Device:

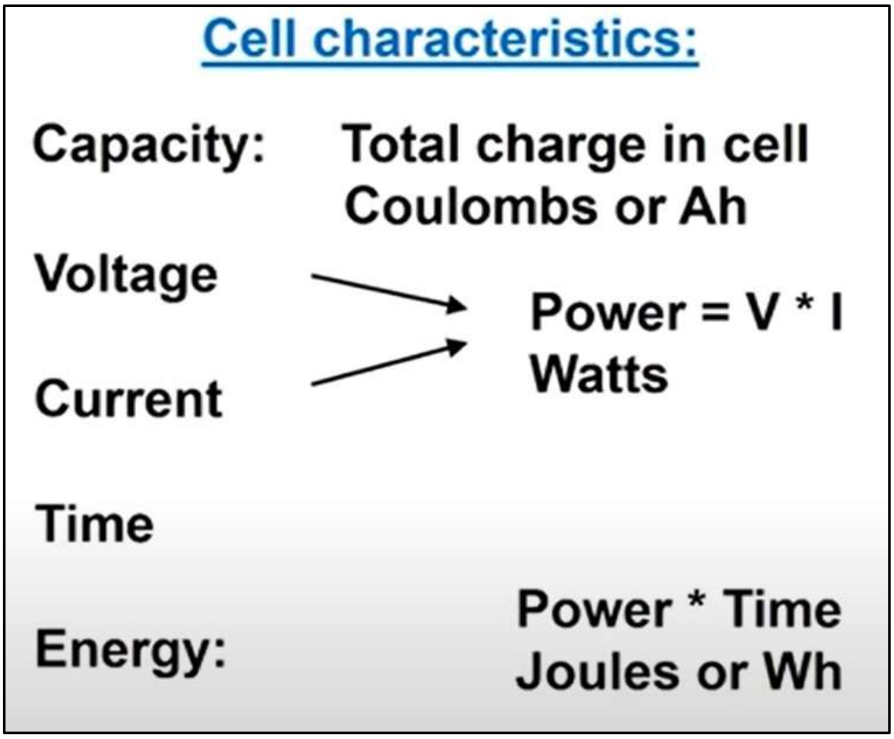
Fuel and oxidant are stored external to the device

Cell:- A single electrochemical unit i.e., one anode, one cathode, and the electrolyte

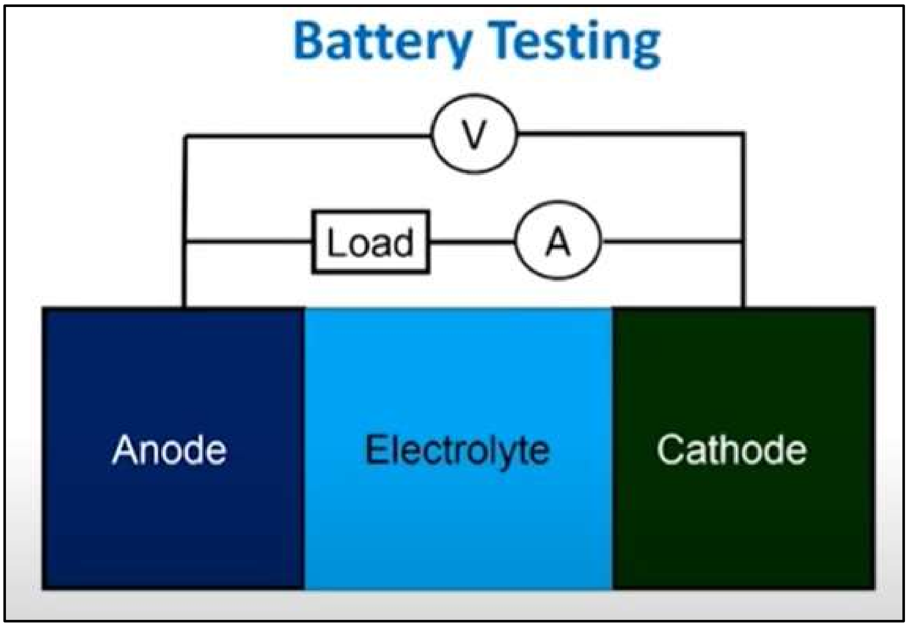
Battery:- A collection of cells in series or parallel

Primary cell:- Single use of power source

Secondary cell:- Can be recharged



Battery Testing and Performance



The C-Rate :- The rate at which the battery is discharge or charged, relative to its capacity

0.1 C Rate => Discharge or charge in 10 hours

1 C Rate => Discharge or charge in 1 hour

2 C Rate => Discharge or charge in ½ hour

5 C Rate => Discharge or charge in 12 minutes

Terminology associated with use

State of charge: % of maximum capacity that is remaining unused

Depth of Discharge: % of maximum capacity that has been discharged

Cycle life: Number of cycles before the battery fails to meet performance specifications. Affected by depth of discharge

Lithium ion batteries

Lithium:

One of the most electropositive elements

Light weight (0.53 gm/cm^3)

Environmentally friendly

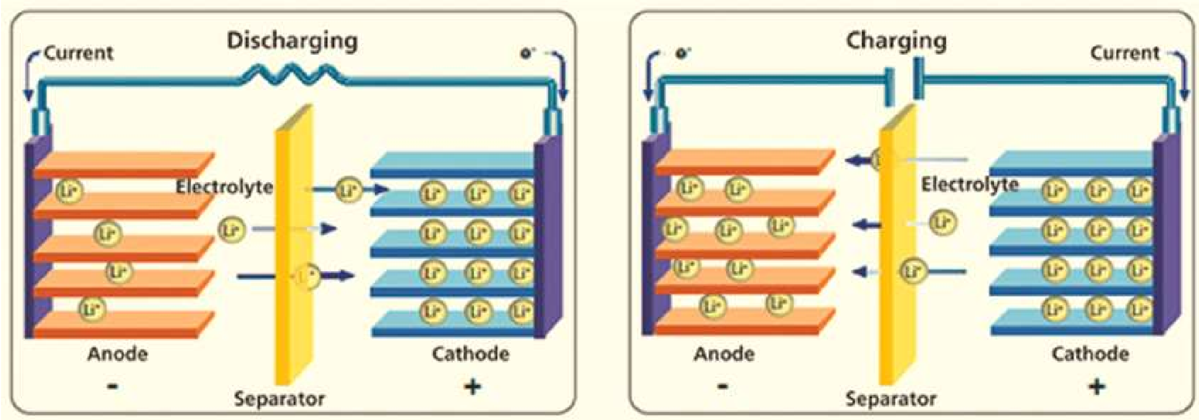
Dendritic growth of Lithium:

Porous structure that grows on anode with each, Can result in internal short circuit

What is a lithium-ion battery and how does it work?

A lithium-ion (Li-ion) battery is an advanced battery technology that uses lithium ions as a key component of its electrochemistry. During a discharge cycle, lithium atoms in the anode are ionized and separated from their electrons. The lithium ions move from the anode and pass through the electrolyte until they reach the cathode, where they recombine with their electrons and electrically neutralize. The lithium ions are small enough to be able to move through a micro-permeable separator between the anode and cathode. In part because of lithium's small size (third only to hydrogen and helium), Li-ion batteries are capable of having a very high voltage and charge storage per unit mass and unit volume.

Li-ion batteries can use a number of different materials as electrodes. The most common combination is that of lithium cobalt oxide (cathode) and graphite (anode), which is most commonly found in portable electronic devices such as cellphones and laptops. Other cathode materials include lithium manganese oxide (used in hybrid electric and electric automobiles) and lithium iron phosphate. Li-ion batteries typically use ether (a class of organic compounds) as an electrolyte.



advantages of Lithium Ion Battery

➡As mentioned it has high energy density which is two times compare to Ni-Cd.

➡The Lithium-Ion battery is rechargeable.

➡There is no memory effect. Hence it is not needed to discharge them completely before recharging.

➡The battery can handle many charge/discharge cycles.

➡The battery can hold the charge and it can lose only 5% of its charge every month.

disadvantages of Lithium Ion Battery

➡It lasts only two to three years after manufacturer.

➡It is sensitive to high temperatures.

➡If the battery is completely discharged, it can no longer be recharged again.

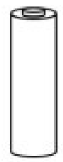
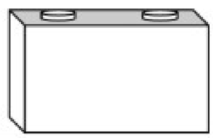
➡It is relatively expensive.

➡If the "separator" gets damaged, it can burst into flames.

Common battery structures and types:

Different Battery Structures

- Cylindrical cell
- Button cell
- Prismatic cell
- Pouch cell

Cylindrical cell	Prismatic cell	Pouch cell
		
• Small size (e.g. 18650 type (ø 18 mm, height 650 mm)) • Hard casing • Low individual cell capacity • Build in safety features • Comparably cheap	• Hard casing • Large size • High individual cell capacity	• Soft casing • Large size • High individual cell capacity • Geometrical deformation during (dis-)charging

Types of Batteries

Batteries generally can be classified into different categories and types, ranging from chemical composition, size, form factor and use cases, but under all of these are two major battery types;

1. Primary Batteries
2. Secondary Batteries

Let's take a deeper look to understand the major differences between a **Primacy cell and Secondary Cell.**

1. Primary Batteries

Primary batteries are batteries that **cannot be recharged** once depleted. Primary batteries are made of electrochemical cells whose electrochemical reaction cannot be reversed.

2. Secondary Batteries

Secondary batteries are batteries with electrochemical cells whose chemical reactions can be reversed by applying a certain voltage to the battery in the reversed direction. Also referred to as **rechargeable batteries**, secondary cells unlike primary cells can be recharged after the energy on the battery has been used up.

The following are the **different types of rechargeable batteries** that are commonly used.

1. Lithium-ion(Li-ion)
2. Nickel Cadmium(Ni-Cd)
3. Nickel-Metal Hydride(Ni-MH)
4. Lead-Acid

1. Nickel-Cadmium Batteries

The nickel–cadmium battery (NiCd battery or NiCad battery) is a type of rechargeable battery which is developed using nickel oxide hydroxide and metallic cadmium as electrodes. Ni-Cd batteries excel at maintaining voltage and holding charge when not in use. However, NI-Cd batteries easily fall a victim of the dreaded “memory” effect when a partially charged battery is recharged, lowering the future capacity of the battery.

2. Nickel-Metal Hydride Batteries

Nickel metal hydride (Ni-MH) is another type of chemical configuration used for rechargeable batteries. The chemical reaction at the positive electrode of batteries is similar to that of the nickel–cadmium cell (NiCd), with both battery type using the same nickel oxide hydroxide (NiOOH). However, the negative electrodes in Nickel-Metal Hydride use a hydrogen-absorbing alloy instead of cadmium which is used in NiCd batteries

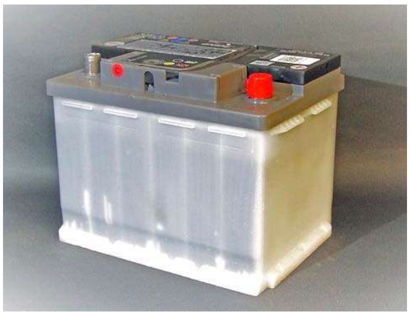
.

3. Lithium-ion Batteries

Lithium-ion batteries are one of the most popular types of rechargeable batteries. There are many **different types of Lithium batteries**, but among all the lithium-ion batteries are the most commonly used. You can find these lithium batteries being used in different forms popularly among electric vehicles and other portable gadgets. If you are curious to know more about batteries used in Electric vehicles, you can check out this article on Electric Vehicle Batteries. They are found in different portable appliances including mobile phones, smart devices and several other battery appliances used at home. They also find applications in aerospace and military applications due to their lightweight nature.

4. Lead-Acid Batteries

Lead-acid batteries are a low-cost reliable power workhorse used in heavy-duty applications. They are usually very large and because of their weight, they're always used in non-portable applications such as solar-panel energy storage, vehicle ignition and lights, backup power and load levelling in power generation/distribution. The lead-acid is the oldest type of rechargeable battery and still very relevant and important into today's world. Lead-acid batteries have very low energy to volume and energy to weight ratios but it has a relatively large power to weight ratio and as a result, can supply huge surge currents when needed. These attributes alongside its low cost make these batteries attractive for use in several high current applications like powering automobile starter motors and for storage in backup power supplies. You can also check out the article on Lead Acid Battery working if you want to know more about the different types of Lead-acid batteries, its construction and applications.



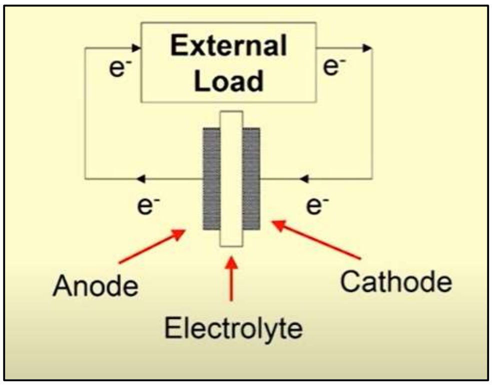
Types of full Cells

What is a Fuel Cell?

Fuel cells require a continuous input of fuel and an oxidizing agent (generally oxygen) in order to sustain the reactions that generate the electricity. Therefore, these cells can constantly generate electricity until the supply of fuel and oxygen is cut off.

A fuel cell is similar to electrochemical cells, which consists of a cathode, an anode, and an electrolyte. In these cells, the electrolyte enables the movement of the protons.

A block diagram of this fuel cell is provided below.



Types of Fuel Cells

Despite working similarly, there exist many varieties of fuel cells. Some of these types of fuel cells are discussed in this subsection.

The Polymer Electrolyte Membrane (PEM) Fuel Cell

- These cells are also known as proton exchange membrane fuel cells (or PEMFCs).
- The temperature range that these cells operate in is between 50°C to 100°C
- The electrolyte used in PEMFCs is a polymer which has the ability to conduct protons.
- A typical PEM fuel cell consists of bipolar plates, a catalyst, electrodes, and the polymer membrane.
- Despite having eco-friendly applications in transportation, PEMFCs can also be used for the stationary and portable generation of power.

Alkaline Fuel Cell

- This was the fuel cell which was used as the primary source of electricity in the Apollo space program.
- In these cells, an aqueous alkaline solution is used to saturate a porous matrix, which is in turn used to separate the electrodes.
- The operating temperatures of these cells are quite low (approximately 90°C).
- These cells are highly efficient. They also produce heat and water along with electricity.

Phosphoric Acid Fuel Cell

- These fuel cells involve the use of phosphoric acid as an electrolyte in order to channel the H^+
- The working temperatures of these cells lie in the range of 150°C – 200°C
- Electrons are forced to travel to the cathode via an external circuit because of the non-conductive nature of phosphoric acid.
- Due to the acidic nature of the electrolyte, the components of these cells tend to corrode or oxidize over time.

Molten Carbonate Fuel Cell

- The electrolyte used in these cells is lithium potassium carbonate salt. This salt becomes liquid at high temperatures, enabling the movement of carbonate ions.
- Similar to SOFCs, these fuel cells also have a relatively high operating temperature of 650°C
- The anode and the cathode of this cell are vulnerable to corrosion due to the high operating temperature and the presence of the carbonate electrolyte.
- These cells can be powered by carbon-based fuels such as natural gas and biogas.

Solid Oxide Fuel Cell

- These cells involve the use of a solid oxide or a ceramic electrolyte (such as yttria-stabilized zirconia).
- These fuel cells are highly efficient and have a relatively low cost (theoretical efficiency can even approach 85%).
- The operating temperatures of these cells are very high (lower limit of 600^{o}C, standard operating temperatures lie between 800 and 1000^{o}C).
- Solid oxide fuel cells are limited to stationary applications due to their high operating temperatures.

Solid Acid Fuel Cell

- A solid acid material is used as the electrolyte in these fuel cells.
- The molecular structures of these solid acids are ordered at low temperatures.
- At higher temperatures, a phase transition can occur which leads to a huge increase in conductivity.
- Examples of solid acids include $CsHSO_4$ and CsH_2PO_4 (cesium hydrogen sulfate and cesium dihydrogen phosphate respectively)

Applications of fuel cell

Fuel cell technology has a wide range of applications. Currently, heavy research is being conducted in order to manufacture a cost-efficient automobile which is powered by a fuel cell. A few applications of this technology are listed below.

- Fuel cell electric vehicles, or FCEVs, use clean fuels and are therefore more eco-friendly than internal combustion engine-based vehicles.
- They have been used to power many space expeditions including the Appolo space program.
- Generally, the byproducts produced from these cells are heat and water.
- The portability of some fuel cells is extremely useful in some military applications.
- These electrochemical cells can also be used to power several electronic devices.
- Fuel cells are also used as primary or backup sources of electricity in many remote areas.

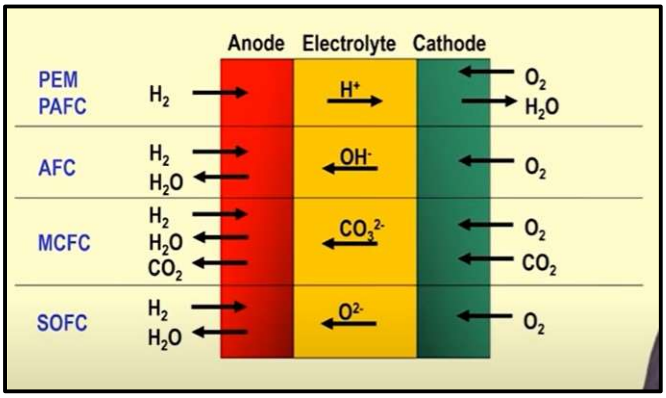
Advantages:

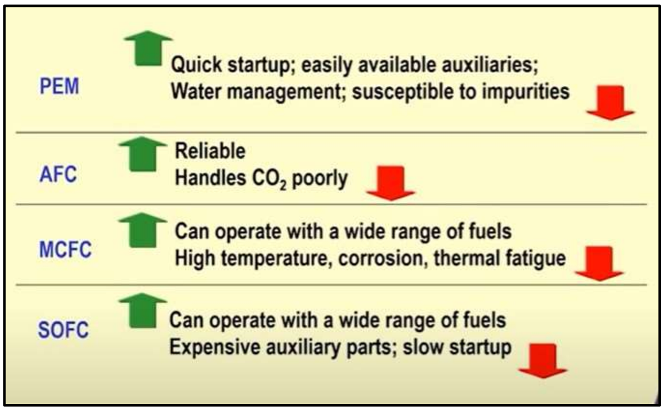
- High Efficiency- when utilizing co-generation, fuel cells can attain over 80% energy efficiency
- Good reliability- quality of power provided does not degrade over time.
- Noise- offers a much more silent and smooth alternative to conventional energy production.
- Environmentally beneficial- greatly reduces CO2 and harmful pollutant emissions.
- Size reduction- fuel cells are significantly lighter and more compact

Disadvantages:

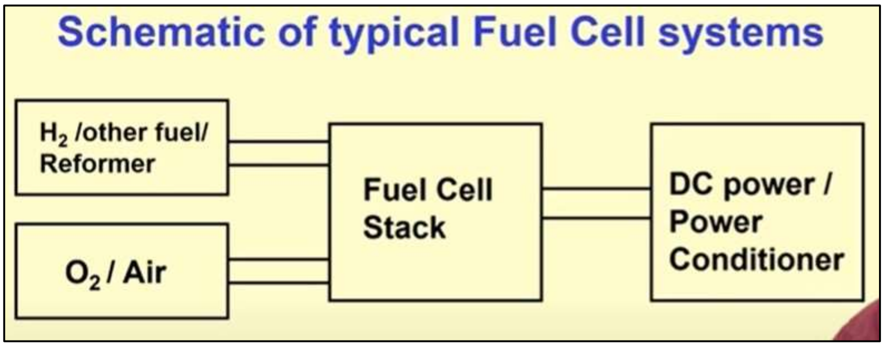
- Expensive to manufacture due the high cost of catalysts (platinum)
- Lack of infrastructure to support the distribution of hydrogen
- A lot of the currently available fuel cell technology is in the prototype stage and not yet validated.
- Hydrogen is expensive to produce and not widely available

Type of fuel cell	Temperature
PEFC / PEM *Polymer electrolyte fuel cell*	< 100 °C
AFC *Alkaline fuel cell*	100 - 250 °C
PAFC *Phosphoric acid fuel cell*	160 - 220 °C
MCFC *Molten carbonate fuel cell*	600 - 700 °C
SOFC *Solid oxide fuel cell*	~ 1000 °C





Fuel Processing for PEM Fuel Cells



Fuel Processing Module

Fuel processing can be defined as the conversion of the raw fuel into a hydrogen-containing gas that can be fed directly into the fuel cell stack. It comprises several steps:

Conditioning,

such as removal of impurities detrimental to the fuel processor or the fuel cell stack, addition of reagents for subsequent conversion steps, evaporation, heating, etc.

Conversion,

such as reforming or cracking.

Purification,

such as removal of any conversion products detrimental to the fuel cell stack.

Efficient processing of the input fuel is of key importance for the overall performance of the fuel cell power system. Most of the residential CHP systems are powered by natural gas. However, a significant number of systems are also powered by liquid petroleum gas (LPG) and kerosene in Japan and the United States.

Why 'Fuel Processing' ?

Type of fuel cell / availability of fuel

Hydrogen Vs other fuels

Infrastructure

Steam Reforming

Fuel ($C_nH_mO_p$) + Steam $\longrightarrow$ Carbon Oxides + Hydrogen

$\Delta H > 0$

Strongly endothermic
Reactor design limited by heat transfer
Reactors tend to be large and heavy
Typically catalyst required, usually Ni

Partial Oxidation

Fuel ($C_nH_mO_p$) + Air $\longrightarrow$ Carbon Oxides + Hydrogen + Nitrogen

$\Delta H < 0$

Temperature can climb over 1000 °C
May not require a catalyst

Auto Thermal Reforming

Fuel ($C_nH_mO_p$) + Air + Steam $\longrightarrow$ Carbon Oxides + Hydrogen + Nitrogen

$\Delta H < 0$

Extent of steam reforming limits the maximum temperature attained

Output of Reforming

Is it good enough?

Water Gas Shift Reaction

$$CO + H_2O \longrightarrow CO_2 + H_2$$

$\Delta H^o = -41.2 \text{ kJ mol}^{-1}$

Catalysts: Fe_3O_4, CuO/ZnO

Selective Oxidation / Preferential Oxidation

$$2CO + O_2 \longrightarrow CO_2$$

Ruthenium and Rhodium, supported on Alumina, are usually used as catalyst. Cu and ZnO on Alumina also used

Issues with Reforming

System complexity

Presence of carbon monoxide

Response time

Start up and shut down in case of automotive use

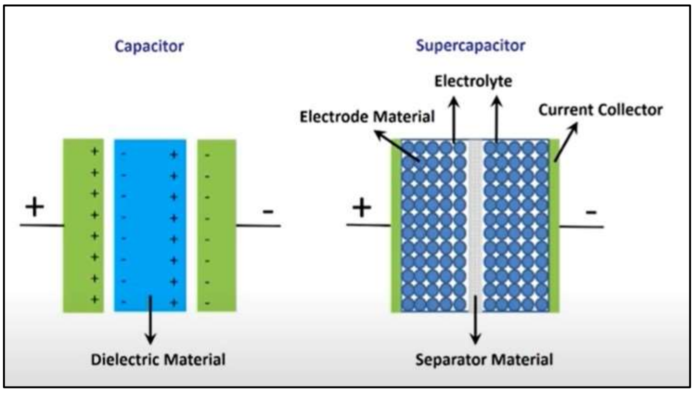
Supercapacitor

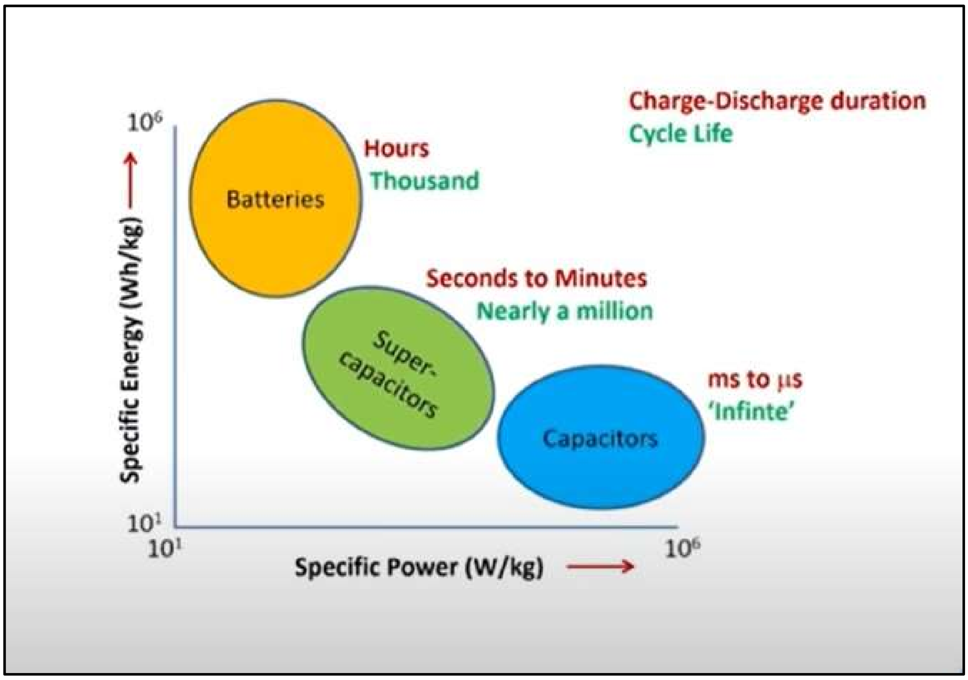
Supercapacitors (SCs) are electrochemical energy storage devices that store and release energy by reversible adsorption and desorption of ions at the interfaces between electrode materials and electrolytes.

Supercapacitor:

- High capacitance
- High energy density
- Lower voltage
- High cycle life
- Charge and discharge much faster than batteries
- Bridges the gap between capacitors and rechargeable batteries
- Regenerative breaking
- Loading and unloading activities
- Start-stop of electric vehicles

Supercapacitor:	Electrical energy, uses ions
Battery:	Chemical energy, uses ions
Capacitor:	Electrical energy, uses electrons





Materials used:

Electrode: Activated carbon, Graphene, Carbon nanotubes

Activated carbon:- Natural carbons and polymers heat treated in inert atmosphere

Graphene:- can restack

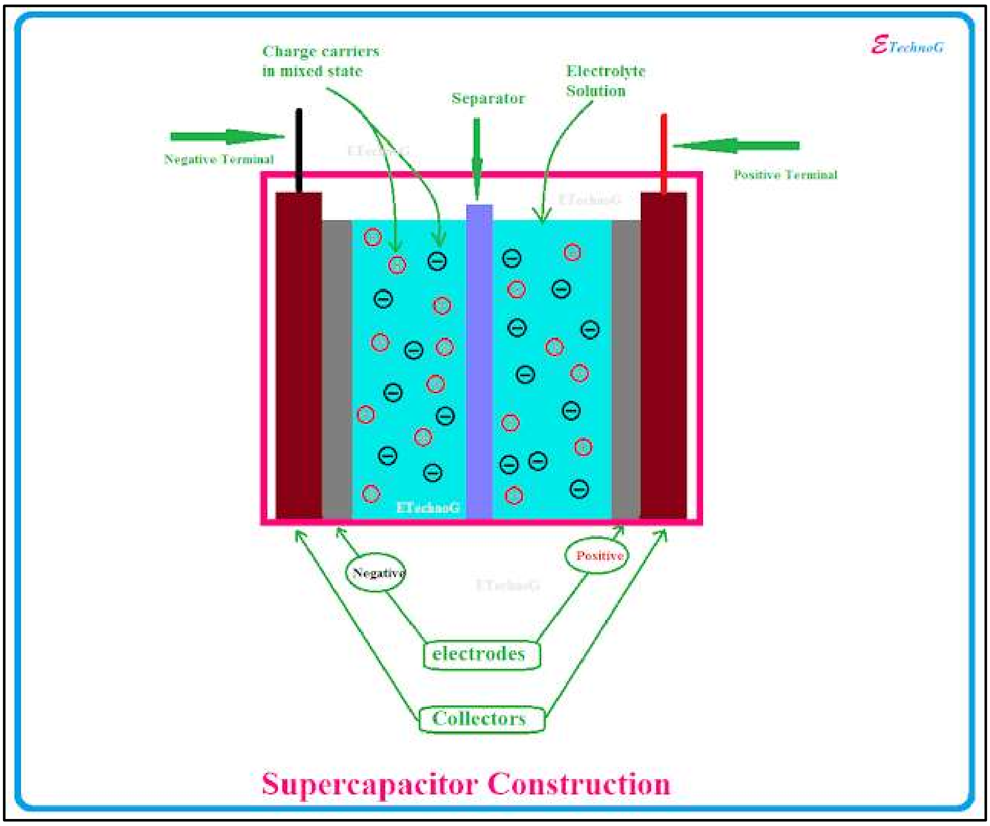
Carbon nanotubes:- cylindrical surface is used

Electrolyte:

Aqueous electrolytes:	Voltage restricted to 1.23 V
Organic electrolytes:	Lower conductivity(Propylene Carbonate)
Ionic liquids:	Organic salts with no solvents and melting point below 100 ◦C

Conclusions:

1. Supercapacitors bridge the gap between capacitors and batteries
2. High surface area carbon materials used in electrodes
3. Aqueous, organic as well as ionic liquids considered as electrolytes



Advantages of Supercapacitor

Following are the benefits or advantages of Supercapacitor:

➡It offers high energy density and high power density compare to common capacitor.

➡It offers high capacitance (From 1 mF to >10,000F) .

➡It offers fast charging ability.

➡It offers superior low temperature performance (from -40°C to 70°C).

➡It offers longer Service and long life (about 10 to 15 years compare to 5-10 years of Li-ion battery) . It offers virtually unlimited cycle life and can be cycled millions of time.

➡It offers higher reliability of performance.

➡It reduces size of the battery, its weight and consecutively cost.

➡Supercapacitors meet environmental standards. Hence they are eco-friendly.

Disadvantages of Supercapacitor

Following are the drawbacks or disadvantages of Supercapacitor:

➡They have higher self discharge rate. This is considerably high compare to battery.

➡Individual cells have low voltages. Hence series connections are required in order to achieve higher voltages.

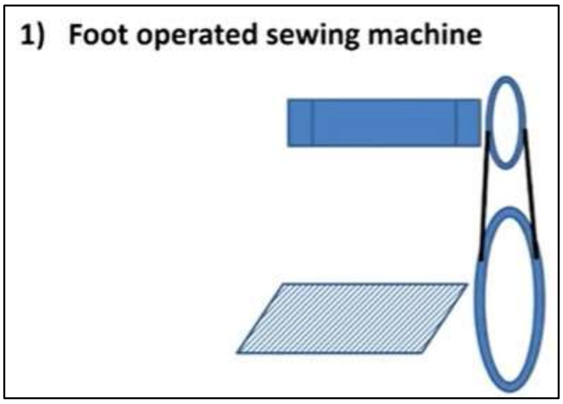
➡Amount of energy stored per unit weight is considerably lower compare to electrochemical battery. This is about 3 to 5 W.h/Kg for an ultracapacitor than 30 to 40 W.h/Kg of a battery.

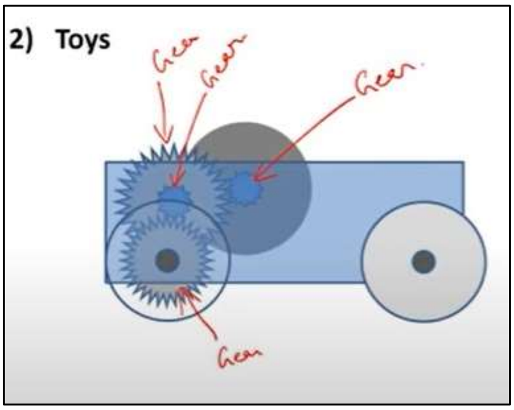
➡It offers low energy density compare to battery. This is about $(1/5)^{th}$ to $(1/10)^{th}$ the energy of the battery.

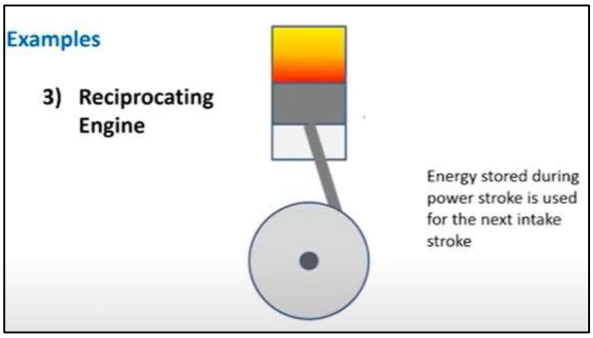
➡It can not be used in AC and higher frequency circuits.

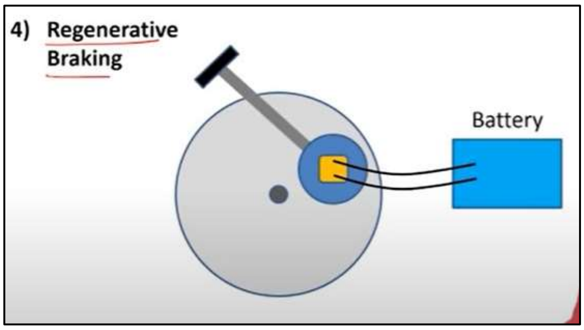
Flywheels

1. Mechanical energy storage device
2. Energy stored by increasing rpm of a rotating wheel
3. Energy extracted from the wheel, as needed which slows the wheel down
4. Smoothing of the power output of an energy source
5. Extends the ability of an energy source to operate outside of its rating by storing its energy and releasing it as needed
6. Regenerative braking

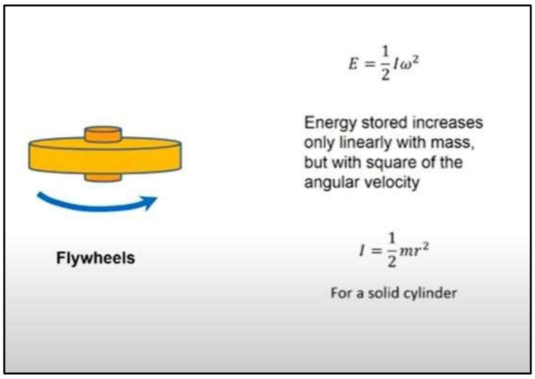


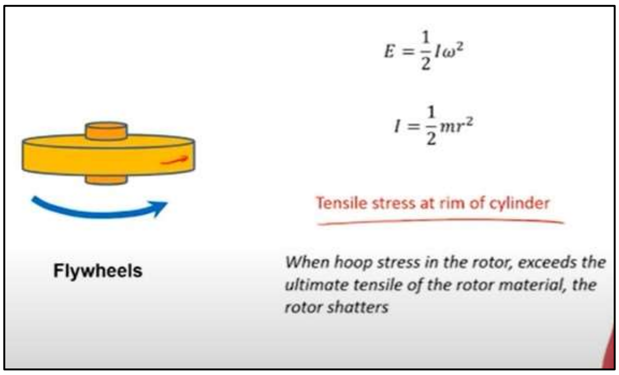


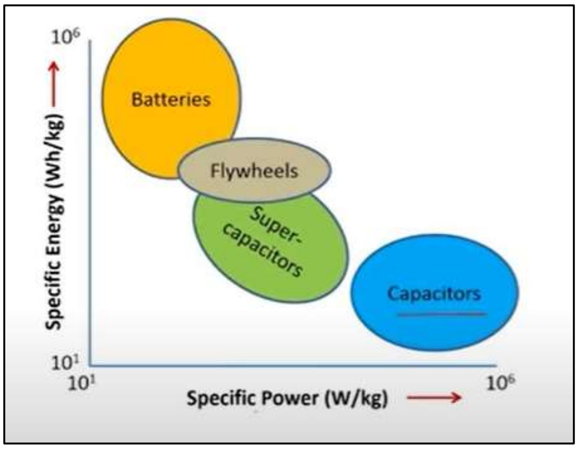


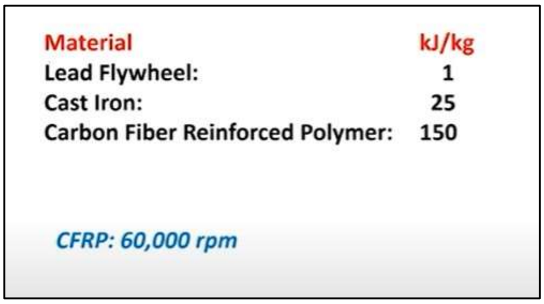


Advantages	Disadvantages









Material	kJ/kg
Lead Flywheel:	1
Cast Iron:	25
Carbon Fiber Reinforced Polymer:	150

CFRP: 60,000 rpm

Conclusions

1) Flywheels store energy using a rotating wheel
2) The energy stored increases as the square of the angular velocity and only linearly with the moment of inertia
3) The high angular velocities attained can result in the material disintegrating due to the forces involved
4) Mechanical properties of materials are therefore critical in enabling higher energy storage in flywheels

Power and energy are nearly independent	Complexity of durable and low loss bearings
Fast power response	Mechanical stress and fatigue limits
Potentially high specific energy	Material limits at around 700M/sec tip speed
High cycle and calendar life	Potentially hazardous failure modes
Relatively high round-trip efficiency	Relatively high parasitic and intrinsic losses
Short recharge time	Short discharge times

Magnetohydrodynamic Power Generation

MHD power generation is a new system of electric power generation which is said to be of high efficiency and low pollution

Magnetohydrodynamics (MHD) is the dynamics of electrically conducting fluids.

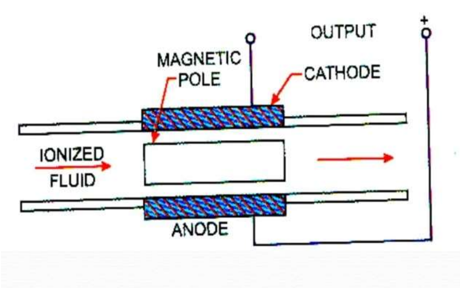
Examples of such fluids include plasmas, liquid metals, and salt water or electrolytes.

Principle of MHD power generation:

An conductor moving through a magnetic field experiences a retarding force as well as an induced electric field and current, The flow direction is right angles to the magnetic fields direction. An electromotive force (or electric voltage) is induced in the direction at right angles to both flow and field directions.

The MHD systems are broadly classified into two types:

1. Open cycle system
2. Closed cycle system
    - Seeded inert gas system
    - Liquid metal system



Advantages of MHD system:

- The conversion efficiency of a MHD system can be around 50% much higher compared to the most efficient steam plants.
- Large amount of power is generated.
- It has no moving parts, so more reliable.
- The closed cycle system produces power, free of pollution.
- It has ability to reach the full power level as soon as started.
- The size of the plant is considerably smaller than conventional fossil fuel plants.

Disadvantages of MHD system:

- The metallic vapours are poor electrical conductors.
- High velocities cannot be obtained by expansion in the system while it is much easier to achieve a high fluid velocity.
- Employing a gas and a nozzle. This is because the liquids are practically in compressible.
- The overall conversions efficiencies obtainable with liquid metal system are quite below to that of plasma system.

Applications of MHD system:

- Laser power MHD generators.
- Plasma physics applications.
- Power generation in space crafts.
- Hypersonic wind tunnel experiments.
- Defense applications.