UNIT-IV: ENERGY SOURCES
Renewable and non-renewable energy sources

There are two major categories of energy: renewable and non-renewable.

Non-renewable energy resources are available in limited supplies, usually because they take a long time to replenish. The advantage of these non-renewable resources is that power plants that use them are able to produce more power on demand. The non-renewable energy resources are:

- Coal
- Nuclear
- Oil
- Natural gas

Renewable resources, on the other hand, replenish themselves. The five major renewable energy resources are:

- Solar
- Wind
- Water, also called hydro
- Biomass, or organic material from plants and animals
- Geothermal, which is naturally occurring heat from the earth

While renewable energy resources have the advantage of unlimited supply over the long haul, they are limited in their availability at any given moment.

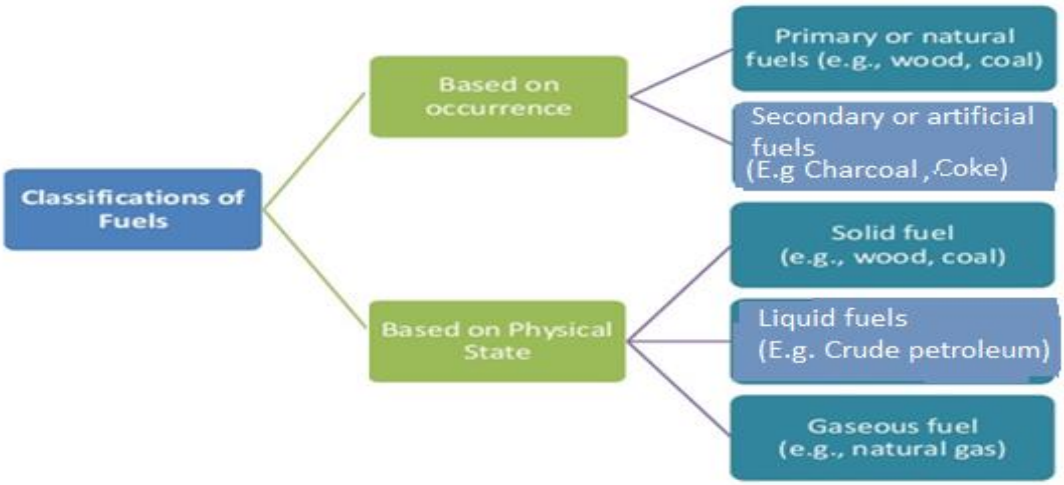
For example, the sun rises each day, but its ability to generate power is limited when its cloudy**.**

Chemical Fuels:

A chemical fuel is defined as any combustible substance used to produce heat by combustion. A chemical process which is accompanied by evolution of heat, when a chemical fuel is subjected to burning in the presence of air or oxygen, is called as combustion.

$$\text{Fuel} + \text{Oxygen} \xrightarrow{\text{combustion}} \text{Combustion products} + \text{Heat}$$

Classification of fuels:



Ignition temperature: It is defined as "the minimum temperature to which the fuel must be pre-heated so that it starts burning smoothly".

Calorific value: It is defined as "the total quantity of heat liberated, when a unit mass or volume of a fuel is burnt completely" in air or oxygen.

Types of calorific value

1. **Higher calorific value or Gross calorific value:**
   It is defined as the total amount of heat liberated; when unit mass or unit volume of the fuel has been burnt completely and the products of combustion are cooled down to room temperature. Measured heat includes latent heat of water vapour produced.

2. **Lower calorific value or Net calorific value:**
   It is defined as "the net heat produced, when unit mass or unit volume of the fuel is burnt completely and the combustion products are allowed to escape.
   Net calorific value = Gross calorific value– Latent heat of water vapour formed
   LCV or NCV = HCV – Latent heat of water vapour formed
   LCV = HCV – $\frac{9H}{100}$ **x 587 cal/g** **(Latent heat of steam is 587 cal/g.)**
   Where, H is the percentage of hydrogen.

Units of calorific value:

The calorific value of a solid or liquid fuel is generally expressed in **Calorie/gram** (cal/g) **or Kilocalorie/kg** (kcal /kg) **or British thermal unit /lb** (B.Th.U /lb).
In the case of gaseous fuels units used are , **(kcal /m^3)** or**(B.Th.U / ft^3)**.

Characteristics of good fuel:

A good fuel should satisfy the following requirements:

1. It should have a high calorific value.
2. An ideal fuel should have moderate ignition temperature.
3. Its moisture content should be low.
4. Low volatile matter content.

5. It should not produce harmful products like CO_2, SO_2, H_2S and other poisonous gases on combustion since they pollute the atmosphere.
6. A fuel should have low content of non-combustible matter.
7. It should be economical and easily available.
8. In case of solid fuel, the size should be uniform.

Solid fuels:

Coal: It is highly carbonaceous matter and is regarded as a fossil fuel produced from large accumulation of vegetable waste and alteration of vegetable matter like plants etc. under certain favourable conditions by the action of heat and pressure over millions of years. Coal is mainly composed of carbon, oxygen, hydrogen and nitrogen.

Ranking of coal: There are four major types (or "ranks") of coal. Rank refers to steps in a slow, natural process called "coalification," during which buried plant matter changes into an ever denser, drier, more carbon-rich, and harder material. The increase in coal rank is accompanied by increases in the amount of fixed carbon and by decreases in the amount of moisture and other volatile material in the coal. In general, the calorific (heat) value of coal increases with rank from lignite through bituminous coal. The four ranks are:

- **Anthracite**: The highest rank of coal. It is a hard, brittle, and black lustrous coal, often referred to as hard coal, containing a high percentage of fixed carbon and a low percentage of volatile matter.
- **Bituminous**: Bituminous coal is a middle rank coal between subbituminous and anthracite. Bituminous coal usually has a high heating (Btu) value and is used in electricity generation and steel making in the United States. Bituminous coal is blocky and appears shiny and smooth when you first see it, but look closer and you might see it has thin, alternating, shiny and dull layers.
- **Subbituminous**: Subbituminous coal is black in color and is mainly dull (not shiny). Subbituminous coal has low-to-moderate heating values and is mainly used in electricity generation.
- **Lignite**: Lignite coal, aka brown coal, is the lowest grade coal with the least concentration of carbon. Lignite has a low heating value and a high moisture content and is mainly used in electricity generation.

The precursor to coal is peat. Peat is a soft, organic material consisting of partly decayed plant and mineral matter. When peat is placed under high pressure and heat, it undergoes physical and chemical changes (coalification) to become coal.

COAL RANKS

Plant material --> Peat --> Lignite --> Subbituminous --> Bituminous –>Semibituminous > Anthracite

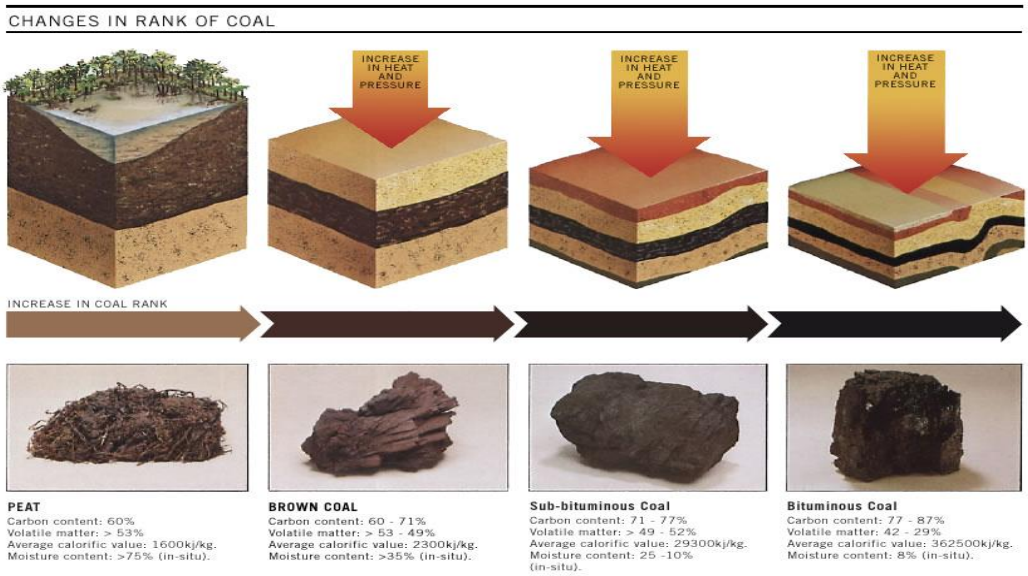
Coal is classified or Ranked based on the carbon content. The following is the sequence of conversion.

Peat → Lignite → Sub Bituminous → Bituminous → Anthracite

← Moisture content, H, O, S, N, Volatile matter

Carbon content, calorific value, hardness →

COAL RANK	CARBON CONTENT (%)	VOLATILE MATTER (%)	CALORIFIC VALUE (kcal /kG)	MOISTURE CONTENT (%)
PEAT	60	>53	5400	80-90
Lignite	60 – 71	53 – 49	5500-5700	20-60
SUB-BITUMINOUS COAL	75-83	50 – 40	7000	25 – 10
BITUMINOUS COAL	78 – 90	45 – 29	8000-8500	8
Semi bituminous	90-93	20-29	8500-8600	5-8
ANTHRACITE	92-98	20 – 8	>8600	<5



LIQUID FUELS:

Petroleum/Crude oil: *Petroleum is a naturally occurring flammable liquid consisting of a complex mixture of hydrocarbons with small quantities of organic compounds containing oxygen, nitrogen and sulphur. It is a fossil fuel formed, when large quantities of dead organisms, usually zooplankton and algae, are buried underneath sedimentary rock and subjected to intense heat and pressure over several millions of year. Petroleum is collected mostly through oil drilling*.

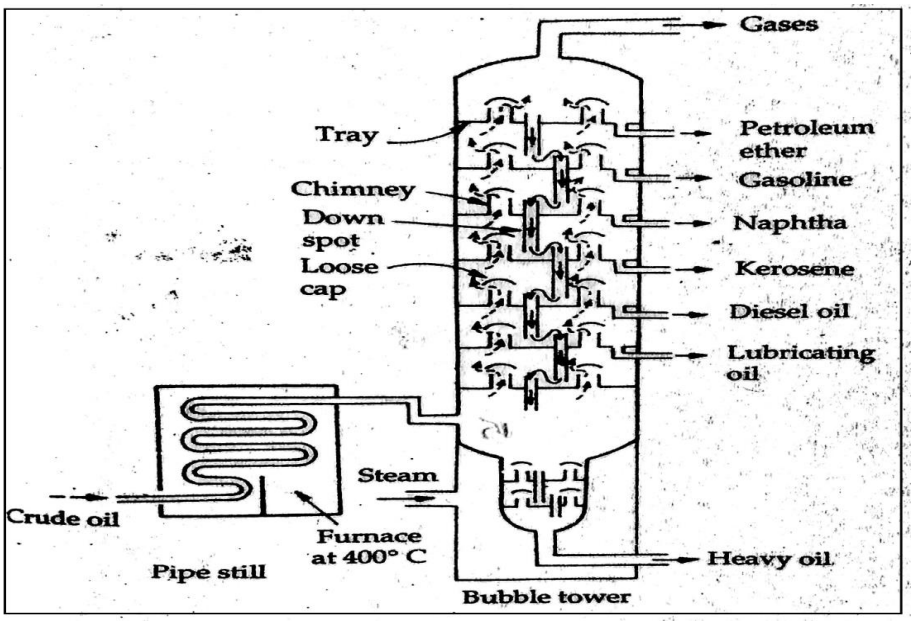
Composition of Petroleum as follows,

C=80-87% , H=11.1 - 15% , S=0.1-3.5% , O = 0.1-0.9% and N =0.4-0.9%

Refining of petroleum or Crude oil:

The crude oil is separated into various fractions having different boiling points by fractional distillation. The fractions are finally converted into desired products by removing objectionable impurities. *This process is called refining of crude oil or petroleum*. The plants set up for this purpose are called **oil refineries**.

1. **Removal of water (Cottrell's process):**
   The crude emulsion is passed through highly charged electrodes where the colloidal water droplets coalesce and separate out from crude oil.
2. **Removal of sulphur compounds:**
   The crude which is free from water is passed over copper oxide where the sulphur present in crude oil gets precipitated as copper sulphide which is separated by filtration.
3. **Fractional distillation:**
   Heating of crude oil at around 400^0C in an iron retort produces hot vapours which are allowed to pass through a fractionating column. Fractionating column is a tall cylindrical tower containing a number of horizontal stainless trays at short distances and is provided with small chimney covered with loose cap. As the vapours go up, the vapours get cooled gradually and fractional condensation takes place. Higher boiling fractions condense first and lower boiling fractions in turns.



Some important fractions of petroleum:

Property/ Fraction	Boiling range	Approx.Carbon chain length	Calorific Value	Uses
Uncondensed gases	<30^{0}C	C_1-C_4		**Domestic fuel as LPG**
Petroleum ether	30-70^{0}C	C_5-C_7		Solvent
Gasoline	40 to 120^{0}C	C_5-C_8	**11,250 Kcal/kg**	As fuel for IC engines, as a solvent, used in dry-cleaning
Naphtha	120-180^{0}C	C_9-C_{10}		**Solvent for paints and varnishes**
Kerosene	180 to 250^{0}C	**C_{10}-C_{16}**	**11,100 kcal/kg**	As a fuel for domestic purposes, Jet engine fuel, for preparing laboratory gas
Diesel	250 to 320^{0}C	**C_{15}-C_{18}**	**11,000 kcal/kg**	As a fuel in diesel engines.
Heavy oil	320-400^{0}C	**C_{17}-C_{30}**		To obtain gasoline by cracking , to obtain fractions like lubricating oil, petroleum jelly, grease and paraffin wax.
Asphalt or Bitumin, Petroleum coke	Above 400^{0}C	**C_{30} and above**		Water proofing of roof and making roads

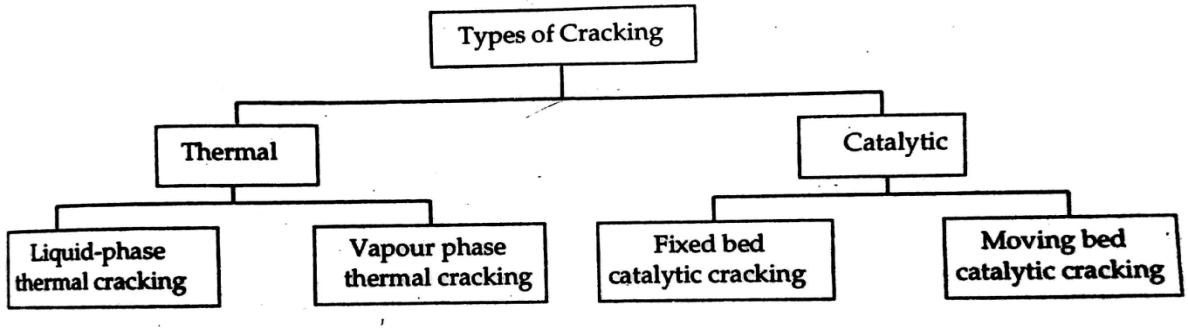
Cracking and its significance:

Cracking is defined as *"the decomposition of higher boiling fractions of hydrocarbons having high molecular weight into low boiling fractions of hydrocarbons having low molecular weight"*

$$\underset{\text{Decane}}{C_{10}H_{22}} \xrightarrow{\text{cracking}} \underset{\text{Pentane}}{C_5H_{12}} + \underset{\text{Pentene}}{C_5H_{10}}$$

B.P = 174°C B.P = 36°C

Gasoline has the highest demand as a motor fuel but the yield of this fraction is only 20 % of the crude oil and the quality of the gasoline obtained from crude is also not so good. Hence it is used only after suitable blending. Moreover, there is a surplus of heavier petroleum fractions. Therefore, middle and heavier fractions are subjected to cracking to more valuable low boiling fractions.



***Catalytic cracking*:**

The quality and quantity of gasoline produced by cracking can be greatly improved by using suitable catalyst like aluminium Silicate $Al_2(SiO_3)_3$ or Alumina (Al_2O_3).

Lower temperature & pressures are required for catalytic cracking comparative to thermal cracking.

KNOCKING

"A sharp metallic /rattling sound produced in an internal combustion engine due to improper ignition of air and fuel mixture is called knocking".

Generally, in petrol engine knocking is due to pre-ignition where as in diesel engine knocking is due to ignition delay. In deisel engines , knocking occurs when fuel is directly injected to highly compressed air towards the end of compression stroke and there is the short lag between the fuel injected and starting of combustion.

Knocking depends on **i)** Engine design **(ii)** Running conditions of engine **(iii)** chemical structure of hydrocarbons.

Knocking tendency decreases in the order,

n-alkanes > Branched chain alkanes > Cyclo alkanes > alkenes > Aromatics

- For Straight chain hydrogen carbons, the tendency to knock increases with molecular weight and boiling point, e.g., n-butane < n-pentane < n-hexane
- Aromatic hydrocarbons have higher antiknocking properties than alkanes and alkenes.

Consequences of knocking, (i) Decreased output (ii) Mechanical damage by overheating of the cylinder parts.

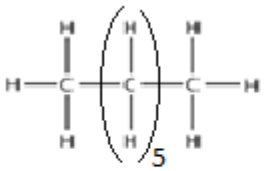
Fuel rating:

Octane Number/ Octane rating:

It was proposed by Graham Edgar in 1926.

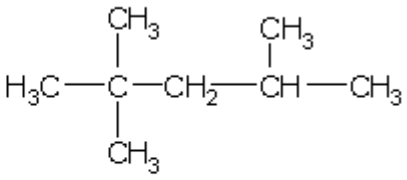
n- Heptane knocks very badly; its anti-knocking value is fixed as zero. Iso-octane

(2, 2, 4 - trimethyl pentane) gives little knocking, its anti-knocking value is fixed as 100.



n-**Heptane**

(Octane number = 0)



Iso -Octane

(Ocatne number = 100)

Octane number of a gasoline is defined as "the % of iso – octane in mixture of iso- octane and n-heptane which has same knocking characteristics with the gasoline under test.

E.g., 60 – octane fuel is one which has the same knocking characteristics as 60:40 mixture of iso-octane and n-heptane respectively.

Higher the octane number better is the quality of gasoline.

DIESEL ENGINE KNOCKING

In a diesel engine air alone is compressed to a very high pressure so that the temperature rises above 500^0C. The fuel is injected at the end of compression stroke, the fuel air mixture ignites spontaneously as it attains ignition temperature.

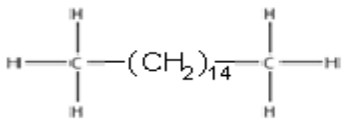
The combustion of the fuel in the diesel engine is sometimes not instantaneous. The interval between the start of the fuel injection and its ignition is called ignition delay.

If the ignition delay is long it will lead to fuel accumulation in the engine before ignition, leading to small explosion at ignition known as Diesel Knock.

Cetane Number /Cetane Value:

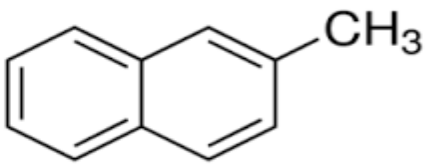
It is a measure of the ease with which a fuel will ignite under compression.

n- Hexadecane (Cetane) knocks very little, its anti-knocking value is fixed as 100 and 2-methyl naphthalene knocks very badly, and its anti-knocking value is fixed as 0.



n-**Hexadecane**

(Cetane number =100)



2-methyl napthalene

(Cetane number = 0)

Cetane number is defined as "the % of hexadecane in a mixture of Cetane and 2-methyl naphthalene which has the same ignition properties as the diesel fuel under test".

E.g., 55 – cetane fuel is the one which has the same knocking characteristics as 55:45 mixture of cetane and 2-methyla naphthalene respectively.

Cetane number of a fuel depends upon nature and composition of its hydrocarbons, for instance in the following series

n-alkanes> naphthalenes(Cycloalkanes)> alkenes>Branched alkanes>Aromatic

- **Ignition delay increases from left to right**
- **Cetane number decreases from left to right**
- **Ignition quality increases from right to left**

Higher the Cetane number, greater is the resistance to knocking.

GASEOUS FUELS:

LPG (Liquefied Petroleum Gas):

It is obtained as a by-product during cracking of heavy oils. Since LPG is normally odourless, small amounts of a pungent gas such as ethanethiols (Mercaptans) are added to help people smell potentially dangerous gas leaks.

Main constituents: **n-butane, iso butane, propane,** butylene and propylene.

Calorific Value: 27,800 Kcal/m^3

Uses: LPG is mostly used as domestic fuel for heating and cooking, it is used as fuel for cars and also for industry.

Advantages:

1. Calorific value and heating rate is high.
2. Easily portable and little care for maintenance purpose.
3. Cleanliness in storage handling and use.
4. Less smoke and no residue left after combustion.

CNG (Compressed Natural Gas):

It is a natural gas compressed to high pressure of about 1000 atmospheres

Composition: Methane (CH_4) = 70 -90%, Ethylene (C_2H_2) = 5-10% , H_2 =3% & Rest = CO + CO_2

Calorific Value: 12,000 – 14000 Kcal/m^3

Uses: Mainly used as automobile fuel, as a domestic fuel.

Advantages: 1. It is a much safer fuel, since it ignites at higher temperature.

2. **It has lesser CO emission than Gasoline.**
3. **The conversion of gasoline operated engine into CNG operated engine is easy.**
4. **The operating cost of CNG is much lower compared to gasoline Operation.**

What are the differences between solid, liquid and gaseous fuels? Or

What are the advantages, disadvantages of solid, liquid and gaseous fuels

Sr. No.	Property	Solid Fuels	Liquid Fuels	Gaseous Fuels
1.	**Calorific value**	**Low**	**Higher**	**Highest**
2.	Specific gravity	Highest	Medium	Lowest
3.	Ignition point	High	Low	Lowest
4.	**Efficiency**	**Poor**	**Good**	**Best**
5.	Air required for combustion	Large and excess of air	Less excess of air	Slight excess of air
6.	Use in I.C. engine	Cannot be used	Already in use	Can be used
7.	Mode of supply	Cannot be piped	Can be piped	Can be piped
8.	Space for storage	Large	50% less than solid fuel	Very high space
9.	Relative cost	Cheaper	Costly	More costly than other two
10.	Care in storage and transport	Less care required	Care is necessary	Great care required

BIO DIESEL

Biodiesel is alternative diesel fuel produced from biomass (i.e., vegetable oil or animal oils /fats).

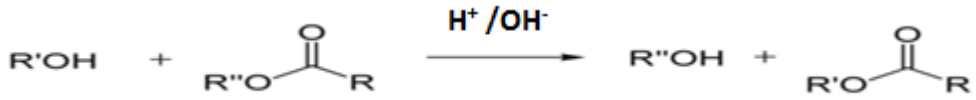
The Largest possible source of suitable oil comes from oil crops such as rape seed, palm, sunflower, and soybean.

Most of the biodiesel at present is produced from waste vegetable oil sourced from restaurants, chip shops and industrial food producers.

Concept of Transesterfication:

Transesterfication is "the process of conversion of vegetable oils/animal oils /fats into biodiesel".

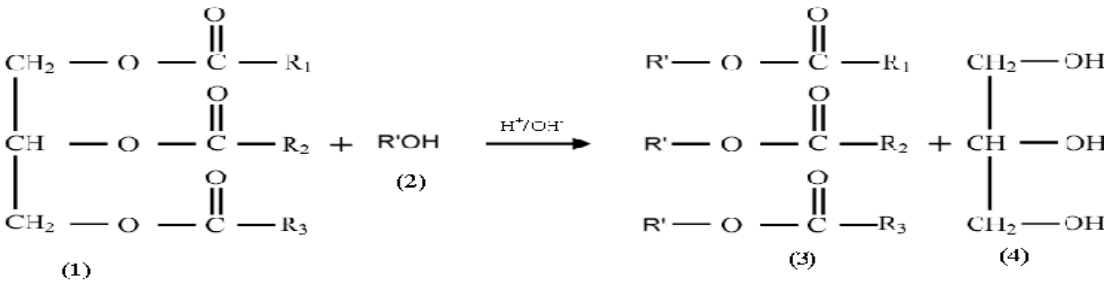
In transesterfication, the organic group R" of an ester exchanges with the organic group R' of an alcohol. These reactions are often catalyzed by an acid or base.



Strong acids catalyze the reaction by donating a proton to the carbonyl group, thus making it a stronger electrophile.

Bases catalyze the reaction by removing a proton from the alcohol, thus making it stronger nucleophile.

E.g.; Triglycerides (1) reacts with alcohols (2) to give alkyl esters (3) of a fatty acid and glycerol (4)



Base catalyzed transesterfication predominantly is used for production of biodiesel.

Advantages:

1. Biodiesel has better lubricating properties and much higher cetane ratings.
2. Biodiesel has very good lubricating properties, significantly better than standard diesel which can prolong engine's life.
3. Biodiesel has shorter ignition delay compared to standard diesel.
4. Biodiesel has no or less sulphur content.
5. Biodiesel can be easily blended with standard diesel, and it can be used in most of today's vehicles.
6. Bio-diesel is a source of renewable source of energy.

Disadvantages:

1. Biodiesel may contain small amount of water which reduces the heat of combustion or may cause corrosion.
2. Pure biodiesel has significant problems with low temperatures.
3. Biodiesel is significantly more expensive compared to standard diesel.
4. Its calorific value is about 10% less than standard petroleum diesel.
5. Biodiesel can release nitrogen oxide which can lead to the formation of smog.

Carbon neutrality:

What is carbon neutrality?

- Carbon neutrality, or having a net zero carbon footprint, refers to achieving net zero carbon dioxide emissions by balancing carbon emissions with carbon removal (often through carbon offsetting) or simply eliminating carbon emissions altogether.
- Carbon neutrality means having a balance between emitting carbon and absorbing carbon from the atmosphere in **carbon sinks**. Removing carbon oxide from the atmosphere and then storing it is known as carbon sequestration.
- In order to achieve net zero emissions, all worldwide greenhouse gas emissions will have to be counterbalanced by carbon sequestration.
- Carbon sink is any system that absorbs more carbon than it emits. The main natural carbon sinks are **soil,** forests **and oceans**.
- **Biofuels are said to be carbon-neutral because the carbon dioxide that is absorbed by the plants is equal to the carbon dioxide that is released when the fuel is burned. ... However, biofuel isn't truly carbon-neutral, because of the processes used in its production.**
- **Biodiesel is a fuel that can be used in any diesel powered vehicle. It is biodegradable and non-toxic. Biodiesel is a fantastic way of reducing your carbon footprint as it only releases the carbon dioxide that the plants absorbed whilst growing, therefore there is no negative impact on the carbon cycle.**