Topic 5 – Fuels

- **CRUDE OIL**
- Crude oil and natural gas are fossil fuels found in some sedimentary rocks deep underground
- **Formation of crude oil/natural gas:**
    - When microscopic plants and animals in the sea die, their remains fall to the bottom of the sea
    - Over millions of years, their remains are buried by sediments, stopping entry of oxygen→preventing their decay
    - As more sediments build up on top of the remains, the heat and pressure increases and crude oil or natural gas are gradually formed
- **Composition of crude oil:**
- A hydrocarbon is a compound that contains only carbon and hydrogen atoms
- Hydrocarbons with many carbon atoms are said to have ‘long’ carbon chains
- Hydrocarbons with few carbon atoms are said to have ‘short’ carbon chains
- Crude oil is a mixture of different hydrocarbon molecules (i.e some with long carbon chains and others with short carbon chains)
- Crude oil can also contain some impurities like sulphur
- **Crude oil is a non-renewable resource:**
- The rate at which we are using crude oil is much greater than that at which it is being formed underground
- At the present rate of consumption, the supply of crude oil is estimated to run out in the next 40 to 50 years
- Currently most oil is obtained from drilling wells, but as demand for oil increases, surface mining of oil sands (which contain over half of the world’s remaining reserves of oil) will increase
    - But is it economic to mine these sands?
    - Is it worth the damage to habitats?
- **CRUDE OIL FRACTIONS**
- **Fractional distillation:**
- The mixture of hydrocarbons in crude oil needs to be separated into simpler mixtures (called ‘fractions’) in a process called fractional distillation
- The mixture of liquids is boiled in a fractional distillation tower and the vapour from it is condensed
- The fractional distillation tower is hot at the bottom and cooler near the top
- Different liquids condense at different temperatures→separating the mixture into smaller fractions of crude oil (bitumen, kerosene, petrol, diesel oil etc…)
- Fractions with short carbon chains (e.g gases):
    - Ignite (set alight) easily, have low boiling points and have low viscosity (they are runny) when in liquid form
    - →condense at the top of the distillating tower
- Fractions with long carbon chains (up to 40 carbons e.g bitumen):
    - Have much higher boiling points, are harder to ignite and have high viscosity (they are thick and sticky) when in liquid form
    - →condense at the bottom of the distillating tower
- Order of fractions according to carbon chain length (from shortest to longest):
    - Gases→petrol→kerosene→diesel oil→fuel oil→bitumen

- Summary table:

Fraction	Length of molecule	Ease of ignition	Boiling point	Viscosity
gases	short carbon chains (only a few carbon atoms)	easy	low (< 0°C)	runny
petrol	↓	↓	↓	↓
kerosene				
diesel oil				
fuel oil	long carbon chains			
bitumen	(up to 40 Carbon atoms)	difficult	high (> 350°C)	thick and sticky

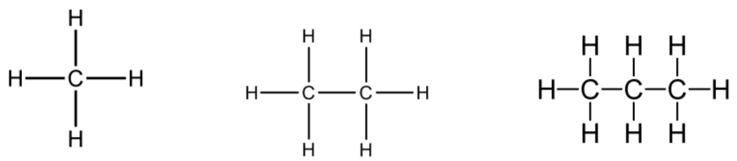
- **Uses of crude oil fractions:**
- The different fractions of crude oil have different properties→have different uses…
- Gases (e.g methane): fuel for vehicles, bottled gas for camping stoves, heating and cooking in homes
- Petrol: fuel for cars
- Kerosene: fuel for aircraft
- Diesel oil: fuel for diesel engines (some cars, lorries, trains)
- Fuel oil: fuel for large ships and some power stations, fuel for heating
- Bitumen: making roads, waterproofing flat roofs
- **COMBUSTION**
- When hydrocarbon fuels burn they react with oxygen and release heat and light energy. This is an oxidation reaction called combustion
- When enough oxygen is present, all the hydrocarbon is used up and the only products are carbon dioxide and water. This is known as 'complete combustion'
    - E.g combustion of methane (the main gas in natural gas):
        - Methane + oxygen → carbon dioxide + water
        - Balanced equation: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- **Detecting products of a complete combustion reaction:**
- Anhydrous copper sulphate turns blue when it comes into contact with water
- Limewater turns cloudy when carbon dioxide is bubbled through it
- →when hydrocarbons are burnt fully in air (i.e when complete combustion occurs), anhydrous copper sulphate turns blue and limewater turns cloudy
- **INCOMPLETE COMBUSTION**
- Sometimes a burning fuel may not have enough oxygen. In this case, 'incomplete combustion' occurs:
    - There isn't enough oxygen for all the carbon atoms to form carbon dioxide (as each carbon must combine with 2 oxygen atoms)
    - →some of the carbon may form carbon monoxide (CO – 1 carbon combines with 1 oxygen atom) and/or solid particles of carbon (C – no oxygen combined with carbon atom)
- 2 possible reactions occur when hydrocarbon fuels burn without enough oxygen...
- E.g with methane:
    1. Methane + oxygen→carbon monoxide + water
    2. Methane + oxygen→carbon + water
- If there's very little oxygen then more of reaction 2 will take place
- If there's a bit more oxygen (but still not enough for complete combustion), then more of reaction 1 will take place
- (Recall that when lots of oxygen is available, fuel burns fully so complete combustion occurs and only carbon dioxide and water are produced)

- **Bunsen burners and combustion:**
- When the air hole of a bunsen burner is open, complete combustion occurs and the flame is blue (→often called a 'clean' flame)
- When the air hole of a Bunsen burner is closed:
    - There isn't enough oxygen→incomplete combustion occurs and flame is yellow
    - The yellow colour is caused by the hot carbon particles (soot) glowing
- **Carbon monoxide problems:**
- Carbon monoxide is an odourless, colourless toxic gas
- It reduces the amount of oxygen that can be transported around the body in the blood
- Faulty gas boilers (in which oxygen flow is restricted) and fires produce carbon monoxide and this can lead to death by carbon monoxide poisoning…→:
    - All fuel-burning appliances must be serviced regularly
    - Homes should be fitted with carbon monoxide detectors
- **Soot problems:**
- Soot produced in appliances such as boilers can clog up pipes carrying waste gases away
- Soot is also produced by vehicles. Breathing in sooty air can lead to lung disease
- Soot also leaves black marks on buildings/walls
- **ACID RAIN**
- **Discovering the problem:**
- In the 1970s, the numbers of fish caught in lakes and rivers in southern Norway started to decrease
- Scientists noticed that these lakes and rivers were much more acidic than those in other parts of the country that still had healthy fish
- Looking at weather patterns, scientists concluded that pollution from factories and power stations in Europe was being carried in the atmosphere, making the rainfall (more) acidic…→acid rain was killing the fish
- **Causes of acid rain:**
- Acid rain is rain that is more acidic than usual (has a pH of less than 5.2)
- As mentioned above, hydrocarbon fuels contain sulphur impurities…:
    - →When fuels are burnt, the sulphur reacts with the oxygen from the air to form sulphur dioxide gas
    - Sulphur dioxide dissolves in rainwater→lowers its pH, forming acid rain
- **Effects of acid rain:**
- Makes rivers, lakes and soils acidic→harming organisms that live there
- Damages trees
- Speeds up the weathering of buildings/statues made of limestone or marble and the corrosion of metal
- **Solutions to problem of acid rain:**
- Reducing amount of sulphur in petrol, diesel and fuel oil
- Removing acidic gases from power station emissions (by neutralising them with a basic (alkaline) compound such as calcium carbonate)
- **CLIMATE CHANGE**
- Some gases in the atmosphere, such as carbon dioxide, methane and water vapour, trap heat energy and help keep the Earth warm

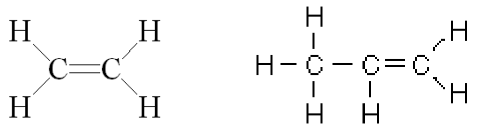
- This is known as the greenhouse effect and these global warming gases are referred to as 'greenhouse gases'
- Over the last 200 years there has been a dramatic increase in the levels of these greenhouse gases in the atmosphere, particularly CO_2→global warming effect
- This increase in temperature is likely to change weather patterns, causing climate change (also, the rising sea levels caused by melting ice caps mean flooding is an ever increasing danger to low-lying places)
- As we saw in Topic 1, the concentration of gases in the atmosphere (and the Earth's temperature) can change due to natural processes
- However, most scientists believe that the large increases in the levels of greenhouse gases in the atmosphere are due to human activities…:
    - The dramatic increase in CO_2 concentration in the atmosphere is thought to be due to more burning of fossil fuels
    - The increase in methane levels is thought to be due to increased large-scale farming
- **Reducing the amount of carbon dioxide:**
- One way of reducing the amount of carbon dioxide being added to the atmosphere is by limiting the use of fossil fuels
- Chemists are currently investigating two further methods to actively reduce the level of carbon dioxide in the atmosphere…
    - 1. Adding iron compounds to oceans – known as iron seeding:
        - Iron is an essential nutrient for plants and is often in short supply
        - →adding iron encourages plants to grow
        - Plants use carbon dioxide for photosynthesis
        - When they die, the plants sink to the ocean floor and the carbonate in their shells is buried
        - →carbon is removed from the atmosphere for a long time
    - 2. Converting carbon dioxide into hydrocarbons:
        - The idea is to capture carbon dioxide from fossil-fuelled power stations and reacting it to make hydrocarbon compounds such as propane and butane (see alkanes later in this topic)
- **CHOOSING FUELS**
- **What makes a good fuel?**
- **1.** It doesn't produce harmful gases:
    - Most fuels cause pollution because when they burn completely they release CO_2 into the atmosphere (or carbon monoxide and soot if not enough oxygen is present and incomplete combustion occurs)
    - Also, recall that crude oil contains sulphur impurities→when it burns, sulphur dioxide gas is also formed→acid rain
- **2.** It burns easily (i.e is flammable)…:
    - However, fuels that are very easy to light can also be dangerous if they're not stored and transported carefully (see hydrogen below)
- **3.** A small amount of it produces a lot of heat energy:
    - E.g burning hydrogen produces most energy→it's used as fuel for rockets
- **4.** It's easy to store and transport:
    - Coal and other solid fuels are easy to store and transport by lorry or train
    - Gas fuels such as methane and hydrogen must be stored at high pressure to reduce the size of the tanks needed to store them

- **BIOFUELS**
- Biofuels are obtained from living organisms or from organisms that have recently died e.g wood, crops. They're possible alternatives to fossil fuels.
- Examples of biofuels:
  - Ethanol:
    - It's made by processing wheat, sugar cane or sugar beet
    - It can be mixed with petrol for use as fuel in car engines
    - →Using ethanol helps reduce demand for petrol→conserves crude oil supplies
  - Biodiesel - made from vegetable oils by chemical reactions
- **Advantages of biofuels:**
- **1.** Biofuels are renewable (i.e stores can be quickly replaced)…:
  - Crude oil (petrol, kerosene, diesel oil…)/natural gas (methane) stores instead can't be replaced→are non-renewable
- **2.** Biofuels are less polluting:
  - The carbon dioxide released when biofuel plants are burned gets re-absorbed by (biofuel) plants for photosynthesis...
    - →overall, biofuels don't add carbon dioxide to the atmosphere
    - →biofuels are said to be 'carbon neutral'
    - (Note: energy is needed to make fertiliser for the crops, to harvest them, to process them and to transport the biofuel to where it's needed. So if you take into account the manufacturing and distributing processes then biofuels are not carbon neutral)
  - Burning of fossil fuels instead releases sulfur dioxide (causes acid rain) and carbon dioxide (contributes to global warming) into the atmosphere
- **Disadvantages of biofuels:**
- **1.** Lots of land is required in order to grow the crops...
  - →less farmland for growing food
  - →clearing of forests (deforestation) to make space in which to plant biofuel crops
- **2.** There are fewer gas stations where you can fill up on biofuels
- **3.** Lower fuel efficiency (so you have to fill up more often)
- **USING HYDROGEN AS A FUEL**
- **Advantages of hydrogen vs petrol:**
- **1.** Hydrogen fuel is renewable, petrol is non-renewable
- **2.** Hydrogen is less polluting:
  - Hydrogen burns (reacts with oxygen) in a fuel cell to release energy
    - Equation: $2H_2 + O_2 \rightarrow 2H_2O$
    - Water is the only waste product
    - →hydrogen is known as a 'clean' fuel
  - Burning petrol instead releases sulfur dioxide (causes acid rain) and carbon dioxide (contributes to global warming) into the atmosphere
- **Disadvantages of hydrogen vs petrol:**
- Before cars with fuel cells can become widely used, hydrogen has to be more easily and economically available...
- **1.** Using hydrogen fuel is more expensive because...
  - Electricity is required to produce it (because hydrogen is obtained by electrolysing water)
  - Lower fuel efficiency (so you have to fill up more often)

- **2.** Hydrogen fuel is less safe:
  - Hydrogen is flammable so care must be taken when transporting it
  - Hydrogen is a gas, petrol is a liquid→hydrogen gas leaks are more likely
- **3.** Hydrogen is more difficult to store:
  - Hydrogen must be stored at high pressure to reduce the size of the tanks needed to store them
- **4.** There are fewer gas stations where you can fill up on hydrogen fuel
- **INVESTIGATING FUELS**
- Note: the amount of energy released when a fuel burns can be determined experimentally using a calorimeter…:
  - Observe the temperature rise when the same volume of water is heated by different fuels
  - The greater the temperature rise, the more energy released by the fuel
- **ALKANES AND ALKENES**
- Carbon is in group 4 of the periodic table→each carbon forms four bonds with other atoms (either 4 single bonds, or 2 single bonds and a double bond)
- Hydrogen is in group 1 so forms just one bond with other atoms
- **Alkanes:**
- In an alkane molecule, each carbon is bonded to four other atoms with single bonds (see diagrams below)
- Hydrocarbons with single carbon-carbon (C-C) bonds are referred to as 'saturated'
- →Alkanes are known as saturated hydrocarbons ('saturated' because they can't form bonds with any more atoms)



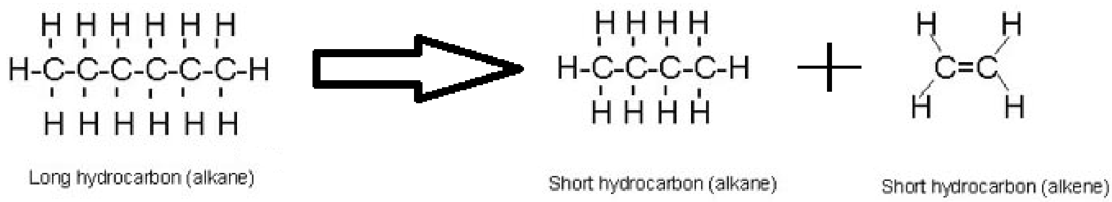
- Methane (CH_4 – left hand panel) is the simplest alkane, with one carbon atom joined to four hydrogen atoms
- Ethane (C_2H_6 – middle panel) has two carbon atoms
- Propane (C_3H_8 – right hand panel) has three carbon atoms
- **Alkenes:**
- Hydrocarbon molecules that have a double bond (*just one!*) between two of the carbon atoms (C=C) are known as alkenes
- The C=C double bond means that these carbon atoms are not bonded to the maximum number of other atoms (i.e they're bonded to 3 not 4 other atoms)
- →Alkenes are known as 'unsaturated' hydrocarbons



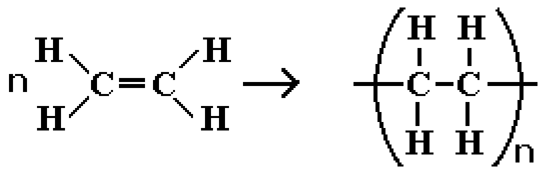
- Ethene (C_2H_4 – left hand panel) is the simplest alkene. It has 2 carbon atoms
- Propene (C_3H_6 – right hand panel) has 3 carbon atoms
- **Bromine test to tell alkanes and alkenes apart:**
- The bromine test is used to find out if a compound has double bonds (i.e whether it is an alkane or an alkene)
- When bromine water (orange colour originally) is mixed with a saturated hydrocarbon (alkane)→no colour change (i.e stays orange)

- E.g ethane + bromine water (orange)→orange-coloured liquid

- When bromine water is mixed with an unsaturated hydrocarbon (alkene), it goes from orange to colourless
  - E.g ethene + bromine water (orange)→colourless liquid
- **CRACKING**
- Longer hydrocarbons can be broken down by heat ('thermally decomposed') into more useful shorter hydrocarbons – this is done by a process called cracking
  - In most cases, a long chain alkane is thermally decomposed into a shorter chain alkane and an alkene…



  - $C_6H_{14} \rightarrow C_4H_{10} + C_2H_4$
  - Note: there are still the same numbers of carbon and hydrogen atoms before and after cracking
- Shorter chain alkanes produced in cracking are used as fuels (e.g petrol)
- Most of the short chain alkenes produced in cracking are used for making plastics
  - Ethene is also used for ripening fruit
- **Why is cracking needed?**
- When crude oil is separated by fractional distillation, some fractions are present in greater amounts than others (e.g more fuel oil is present than petrol or diesel)
- The shorter fractions in crude oil (petrol, diesel) are in greater demand than the longer fractions (fuel oil, bitumen)
- →to make supply meet demand, oil companies use cracking to break down longer molecules into more useful shorter molecules
- **POLYMERISATION**
- Polymers are substances made up of thousands of simple repeating units
- Monomers are substances whose molecules react together to form polymers. This process is called polymerisation.
- E.g poly(ethene) (a polymer) is made from lots of ethene monomers…:
  - The number of ethene molecules that join together to make one molecule of poly(ethene) is very large (thousands/millions)
  - →we use 'n' to indicate a large number (i.e 'n' lots of ethene molecules join to form a polymer made up of 'n' number of ethene repeating units)
  - *Note polymers lose the C=C double bond*



- Some polymers are natural e.g cellulose (found in plant cell walls)
- Other polymers are manufactured e.g plastics
- **Properties and uses of (manufactured) polymers:**
- Poly(ethene) – made from ethene monomers:
  - Properties: Flexible, cheap, good insulator

  - Uses: carrier bags, plastic bottles, insulation for electrical wires, cling film
- Poly(propene) – made from propene monomers:
  - Properties: flexible, shatterproof, strong, long lasting, high softening point
  - Uses: plastic bags, buckets, ropes, washing up bowls, carpets
- Poly(chloroethene) – PVC……made from chloroethene monomers:
  - Properties: tough, cheap, long-lasting, good insulator
  - Uses: window frames, gutters, pipes, insulation for electrical wires
- Poly(tetrafluoroethene) – PTFE or Teflon……made from tetrafluoroethene monomers:
  - Properties: tough, slippery, resistant to corrosion, good insulator
  - Uses: non-stick coatings for saucepans, bearings and skis, containers for corrosive substances, stain-proofing carpets, insulation for electrical wires
- **PROBLEMS WITH POLYMERS**
- Materials such as wood and paper are biodegradable – i.e they rot because microbes can feed on them
- Most manufactured polymers have many uses because they are not biodegradable →last for a long time
- However, the fact they're non-biodegradable means they don't rot→when thrown away in landfill sites, polymers stay there for a long time
- When burned ('incinerated'), they release energy that can be used to generate electricity, however most also produce toxic products
- **Overcoming problems associated with disposal of polymers:**
- 1. Developing biodegradable polymers:
  - Biodegradable polymers would rot after only a few years if they ended up in a landfill site
  - However, this is still quite a long time→best option is to reduce the amount of plastic sent to landfill sites in the first place…
- 2. Reusing and recycling materials:
  - One way to reduce the amount of plastic sent to landfill sites is by reusing materials
  - E.g reusing plastic bags rather than throwing them away after just a single use
  - If an item can't be reused anymore then the material it is made from can be recycled (i.e processed and used to make new objects)…
  - Paper, glass and metal waste is already recycled in the UK
  - However, polymers are more difficult to recycle because the waste needs to be sorted into different types of polymer before each type can be made into new objects