

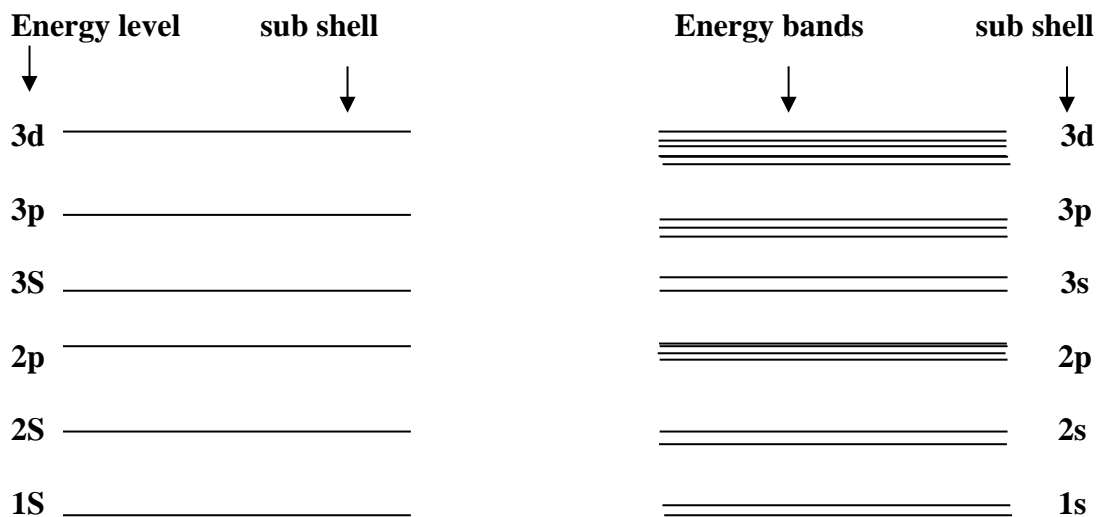
UNIT IV

SEMICONDUCTORS

Conductivity in solids:

Failure of the classical free electron theory to explain conductivity in solid made to develop Band theory of solids.

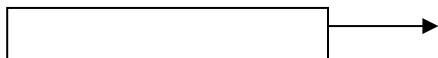
Band theory of solids:

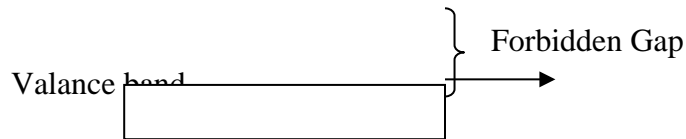


Energy level diagram for, isolated atom **Energy level diagram for crystal lattice**

All metals are exceptionally good conductors of heat and electricity. Electrical conduction arises due to the movements of electrons. The conductivities of metals are explained on the basis of band theory. It is assumed that the atoms in a metal lose their valence-shell electrons and become positive ion. The conductance of metals is due to these mobile electrons the band theory explains the positions of these mobile electrons and the mechanism of electrical conduction. For all individual atoms the electrons occupy sharp and definite energy levels, thus the energy level diagram of an atom consists of discrete lines and the energy levels carry the same designation as the corresponding sub shells. For example 3p level signifies the energy of an electron in 3p sub shell, as shown in the energy level diagram. But in a crystal lattice the electrons are influenced by several numbers of adjacent nuclei and thus energy levels splits in to closely spaced bands. The electron may now take positions in the band. The band are however not continuous, but separated by forbidden zones.

Conduction band



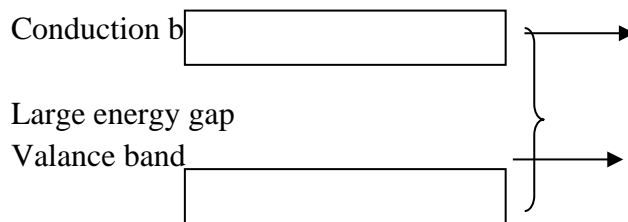


The following energy bands are important in band theory of solids. Energy bands which are occupied by the valence electrons are known as **Valence band**. It is the highest occupied band. It may be completely or partially filled with electrons but never empty. Energy bands which are occupied by the free electrons are known as **Conduction band**; this band may be completely or partially filled. The gap between the valence band and conduction band is called **forbidden energy gap**.

Insulators, semiconductors and conductors:

On the basis of the energy of the energy gap, the insulators, semiconductors and conductors are described as follows

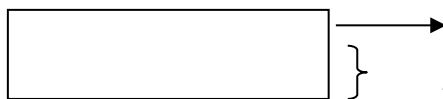
Insulators: In case of insulators the energy gap is very wide due to this fact electrons cannot jump from the valence band to the conduction band.



Note: For example, materials like glass, the valence band is completely full at 0K and the energy gap between the valence band and conduction band is of the order of 10eV .

Even in the presence of a high electric field, the electrons do not move from the valence band to the conduction band. When a very high energy is supplied, an electron may be able to jump across the forbidden gap. Increase in temperature enables some electrons to go to the conduction band. This explains why certain materials which are insulators at room temperature become conductors at high temperature.

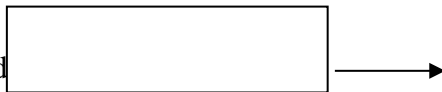
Conductors: In case of conductors, there is no forbidden energy gap and the valence band and conduction band overlap each other. The electrons from the valence band freely enter the conduction band. Due to the overlapping of the valence and conduction band, a slight potential difference across the conductors causes the free electrons to constitute an electric current. Example: Al, Cu etc.



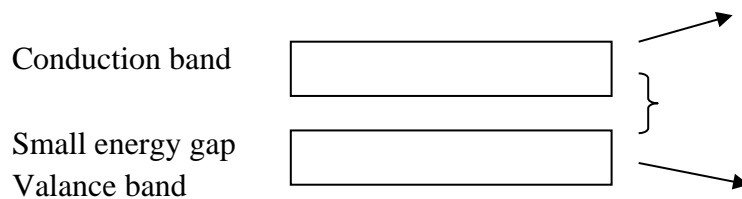
Conduction band

Over lapping

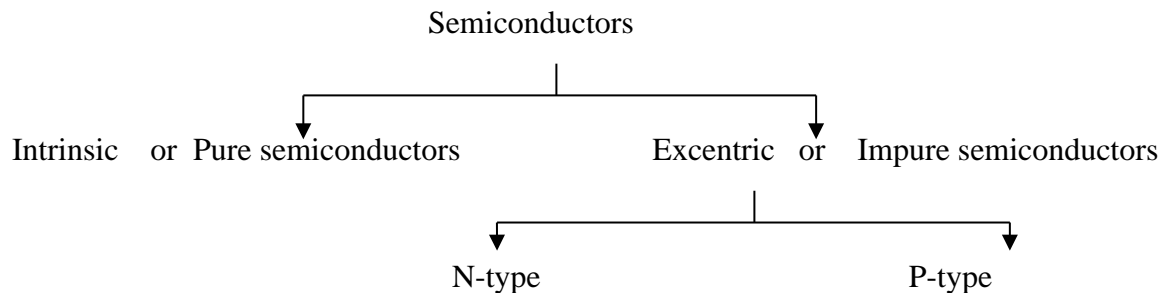
Valance band



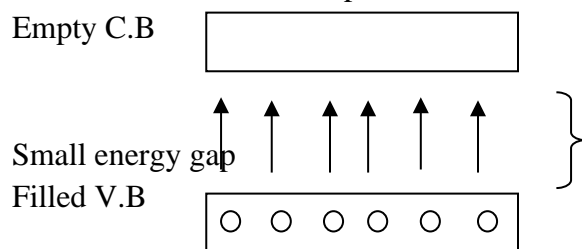
Semiconductors: Are class materials whose conductivity is in the range between that of good conductors and insulators. Narrow band gap is the characteristic feature of semiconductors, because of which a significant number of thermally excited electrons are available for conduction at room temperature.



Semiconductors may be classified as

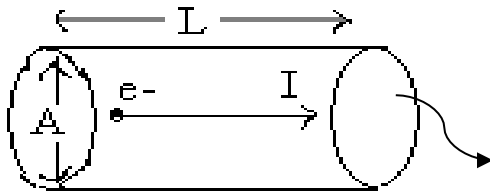


Intrinsic semiconductors: It is pure semiconductor whose conductivity is due to thermal excitation only. In these conductors, for every electron freed from the band, there will be one hole created in the crystal. The total semi conductivity of intrinsic semiconductor is due to both electrons and holes at temperatures above 0 K as shown below



Electrical conductivity of an intrinsic semiconductor:

Let us consider an intrinsic semiconductor of an area of cross section A and length L in which a current I amps is flowing.



Intrinsic semiconductor

Then the current density J is given by

$$J = I/A \text{ ----- 1}$$

And if V is the potential difference between two ends, then the electrical field E at any point inside it is given by

$$E = V/L \text{ ----- 2}$$

If R is the electrical resistance, then the electrical conductivity is given by

$$R \propto L/A$$

$$R = \rho L/A \text{ where } \rho \text{ is resistivity i.e } \rho = 1/\sigma$$

$$R = 1/\sigma \left(L/A \right)$$

$$\sigma = \frac{1}{R} \times \frac{L}{A} \text{ ----- 3}$$

$$R = \frac{L}{\sigma A}$$

Now if we consider the product σE , then from 2 & 3 we have

$$\sigma E = \frac{V}{L} \times \frac{1}{R} \times \frac{L}{A} = \frac{V}{RA}$$

$$\sigma E = I/A \text{ Since } \left(I = V/R \right) \text{ ----- 4}$$

Comparing 1 and 4

$$J = \sigma E \text{ ----- 5}$$

Let V_e be the drift velocity of electrons and V_h be the drift velocity of holes (in m/s), whose flow in the semiconductor constitutes the electric current. The volume swept by the electrons/second = AV_e if N_e is the number of electrons/unit volume, and e is the electron charge. Then and e is the electron charge then the charge flow/second = $N_e AV_e$

Since charge flow/second is the current I

$$I = N_e AV_e$$

We know that

$$J = I/A = N_e AV_e/A = N_e V_e \text{ ---- 6}$$

Electron mobility, μ_e is given by

$$\mu_e = V_e/E \text{ ----- 7}$$

Where, E is the electrical field $V_e =$ drift velocity of e^-
substituting for V_e

$$J = (N_e \mu_e) E \text{ ----- 8}$$

From eqn 5 $J = \sigma E$

$$\sigma = N_e \mu_e \text{ or } \sigma_e = N_e \mu_e$$

Now consider the conductivity due to holes

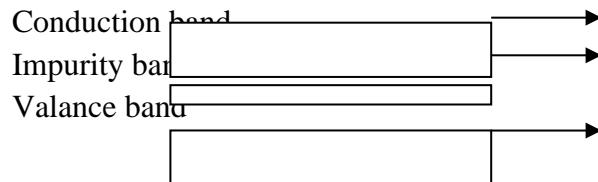
$$\sigma_h = N_h e \mu_h$$

$$\text{Total conductivity } \sigma = \sigma_e + \sigma_h$$

$$= e(N_e \mu_e + N_h \mu_h) \text{ ----- 9}$$

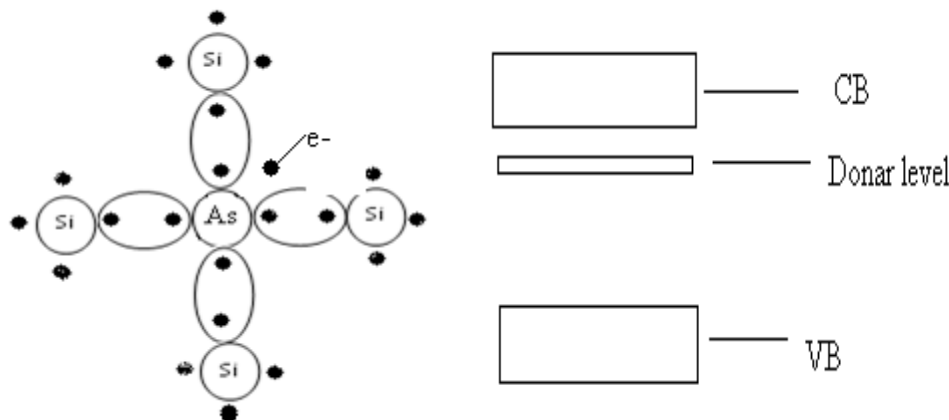
Extrinsic semiconductor:

By incorporating the appropriate doping agent into the pure semiconductor the conductivity can be increased up to 10^4 times. This type of conduction is known as extrinsic conductor. The increased conduction is due to participation of impurity elements in between valence band and conduction band thus making bridge through which electrons can jump easily from valence band to the conduction band.



N – type semiconductor : This type of semiconductor is produced by adding trace amounts of pentavalent impurity (like P, As) to extremely pure germanium or silicon. In this type of semiconductor the current is carried out by excess negatively charged electrons.

When a pentavalent like As is added to tetravalent Ge or Si crystals, four electrons of the impurity element are used in forming bands to Ge or Si, while the fifth electrons remains unused. These extra electrons can be serve to conduct electricity.



The Electrical conductivity can be given as

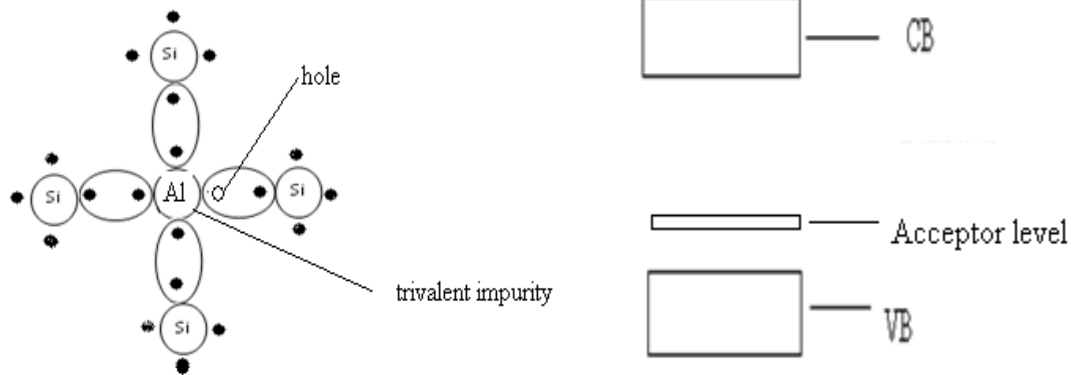
$$\sigma = n_e e \mu_e$$

n_e = no of electrons

μ_e = mobility of electrons

P – type semiconductor : These types of semiconductors are produced by adding trivalent impurity (using Al, In, B) to extremely pure germanium or silicon.

When trivalent impurity like Al added to trivalent impurity like Ge, trivalent impurity forms three covalent with the tetravalent element but unable to complete tetrahedral covalent structure because they have one electron short of the requirements. This gives rise to electron vacancies known as holes, and migration of positively charged holes constitutes electrical conductivity.



The electrical conductivity (σ) can be given as

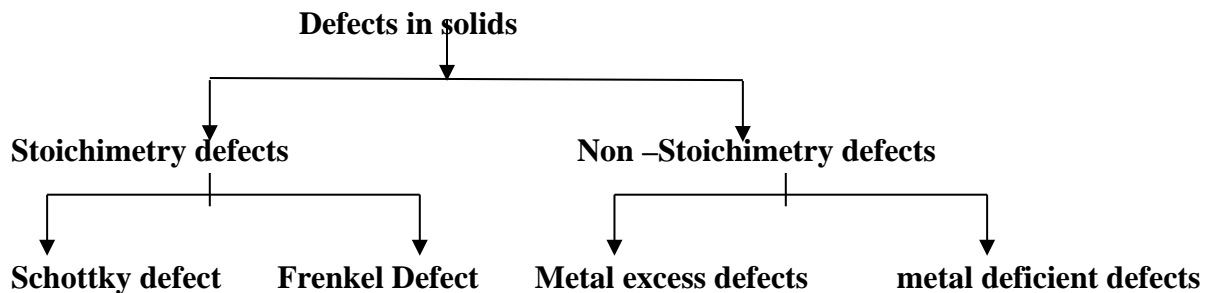
$$\sigma = n_h e \mu_h$$

n_h = number of holes

μ_h = mobility of holes

Non elemental semiconductivity:

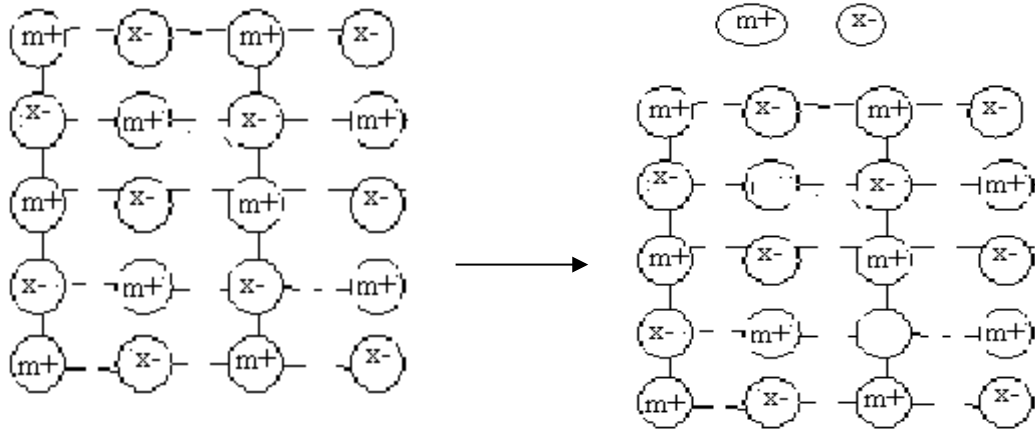
Some crystals (solids) show conductivity due to the presence of imperfection (defects) in solid. Such defects are classified as follows



Schottky defect: This type defect arises when some of the constituent atoms or ions are missing from their normal lattice sites. The lattice sites which are unoccupied are called lattice vacancies or holes. Schottky defects thus consist of a pair of holes (an anion vacancy and a cat ion

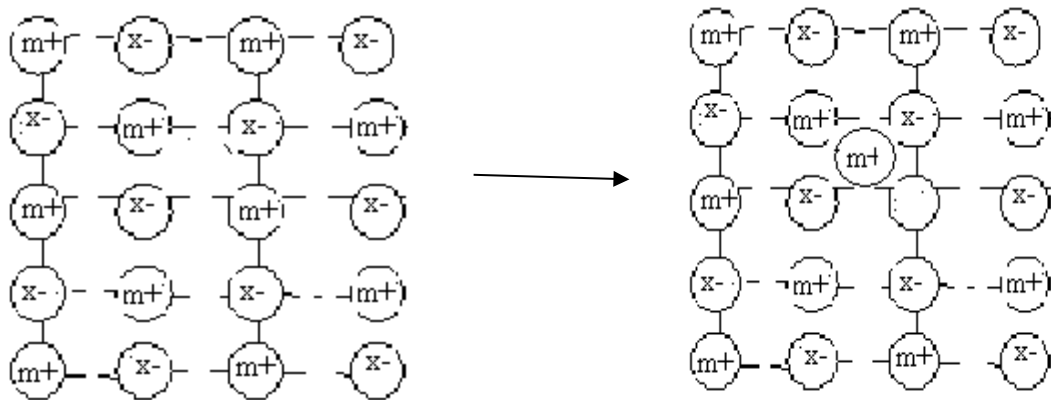
vacancy) in the crystal lattice. Since the crystal is to remain electrically neutral, equal number of cations and anions are missing, the missing ions are found to come to the crystal surface.

This type of defect is usually observed in highly ionic compounds having high coordination number and cations and anions of almost similar sizes ex: NaCl, CsI, KCl, KBr.



Frenkel Defect: This defect arises when an ion (usually cation) is missing from its own position and occupies a interstitial site between the lattice points.

This type of defect generally occurs in compounds in which the anions are much large in size than cations and consequently the coordination number is low. Ex: AgCl, AgBr, AgI.



Frenkel defect:

Occurs when an ion migrates from its regular sites to an inertial site

Schottky defect:

Occurs due to migration of equal number of anion and cation from their lattice sites to the surface

Overall density of the crystal does not change

Dielectric constant of the crystal increases

Occurs in the solids having anions much larger in size than cations

Ex: AgCl, AgBr.

Overall density of the crystal decreases.

Dielectric constant of the crystal remains same.

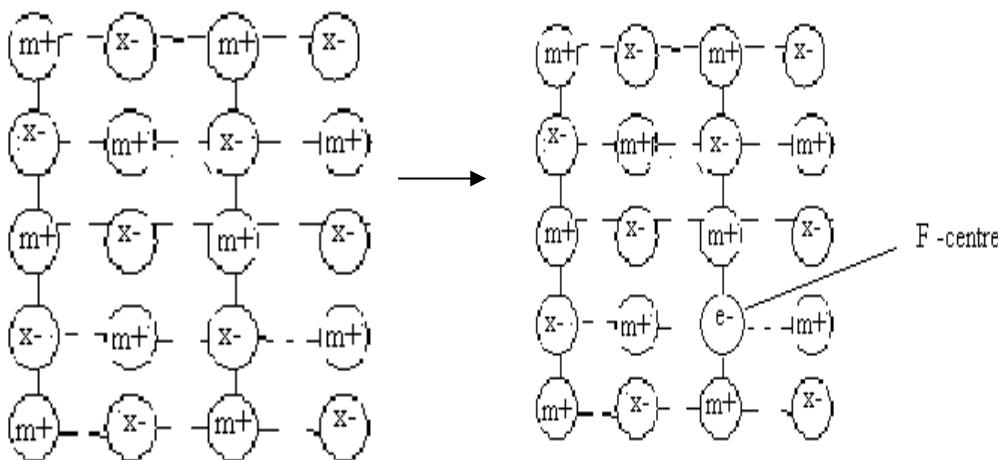
Occurs in the solids having almost similar sizes of cation and anion

Ex: NaCl, KCl.

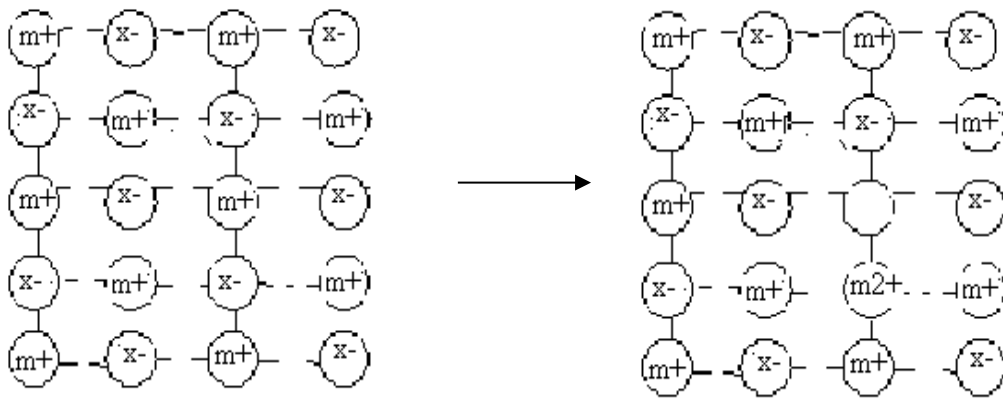
Non-stoichiometric defects:

Metal excess defects: In this case, the negative ions (anion) may be missing from their lattice sites leaving holes in which the electrons remain entrapped to maintain the electrical neutrality.

The anion sites occupied by electrons in this way are called F-centers (German, Farbe means color). These F-centers are associated with the color of the compound and more the intensity of coloration. The non stoichiometric form of LiCl is pink, KCl is violet and NaCl is yellow.



Metal deficient defects: In this case, positive ions may be missing from the lattice sites the extra negative charge then may be balanced by some adjacent metal ion having an extra positive charge.

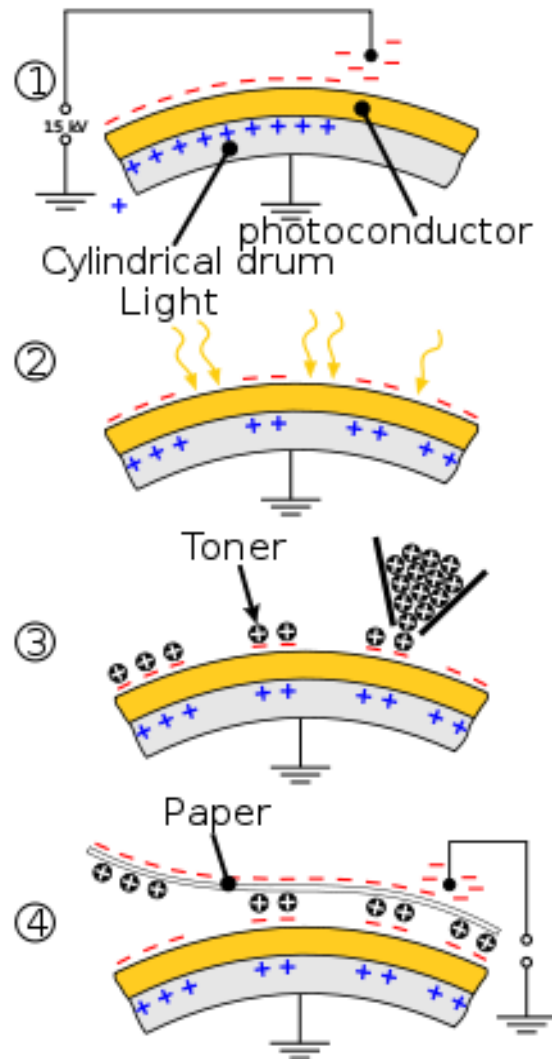


Photocopying process:

How a Photocopier works (using xerography)

Schematic overview of the xerographic photocopying process (step 1- 4)

1. **Charging:** Cylindrical drum is electro statically charged by a high voltage wire called a corona wire or a charge roller. The drum has a coating has a coating of a photoconductive.
2. Photoconductor is a semiconductor that becomes conductive when exposed to light.
3. **Exposure:** A bright lamp illuminates the original document, and the white areas of the original document reflect the light onto the surface of the photoconductive drum. The areas of the drum that are exposed to light become conductive and therefore discharge to ground. The areas of the drum not exposed to light (those areas that correspond to black portions of the original document) remain negatively charged. The result is a latent electrical image on the surface of the drum.
4. **Developing:** The toner is positively charged. When it is applied to the drum to develop the image, it is attracted and sticks to a toy balloon with a static charge.



5. **Transfer:** The resulting toner image on the surface of the drum is transferred from the drum onto a piece of paper with a higher negative charge than the drum.
6. **Fusing:** The toner is melted and bonded to the paper by heat and pressure rollers.

Super conductors:

The resistance offered by certain materials to the flow of electrical current abruptly drops to zero below a critical temperature. This phenomenon is called superconductivity.

Problems

1. What is the current density of a material with a resistivity of $12\Omega\text{m}$ and an electric field of 64V/m ?
2. If the voltage of 6V is passed through a substance with a radius of 2m and a length of 3m , what is the electric field?
3. What is the electric field of a material when the current is equal to 25A , the resistance is measured to be 78Ω , the current density equals 24A/m^2 , and the length the current flows is 100m ?
4. A material has a voltage of 150V and width of 24m . The material also has a current of 62A and travels a distance of 5m . What is the conductivity?
5. A metal originally has an electron colliding with every fifth atom and increases from a temperature of 6K to 100K . A semiconductor originally has an electron colliding with every fifth atom and increases from a temperature of 6K to 100K . What material will have a greater resistivity? Why?

Answers to Problems:

1. $E/J = \rho \rightarrow J = E/\rho = 64\text{V/m} / 12\Omega\text{m} = 5.33\text{A/m}^2$

2. $E = V/l = 6\text{V}/3\text{m} = 2\text{V/m}$

3. $E = V/l$

$V = IR \rightarrow E = IR/l = 25\text{A} \times 78\Omega / 100\text{m} = 19.5\text{V/m}$

4. $E/J = \rho$

$E = V/l$

$J = I/A \rightarrow \rho = (V/l) / (I/A) = (150\text{V}/5\text{m}) / (62\text{A} / (24\text{m} \times 5\text{m})) = 58\Omega\text{m}$

$\rho = 1/\sigma \rightarrow 1/\rho = \sigma = 1/58\Omega\text{m}$

5. The material that has the greatest resistivity is the metal because as temperature increases metals are more likely to increase in resistivity and semiconductors usually decrease in resistivity as temperature increase.

RENEWABLE ENERGY SOURCES

Every day we rely on energy to provide us with electricity, hot water, and fuel for our cars. Most of this energy comes from fossil fuels, such as coal, oil, and natural gas. These are nonrenewable energy sources, which mean that if we use them all up, we can never get more during our lifetime. Fossil fuels also contribute greatly to global climate change by releasing carbon dioxide into the air when they are burned.

Because fossil fuels can run out and are bad for the environment, it is important that we start switching to other energy sources, like renewable energy sources. These are energy sources that are constantly being replenished, such as sunlight, wind, and water. This means that we can use them as much as we want, and we do not have to worry about them running out. Additionally, renewable energy sources are usually much more environmentally friendly than fossil fuels. Overall, they release very few chemicals, like carbon dioxide, that can harm the environment. Currently, less than 10% of all the energy we use comes from renewable sources. So you might be wondering, if renewable energy sources do not harm the environment and will not run out, then why are we not using them everywhere and all the time? It is because many of them are currently expensive to harness, are inefficient, or have other disadvantages. For example, using energy from the wind might be great in an area that is really windy all year round, but it wouldn't work so well in an area with very little wind.

Types of Energy sources

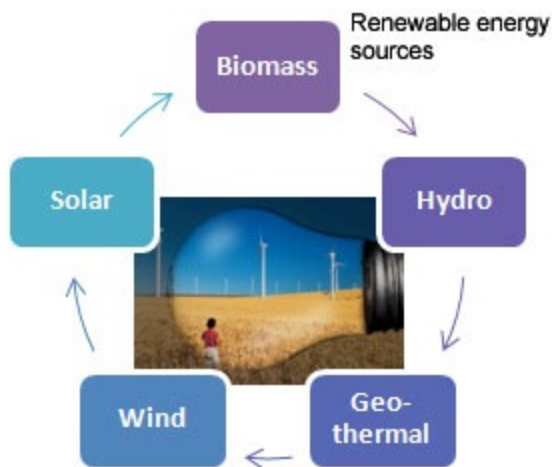
There are two *types of energy sources* on which energy production of the world moves around. These are *Non Renewable energy* and *Renewable energy* sources. Non renewable energy source is still the major source of energy production worldwide. Whereas, Renewable energy is playing small role in production of energy. Let's discuss each type of energy sources in details individually.

Renewable energy sources

Energy from a source that is not depleted when used, such as wind power and solar power.

Any energy resource that is naturally regenerated over a short time scale and derived directly from the sun (such as thermal, photochemical, and photoelectric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy). Renewable energy does not include energy resources derived from fossil fuels, waste product from fossil sources, or waste product from inorganic sources.

Ex. Solar energy, wind energy, biomass, hydroelectric energy



Non Renewable energy source

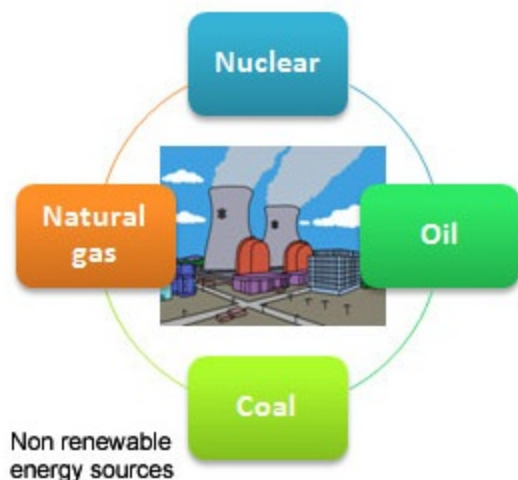
Energy exists freely in nature. Some of them exist infinitely (never run out, called **RENEWABLE**), the rest have finite amounts (they took millions of years to form, and will run out one day, called **NON-RENEWABLE**).

Non-renewable energy is energy from fossil fuels (coal, crude oil, natural gas) and uranium. Fossil fuels are mainly made up of Carbon. It is believed that fossil fuels were formed over 300 million years ago, when the earth was a lot different in its landscape.

Ex. Coal, Oil, Gas

A resource of economic value that cannot be readily replaced by natural means on a level equal to its consumption. Most fossil fuels, such as oil, natural gas and coal are considered nonrenewable resources in that their use is not sustainable because their formation takes billions of years.

Nonrenewable resource fuels are still the primary source of all the power generated in the world due to their affordability and high energy content. Besides the environmental impact of burning fossil fuels, the economic impact of nonrenewable resources can also be very damaging. As nonrenewable resources become more scarce, the cost to obtain them will continue to rise. Eventually, the price will hit a point that end users cannot afford, forcing a move toward alternative energy sources



Biofuel

A type of energy derived from renewable plant and animal materials. Examples of biofuels include ethanol, biodiesel (vegetable oils and liquid animal fats), green diesel (derived from algae and other plant sources) and biogas (methane derived from animal manure and other digested organic material). Biofuels are most useful in liquid or gas form because they are easier to transport and deliver.

Bioethanol: Bioethanol is ethanol (alcohol) that is derived exclusively from the fermentation of plant starches. Though ethanol can be extracted as a by-product from a chemical reaction with ethylene and other petroleum products, these sources are not considered renewable.

Chemically, bioethanol is identical to ethanol and can be represented by either the formula C_2H_6O or C_2H_5OH .

Also Known As: ethanol

Examples: Bioethanol can be fermented from sugar cane, grains and agricultural waste.

BIODIESEL DEFINITION AND BENEFITS : Biodiesel is a non-petroleum based diesel fuel which consists of the mono alkyl esters of long chain fatty acids derived from renewable lipid sources. Biodiesel is typically produced through the reaction of a vegetable oil or animal fat with methanol in the presence of a catalyst to yield glycerin and biodiesel (chemically called methyl esters). Biodiesel is an alternative fuel which can be used in neat form, or blended with petroleum diesel for use in compression ignition (diesel) engines. Its physical and chemical properties as it relates to operation of diesel engines are similar to petroleum based diesel fuel.

1) Biodiesel runs in any conventional diesel engine. No engine modifications are necessary to use biodiesel.

2) Biodiesel dramatically reduces harmful emissions that cause environmental problems such as global warming, acid rain and smog. Biodiesel reduces CO_2 emissions by over 78% compared to petroleum diesel. Furthermore, the plants used to make biodiesel feedstock absorb more CO_2 as

they grow than the biodiesel produces when it is burned greatly reduced by the cleaner emissions of biodiesel.

3) biodiesel emissions are 90% less toxic than petro-diesel and will reduce incidents of health hazards such as asthma, emphysema and lung cancer.

4) Biodiesel is a renewable fuel source. Unlike fossil fuels, biodiesel is made from vegetable oilseed crops

5) Biodiesel is rapidly biodegradable and non-toxic.

6) Biodiesel has superior lubrication quality than that of diesel fuel. It increases engine life and can be used to replace sulfur, the acid-rain-causing lubricating agent in petroleum diesel.

Biodiesel production is the process of producing the biofuel, biodiesel, through the chemical reactions transesterification and esterification. This involves vegetable or animal fats and oils being reacted with short-chain alcohols (typically methanol or ethanol).

The step by step

instructions for making the biofuel Measurements don't need to be very accurate. When dealing with the potassium hydroxide it is advised to wear protective gloves and protective eye wear if available. Make sure participants are aware of the hazards of working with the sodium hydroxide.

1. Pass around the unfiltered cooking oil to each group. Each group should measure out 500ml of the oil in a measuring jug.

2. The oil should be passed through a pair of nylon tights to filter it

3. Measure 100ml of methanol in a measuring jug

4. Measure 4g of Potassium Hydroxide (KOH) on the scales

NOTE: Wear protective gloves and eye wear if available. Potassium hydroxide can be a dangerous chemical and should not be in contact with skin

5. Add the KOH into the meth and keep stirring until it all dissolves (Can take about 5-8 minutes)

6. Heat the oil in the saucepan to about 60°C

7. Once the oil has reached the right temperature turn off the heat and add the solution of methanol and KOH

8. Keep stirring the new solution for about 10 minutes

9. The new mixture will change colour quite a lot. It will go from a yellow oil colour to a dark red/brown.

10. Let the solution settle for 10 minutes. 2 layers should develop, a lighter colour fluid on top and a darker fluid on the bottom (To see this happen it is best to transfer it back to a clear measuring jug)

Finish with a few extra notes about bio diesel-The exact amount of KOH required to make bio diesel should be calculated by doing a titration however for the purpose of a workshop the ratios

above will produce suitable results. The amount of methanol used is generally 20-22% of the amount of oil used. -Once the two layers have developed the process is complete. The lighter fluid on top is the biodiesel whilst the darker fluid on the bottom is the glycerol left over. By swirling the jug with the mixture you should notice that the biodiesel is a lot thinner and moves about quicker than the heavier glycerol. -The biodiesel can be left to settle for a few more days to ensure all of the glycerol and biodiesel has separated. -Once the bio diesel has been separate from the glycerol it can be put into any diesel operated vehicle like normal diesel oil. -If you were making a significant amount of bio diesel at home you could drain the glycerol from the bottom of the processing tank. When the colour changes from dark to light you know you have removed all the glycerol from the remaining mixture. -More often than not the bio diesel needs to be 'washed'. The washing process removes any remaining impurities or chemicals that haven't reacted properly. A quick way to measure the quality of the bio diesel is to have a glass jar filled with half bio diesel and half water. The jar should be shaken quickly and then let to settle for 5 minutes. Between the layers of water and oil there should be a middle layer called emulsion. The smaller this layer the easier the wash process will be. -Mist Wash: Adding water to the bio diesel from the top using a fine misting head. Water droplets will form and fall through the bio diesel to the bottom of the tank collecting any impurities on the way. Draining off the water and repeating will clean the bio diesel affectively. Once the drained off water is clear the bio diesel is ready to use.

How to make Biofuels ?

Biofuel is considered to be the most pure and the easiest available fuels on the planet. Also known as agrofuel, they are classified into gas, liquid and solid form derived from biomass. Most of the people would be very happy to know that most of the forms of biofuels can be easily manufactured even at in one's kitchen garden. One of the key features of biofuels is that they are better than other forms of fuels like petrol or diesel that is manufactured by most of the big oil manufacturing companies. Most of the diesel engines would work more efficiently and even last longer with the use of these home made biofuels. These fuels are also very clean and environment friendly. These biofuels can be a lot more economic if used in the kitchen for cooking purpose. These fuels also encourage the recycling process as most of them are manufactured from waste products.

There are various forms of biofuels and most of them are made through a detailed process having various stages. Most of the animal fats, vegetables and oils contain glycerin and are thus called triglycerides. In the process of manufacturing the biofuels, all the fats and oils are turned into esters, separating the glycerin. At the end of the process, all the glycerin sinks down at the bottom and all the biofuel rests at the top. The process through which the glycerin is separated from the biodiesel is known as transesterification. This process also uses lye as a catalyst in the whole process. Some of the chemicals which are used in the manufacturing of biofuels are ethanol or methanol which brings into use methyl esters. Methanol is derived from fossil fuels while ethanol is derived from plants. One of the advantages of using ethanol is that they can be distilled even at the home without any problem.

The process of manufacturing biofuel can be classified in the following stages. These stages are:

Filtering: In this process, waste vegetable oil is filtered to remove all the food particles. This process generally involves warming up the liquid a little. After warming up the liquid, it can be filtered with the use of coffee filter.

Removing of water: All the water contained in the residual gangue has to be removed which will make the reaction faster. The water can be easily removed by making the liquid boil at 100 degree C for sometime.

Titration: This process is carried out to determine the amount of lye that would be required. This process is the most crucial and the most important stage of biofuel manufacturing.

Preparation of sodium methoxide: In this process, methanol is mixed with sodium hydroxide to produce sodium methoxide. In most of the cases, the quantity of methanol used is generally 20 percent of waste vegetable oil.

Heating and mixing: The residue is heated in between 120 to 130 degree F after which it is mixed well. It should be remembered that process should be done carefully avoiding splashing of the liquid.

Settling and separation: After mixing the liquid, it has to be allowed to cool down. After the cooling process, the biofuel will be found floating at the top while the heavier glycerin would be found at the bottom. The glycerin can be easily separated by allowing it to drain out from the bottom. The person is left over with pure biofuel which can be used for various purposes.

Solar energy

Solar energy, radiant light and heat from the sun, is harnessed using a range of ever-evolving technologies such as solar heating, solar photovoltaics, solar thermal electricity, solar architecture and artificial photosynthesis.

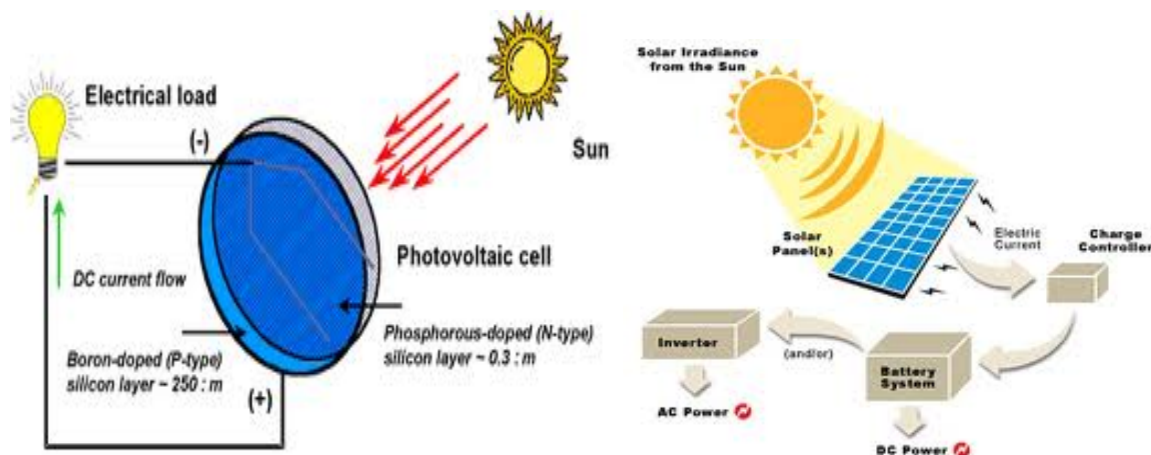
Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

Solar power is the conversion of sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP). Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Commercial concentrated solar power plants were first developed in the 1980s. Photovoltaics convert light into electric current using the photoelectric effect.^[36] Photovoltaics are an important and relatively inexpensive source of electrical energy where grid power is inconvenient, unreasonably expensive to connect, or simply unavailable. However, as the cost of solar electricity is falling, solar power is also increasingly being used even in grid-connected situations as a way to feed low-carbon energy into the grid.

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared".^[34]

Photovoltaic Cells: Converting Photons to Electrons

The solar cells that you see on calculators and [satellites](#) are also called photovoltaic (PV) cells, which as the name implies (photo meaning "light" and voltaic meaning "[electricity](#)"), convert sunlight directly into electricity. A module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can then be grouped into larger solar arrays, like the one operating at Nellis Air Force Base in Nevada.



Photovoltaic cells are made of special materials called semiconductors such as silicon, which is currently used most commonly. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely.

PV cells also all have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use, say, to power a calculator. This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce.

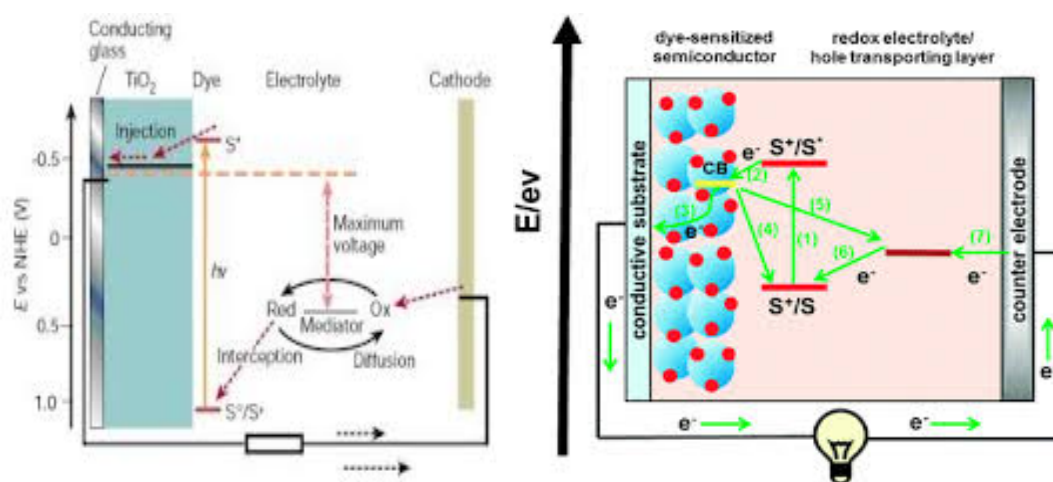
That's the basic process, but there's really much more to it. On the next page, let's take a deeper look into one example of a PV cell: the single-crystal silicon cell.

Dye sensitized solar cells

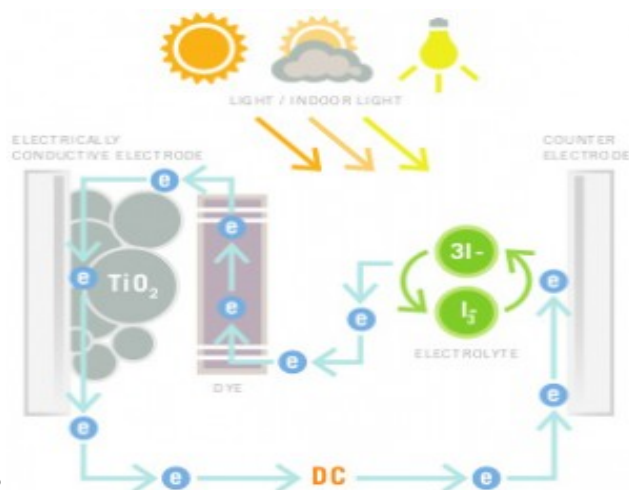
Dye-sensitized solar cells have gained widespread attention in recent years because of their low production costs, ease of fabrication and tunable optical properties, such as colour and transparency.

Dye Sensitized solar cells (DSSC), also sometimes referred to as dye sensitised cells (DSC), are a third generation photovoltaic (solar) cell that converts any visible light into electrical energy.

This new class of advanced solar cell can be likened to artificial photosynthesis due to the way in which it mimics nature's absorption of light energy.



DSSC is a disruptive technology that can be used to produce electricity in a wide range of light conditions, indoors and outdoors, enabling the user to convert both artificial and natural light into energy to power a broad range of electronic devices.



How does DSSC work?

1. The dye is the photoactive material of DSSC, and can produce electricity once it is sensitized by light
2. The dye catches photons of incoming light (sunlight and ambient artificial light) and uses their energy to excite electrons, behaving like chlorophyll in photosynthesis
3. The dye injects this excited electron into the Titanium Dioxide (a white pigment commonly found in white paint)
4. The electron is conducted away by nanocrystalline titanium dioxide (a nano-scale crystallized form of the titanium dioxide).
5. A chemical electrolyte in the cell then closes the circuit so that the electrons are returned back to the dye
6. It is the movement of these electrons that creates energy which can be harvested into a rechargeable battery, super capacitor or another electrical device.

Biomass

Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-derived materials which are specifically called lignocellulosic biomass.^[37] As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into: *thermal*, *chemical*, and *biochemical* methods.

Wood remains the largest biomass energy source today; examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. In the second sense, biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including biofuels. Industrial biomass can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo,^[39] and a variety of tree species, ranging from eucalyptus to oil palm (palm oil).

Plant energy is produced by crops specifically grown for use as fuel that offer high biomass output per hectare with low input energy. Some examples of these plants are wheat, which typically yield 7.5–8 tonnes of grain per hectare, and straw, which typically yield 3.5–5 tonnes per hectare in the UK.^[40] The grain can be used for liquid transportation fuels while the straw can be burned to produce heat or electricity. Plant biomass can also be degraded from cellulose to glucose through a series of chemical treatments, and the resulting sugar can then be used as a first generation biofuel.

Biomass can be converted to other usable forms of energy like methane gas or transportation fuels like ethanol and biodiesel. Rotting garbage, and agricultural and human waste, all release methane gas – also called "landfill gas" or "biogas". Crops, such as corn and sugar cane, can be fermented to produce the transportation fuel, ethanol. Biodiesel, another transportation fuel, can be produced from left-over food products like vegetable oils and animal fats. Also, biomass to liquids (BTLs) and cellulosic ethanol are still under research. There is a great deal of research involving algal, or algae-derived, biomass due to the fact that it's a non-food resource and can be produced at rates 5 to 10 times those of other types of land-based agriculture, such as corn and soy. Once harvested, it can be fermented to produce biofuels such as ethanol, butanol, and methane, as well as biodiesel and hydrogen.

The biomass used for electricity generation varies by region. Forest by-products, such as wood residues, are common in the United States. Agricultural waste is common in Mauritius (sugar cane residue) and Southeast Asia (rice husks). Animal husbandry residues, such as poultry litter, are common in the UK.



Biomass is biological material derived from living, or recently living organisms. In the context of biomass for energy this is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material.

Chemical composition Biomass is carbon based and is composed of a mixture of organic molecules containing hydrogen, usually including atoms of oxygen, often nitrogen and also small quantities of other atoms, including alkali, alkaline earth and heavy metals. These metals

are often found in functional molecules such as the porphyrins which include chlorophyll which contains magnesium.

Plant material

The carbon used to construct biomass is absorbed from the atmosphere as carbon dioxide (CO_2) by plant life, using energy from the sun.

Plants may subsequently be eaten by animals and thus converted into animal biomass. However the primary absorption is performed by plants.

If plant material is not eaten it is generally either broken down by micro-organisms or burned:

- If broken down it releases the carbon back to the atmosphere, mainly as either carbon dioxide (CO_2) or methane (CH_4), depending upon the conditions and processes involved.
- If burned the carbon is returned to the atmosphere as CO_2 .

These processes have happened for as long as there have been plants on Earth and is part of what is known as the carbon cycle.

Fossil fuels

Fossil fuels such as coal, oil and gas are also derived from biological material, however material that absorbed CO_2 from the atmosphere many millions of years ago.

As fuels they offer high energy density, but making use of that energy involves burning the fuel, with the oxidation of the carbon to carbon dioxide and the hydrogen to water (vapour). Unless they are captured and stored, these combustion products are usually released to the atmosphere, returning carbon sequestered millions of years ago and thus contributing to increased atmospheric concentrations.

The difference between biomass and fossil fuels

The vital difference between biomass and fossil fuels is one of time scale.

Biomass takes carbon out of the atmosphere while it is growing, and returns it as it is burned. If it is managed on a sustainable basis, biomass is harvested as part of a constantly replenished crop. This is either during woodland or arboricultural management or coppicing or as part of a continuous programme of replanting with the new growth taking up CO_2 from the atmosphere at the same time as it is released by combustion of the previous harvest.

This maintains a closed carbon cycle with no net increase in atmospheric CO_2 levels.

Categories of biomass materials

Within this definition, biomass for energy can include a wide range of materials.

The realities of the economics mean that high value material for which there is an alternative market, such as good quality, large timber, are very unlikely to become available for energy applications. However there are huge resources of residues, co-products and waste that exist in the UK which could potentially become available, in quantity, at relatively low cost, or even negative cost where there is currently a requirement to pay for disposal.

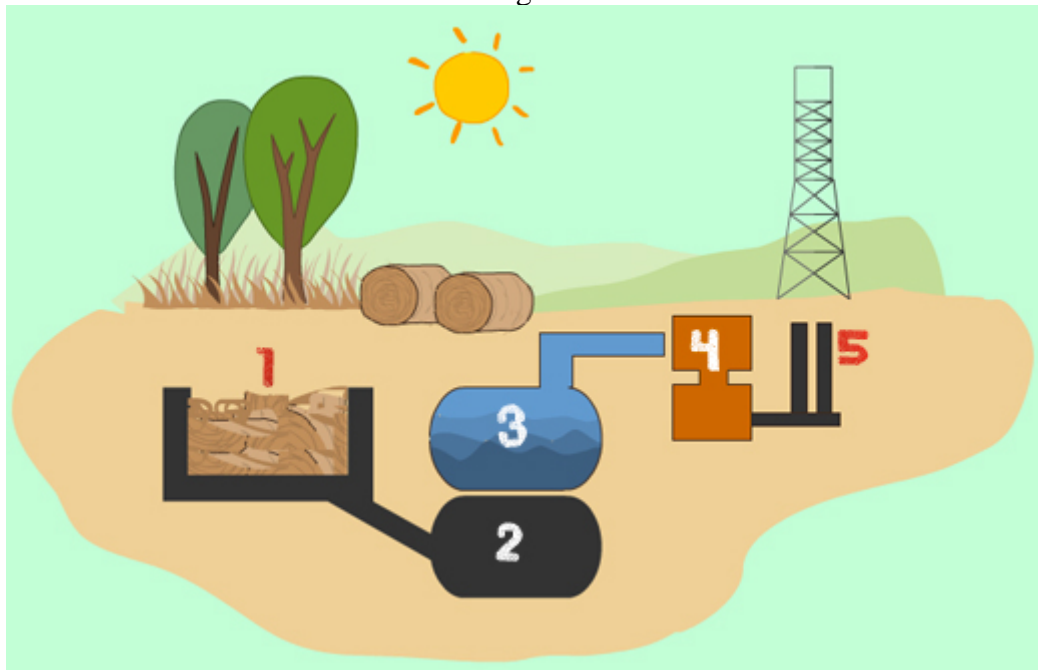
There are five basic categories of material:

- **Virgin wood**, from forestry, arboricultural activities or from wood processing
- **Energy crops**: high yield crops grown specifically for energy applications
- **Agricultural residues**: residues from agriculture harvesting or processing
- **Food waste**, from food and drink manufacture, preparation and processing, and post-consumer waste
- **Industrial waste and co-products** from manufacturing and industrial processes.

How is biomass converted into energy?

Burning:

This is a very common way of converting organic matter into energy. Burning stuff like wood, waste and other plant matter releases stored chemical energy in the form of heat, which can be used to turn shafts to produce electricity. Let's see this simple illustration of how biomass is used to generate electricity.



1. Energy from the sun is transferred and stored in plants. When the plants are cut or die, wood chips, straw and other plant matter is delivered to the bunker

2. This is burned to heat water in a boiler to release heat energy (steam).
3. The energy/power from the steam is directed to turbines with pipes
4. The steam turns a number of blades in the turbine and generators, which are made of coils and magnets.
5. The charged magnetic fields produce electricity, which is sent to homes by cables.

Other ways in which organic matter can be converted into energy include:

Decomposition:

Things that can rot, like garbage, human and animal waste, dead animals and the like can be left to rot, releasing a gas called biogas (also known as methane gas or landfill gas). Methane can be captured by a machine called Microturbine and converted into electricity. Sometimes, animal waste (poop) can also be converted into methane by a machine called 'Anaerobic Digester'

Fermentation:

Ethanol can be produced from crops with lots of sugars, like corn and sugarcane. The process used to produce ethanol is called gasification.