Year 12
Chemistry
Organic Chemistry

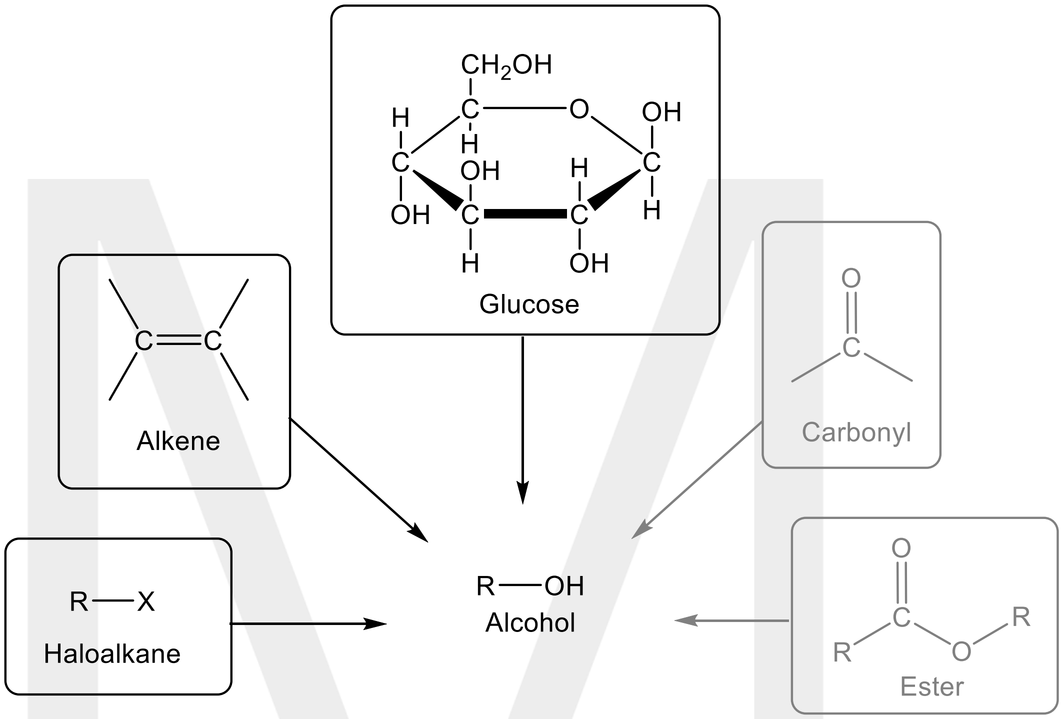
Lesson 5
Alcohols 2
Sample resources

MATRIX
EDUCATION

1. Production of alcohols

☐ Production of alcohols

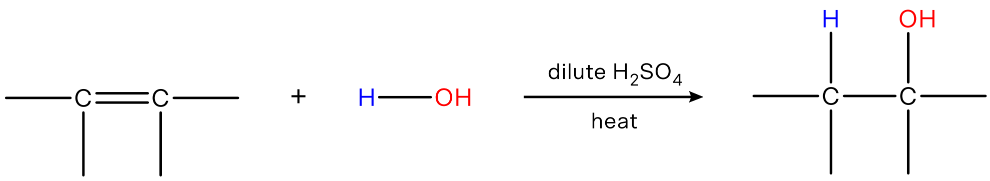
- Alcohols can be prepared in a number of ways, depending on its type and intended use.



  - The majority of alcohols used in industry are prepared by **hydration of alkenes** or **substitution of haloalkanes**.
  - For simple alcohols, such as ethanol used in beverages or fuels, **fermentation** is utilised.
  - In laboratories, carbonyl compounds can be reduced to alcohols (the reverse of oxidation from last lesson). However, this reaction is beyond the scope of the course.
  - **Hydrolysis of esters** produces alcohols as a by-product. This is not a commonly used method to produce desired alcohols. We will cover this reaction in Lesson 7.

☐ Production by addition

- One method to prepare alcohols is the **catalytic hydration of alkenes** (from Lesson 3).

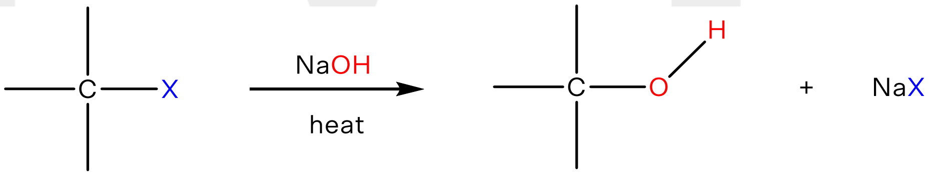


- This reaction tends to give low product yields due to the harsh conditions.

☐ Production by substitution

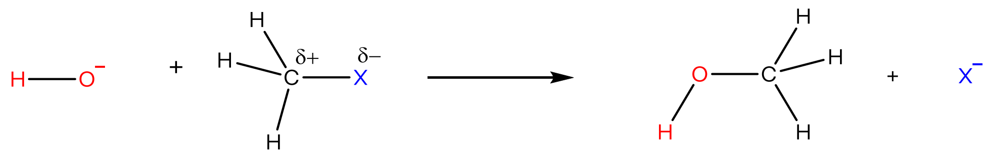
- Alcohols can also be prepared via the substitution of **haloalkanes.**
  - What is a substitution reaction?

  - This reaction occurs by heating the haloalkane with sodium or potassium hydroxide. A hydroxide ion replaces the halogen atom to give an alcohol and a halide salt.



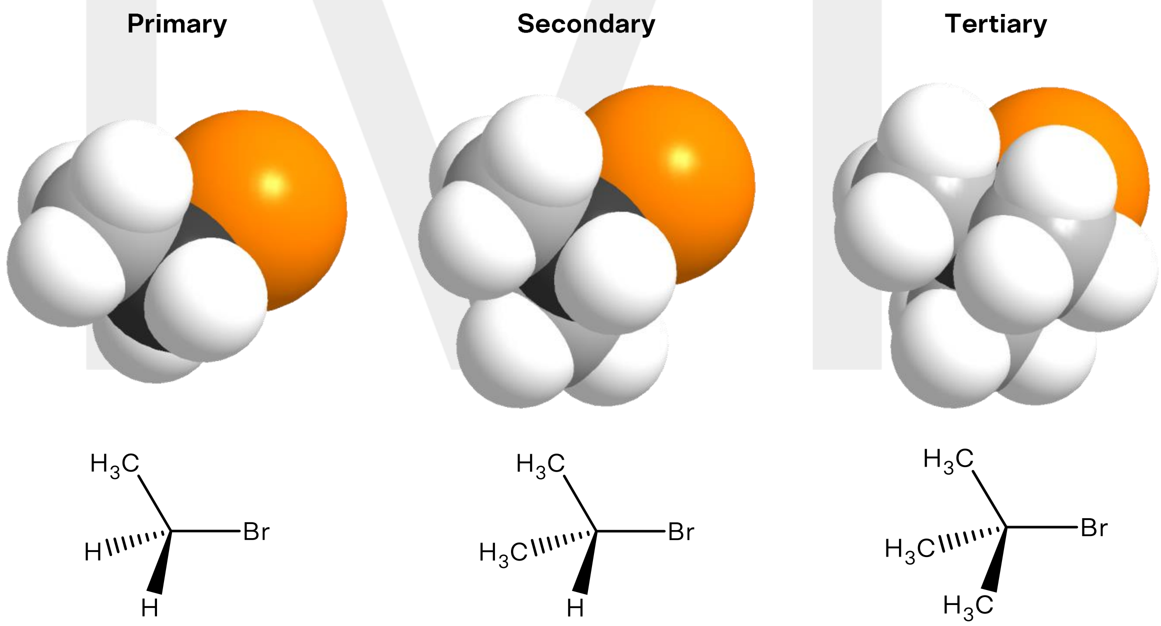
Where X = Cl, Br or I

- The electronegative halogen produces a **partial positive charge** on the carbon atom which can be easily 'attacked' by a hydroxide anion.
  - A covalent carbon-oxygen bond forms.
  - The negative charge from the hydroxide is donated to the electronegative halogen atom, which leaves as a halide ion.



- The rate of this reaction depends on the type of haloalkane and the halogen atom (leaving group).

- Like alcohols, haloalkanes can be categorised as primary, secondary and tertiary.
  - Reactivity decreases in the order **primary > secondary > tertiary**.
  - This is because alkyl groups greatly hinder the approach of the hydroxide ion to the carbon centre and thus slow the reaction.



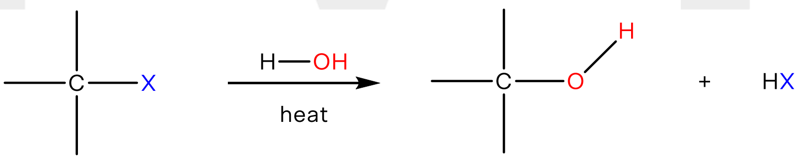
- The **halogen** leaving the molecule also affects rate.
  - Reactivity decreases in the order I > Br > Cl, due to the different strengths of the carbon-halogen bonds.

Bond	Average energy (kJ mol^{-1})
C – F	485
C – Cl	338
C – Br	276
C – I	238

  - The lower the bond energy, the easier it is to break the bond.
  - Explain how bond energy and reactivity are related.

  - The high C–F bond energy means fluoroalkanes do not participate in substitution reactions.

- Haloalkanes can also undergo substitution reactions with **water** to form alcohols.
  - This reaction is much slower.
  - Reactivity decreases in the order tertiary > secondary > primary haloalkanes.



Where X = Cl, Br or I

Concept Check 1.1

(a) Write a structural equation for the hydration of 4-methylpent-2-ene. Include the reagent and catalyst required above the arrow.[1] 2

(b) Write a structural equation for the reaction that occurs when 1-bromo-2,3-dimethylbutane is treated with sodium hydroxide and heat.[2] 2

(c) Give the structural formulae and names of three reactants that can be used to produce butan-2-ol.[3] 3

Concept Check 1.2

Both iodoethane and chloroethane can be treated with sodium hydroxide and heat to produce ethanol. Explain why the production of ethanol occurs quicker with iodoethane than chloroethane. 2

☐ Production by fermentation

- Fermentation involves the conversion of **carbohydrates** into **simple alcohols** by the action of enzymes (biological catalysts) in **microorganisms** such as yeast and bacteria.
  - What are carbohydrates?[4]

- Carbohydrates are abundant in plant material.
  - They are also called saccharides.
  - The simplest carbohydrates are monosaccharides. They are the building blocks of more complex carbohydrates, such as disaccharides like sucrose and polysaccharides like cellulose.

- The fermentation of monosaccharides such as glucose and fructose ($C_6H_{12}O_6$) produces ethanol and carbon dioxide.

$$C_6H_{12}O_{6(aq)} \xrightarrow{\text{zymase}} 2C_2H_5OH_{(aq)} + 2CO_{2(g)} \qquad \Delta H < 0$$

- Ethanol is by far the most common alcohol made from fermentation. Other simple alcohols can be made, but the conditions are more complex and undesirable by-products are generally formed. Thus fermentation is only used to make ethanol on an industrial scale.

> **Note to students**
> An investigation to produce ethanol through fermentation in a school laboratory is described in **Appendix 2**.

☐ Conditions for fermentation

- Four conditions are used for fermentation:
  - presence of zymase – found in yeast
  - warm temperatures (30–40 °C but depends on yeast strain)
  - anaerobic environment
  - aqueous solution of sugar

- Fermentation of monosaccharides are catalysed by a yeast enzyme called zymase. Since zymase is a biological catalyst, it is sensitive to temperature. The optimal temperature is generally 30–40 °C.

- The process must be carried out in anaerobic conditions.
  - What is meant by 'anaerobic conditions'?[5]

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  - In the presence of oxygen, yeast will respire which causes further oxidation of ethanol to acetic acid, or carbon dioxide and water.

- Yeast can produce ethanol concentrations up to about **15% v/v.**
  - Suggest a reason for this.

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  - An aqueous solution allows a larger amount of ethanol to be produced without exceeding 15% concentration.

- To produce a higher alcohol concentration, **distillation** is required.
  - If the fermentation mixture is fractionally distilled, 95% ethanol can be obtained which can be used in industry or laboratories.
  - To obtain 100% ethanol, more elaborate procedures such as molecular sieving are required.

Concept Check 1.3

Glucose ($C_6H_{12}O_6$) can undergo fermentation to ethanol, and ethanol can be converted to ethene.

(a) Write a balanced equation for each of these reactions.[6] **2**

(b) State the reaction conditions required to affect each of these conversions.[7] **2**

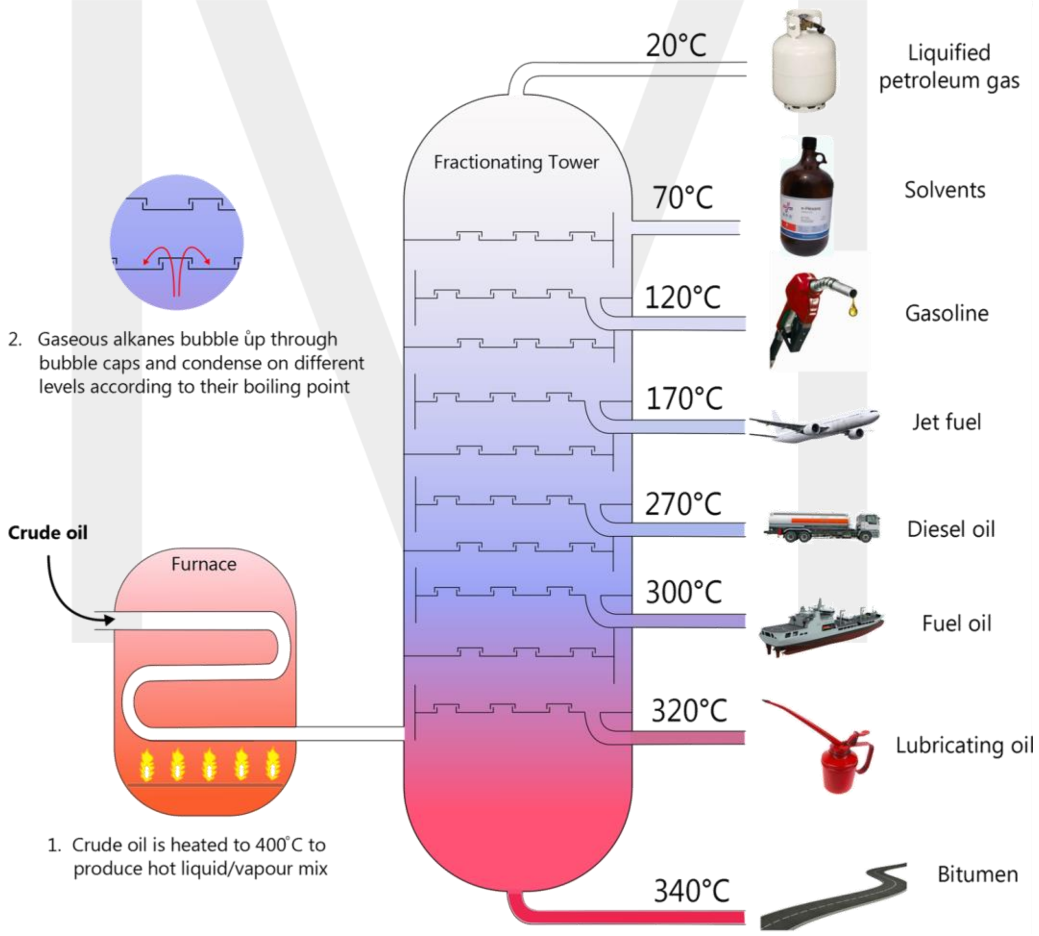
(c) Calculate the volume of $CO_{2(g)}$ produced at STP from the fermentation of 3.0 g of glucose.[8] **2**

(d) Calculate the volume of $CO_{2(g)}$ produced at STP from the fermentation of 3.0 tonnes of glucose.[9] **1**

2. Implications of using hydrocarbons

☐ Hydrocarbons from the Earth

- The primary source of hydrocarbons is **petroleum**, a mixture of hundreds and thousands of different alkanes, ranging from methane up to alkanes with 40 or more carbons.
  - The mixture of gases found in petroleum is called **natural gas** and the mixture of liquid components is called **crude oil.**
  - Petroleum is found within pores of rocks deep in the ground.
- The mixture is separated into fractions according to boiling points using **fractional distillation** in a fractionating tower.



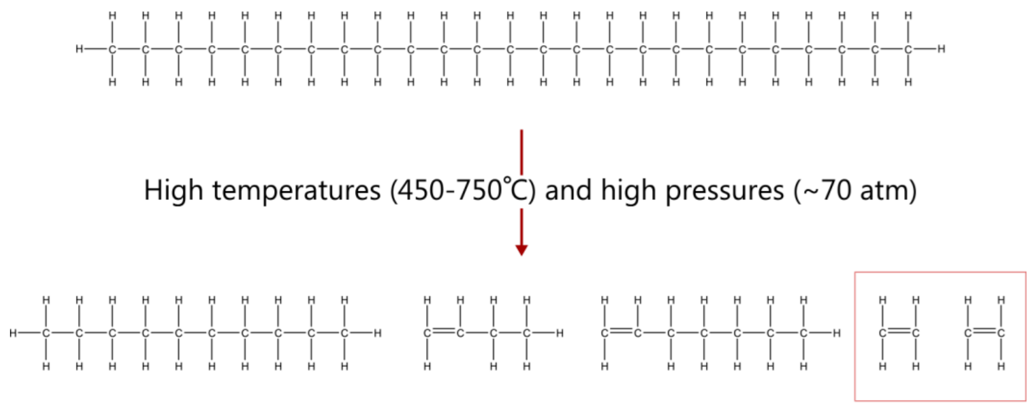
- The petroleum is heated to about **400 °C** to produce a **hot liquid/vapour** mixture that enters a fractionating tower.
- Inside the tower are horizontal trays, each of which contains many **bubble caps** upon which alkanes condense.
- Explain why longer hydrocarbons condense towards the bottom of the tower, in terms of the intermolecular forces involved.

■ Differences in the physical and chemical properties of each petroleum fraction mean that they have different uses.

- Generally, **light fractions** (LPG and petrol) are much **more useful and are in higher demand** than heavy fractions (lubricating oil, bitumen).

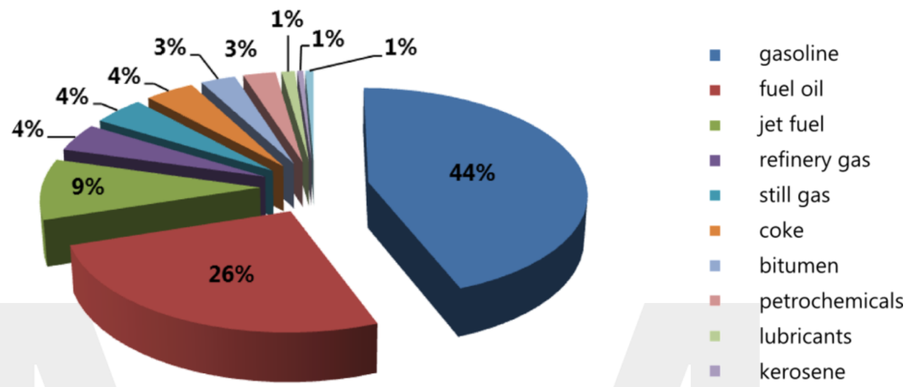
■ Some of the longer alkanes are further processed through **cracking**.

- The alkanes are heated strongly in the absence of oxygen.
- They split to form shorter, more useful alkanes as well as alkenes.
- A **zeolite catalyst** containing Al, Si and O can be added to allow the use of lower temperatures.



☐ Uses of hydrocarbons

- The global consumption of petroleum is shown below.

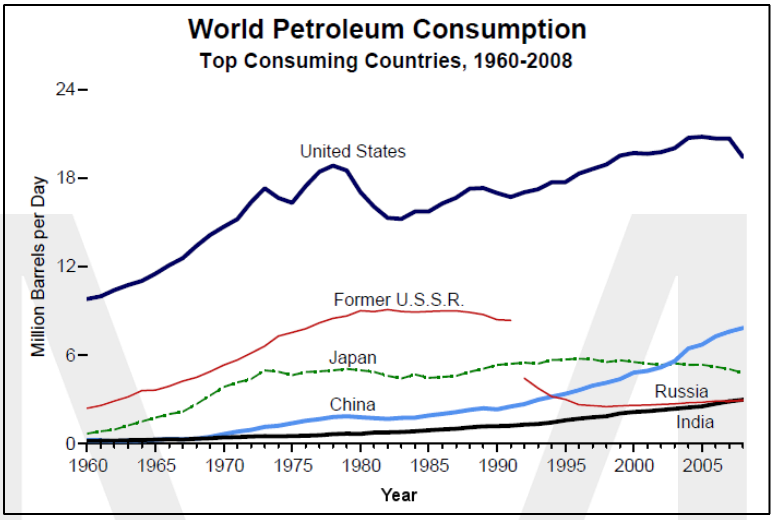


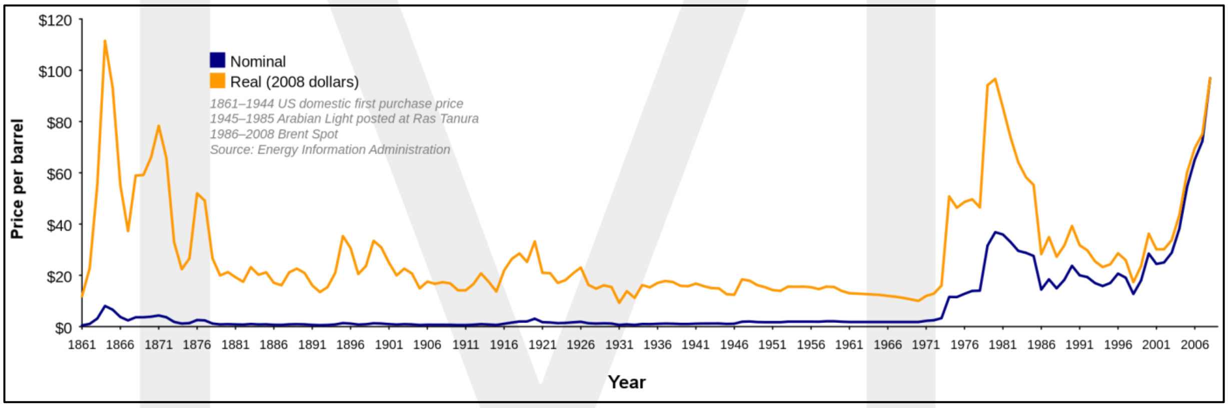
  – What is the major use of petroleum?[10]

- **Saturated** hydrocarbons are excellent **fuels.**
  – The combustion of hydrocarbons is the **main method of energy production** globally.
  – The energy released is used to generate electricity, fuel automobiles, cook food and provide heating.
- **Unsaturated** hydrocarbons are highly reactive and can undergo addition reactions.
  – This makes them extremely important as **raw materials** for the production of **commercially valuable materials** such as haloalkanes, alcohols and plastics.
  – We use a myriad of **products** that originate from hydrocarbons and their derivatives, including clothes, vehicles, tools, furniture, medicines, books, toys, electronics, and cosmetics.

☐ The problems with using petroleum

- Petroleum deposits are formed by the burial and compaction of prehistoric organisms over **millions of years.** Thus petroleum is **finite** and **non-renewable.**
  - Analyse the graphs below and answer the following questions.

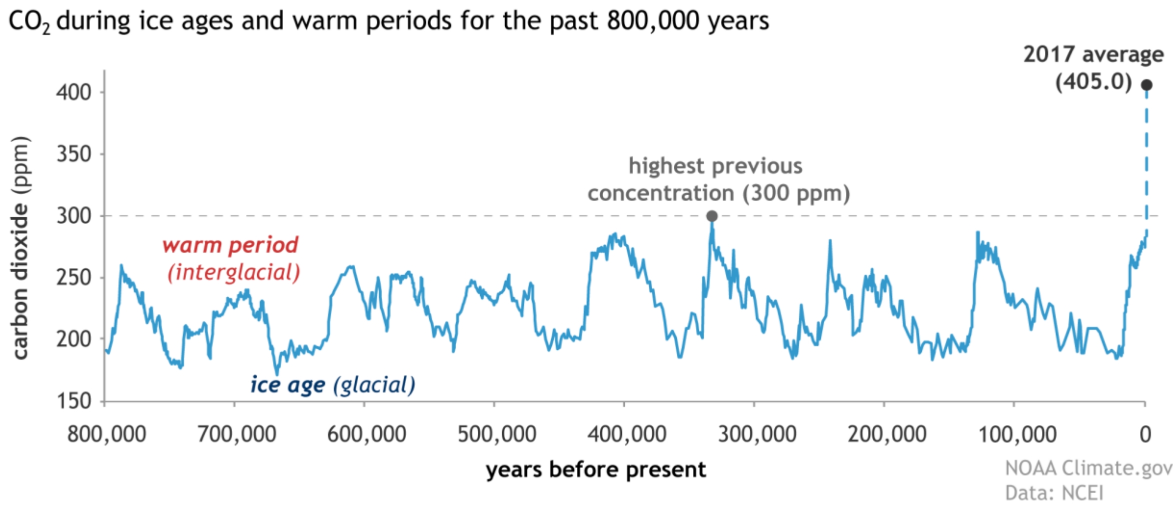




  - Describe and account for the trend in global petroleum consumption. What is the implication of this trend?[11]

- As the world's crude oil diminishes, there will be enormous negative **economic and sociocultural consequences**.
  - What are some economic implications of diminishing crude oil supplies?[12]
  - As the world's crude oil diminishes and prices increase, alternative sources are required to maintain our current standard of living. The lack of alternatives can lead to a drastic decrease in human well-being and safety.

- Combustion of petroleum releases also huge amounts of carbon dioxide (CO_2) into the atmosphere.
  - The graph below shows atmospheric carbon dioxide concentrations in parts per million (ppm) over the past 800,000 years, based on EPICA (ice core) data.



Source: NOAA Climate.gov, based on EPICA Dome C data (Lüthi, D., et al., 2008) provided by NOAA NCEI Paleoclimatology Program.

  - CO_2 is a **greenhouse gas**, so it absorbs infrared radiation from the sun and keeps the Earth warm.
  - CO_2 from combustion is a major contributor to the enhanced greenhouse effect which results in **global warming**.
  - Global warming causes **rising sea levels** which will result in land loss and flooding, more frequent and intense extreme weather events, warming of the oceans and disruptions to the feeding behaviour of wildlife.

- Higher atmospheric CO_2 concentration also causes **acidification of oceans** which threatens aquatic life.
  - Write two equations to illustrate how CO_2 increases the acidity of oceans.

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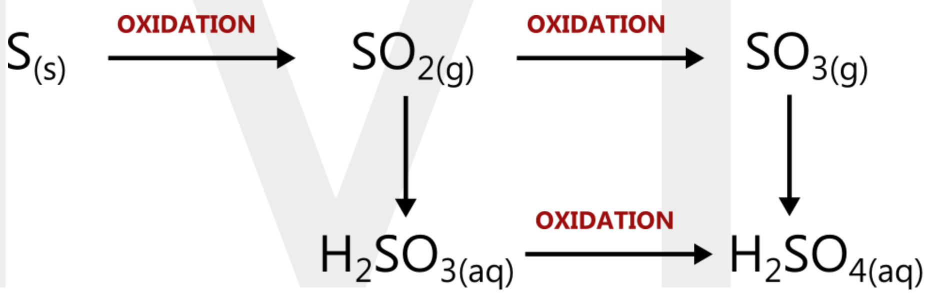
- The combustion of petroleum also releases soot, carbon monoxide and sulfur dioxide into the atmosphere.
  - When are soot and carbon monoxide produced? Explain why they are harmful.

  - Burning of fuels containing **sulfur impurities** produces **sulfur dioxide.**

$$S_{(s)} \quad + \quad O_{2(g)} \quad \longrightarrow \quad SO_{2(g)}$$

  - Sulfur dioxide combines with moisture in the air to form sulfurous acid.
  - Write an equation for this reaction.[13]

  - The sulfur dioxide and sulfurous acid can be oxidised to form sulfur trioxide (SO_3) and sulfuric acid (H_2SO_4) respectively:



  - Dilute solutions of sulfuric and sulfurous acids fall to the earth as **acid rain** which has detrimental environmental effects. Acid rain causes damage to forests as it leaches nutrients from the soil, and decreases the pH of water bodies which negatively impacts fish populations.