AQA GCSE Chemistry (Separate Science) Unit 10: Using Resources

Sustaining Human Life on Earth

The human **population** is **increasing** rapidly and our use of earth's finite resources has increased. If humans continue to use these resources at the rate at which we are, then we will reach a point where the human population cannot be sustained on earth.

Humans use the **earth's natural resources** for warmth, shelter, food, clothing and transport. Scientists are making **technological advances** in **agricultural** and **industrial processes** to provide food and other products that meet the growing needs of the human population but it is of major importance that this is done in a sustainable way so that our finite resources are not used up.

Earth's Resources

Finite resources are those of which there is a **limited supply**, for example coal, oil and gas. These resources can be used to provide energy but, one day, their supply will run out.

Crude oil is processed through **fractional distillation** and **cracking** to produce many useful materials such as petrol, diesel and kerosene.

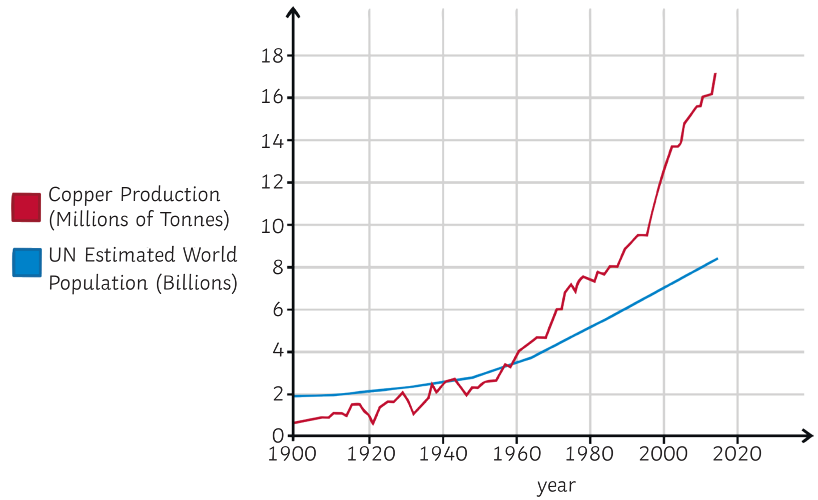
Renewable resources will not run out in the near future because the reserves of these resources are high. Examples of renewable resources include solar energy, wind power, hydropower and geothermal energy.

Haber Process and Copper

Scientists often discover new ways to produce a product; **synthetic methods** of production replace **natural methods**. For example, fertilisers were obtained from manure (a natural resource).

The **Haber process** allowed the synthetic production of **fertilisers** and this enabled **intensive farming** methods to spread across the globe. In turn, this supported the growing human population.

Copper is another resource that has been exploited over time. As the human population has increased since 1900, the demand for copper has also increased. Copper is a finite resource which means that there is a limited supply.



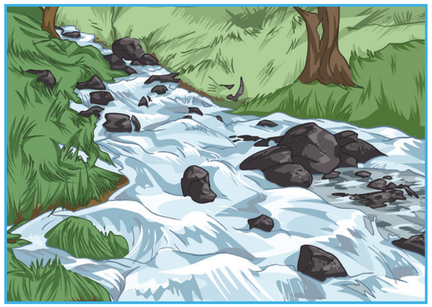
Water

Potable water is water that is **safe to drink**. Potable water is **not pure; dissolved impurities** still **remain** in the water. Pure water is odourless, tasteless and colourless compared to rainfall or water from streams and wells as these **harbour chemicals** such as acid.

Pure – the **definition** of a pure substance is one that contains only a single type of material that has not been contaminated by another substance.

Potable water must contain **low levels** of microbes and salts for it to be deemed safe to consume. This is because **high levels** of microbes and salts can be harmful to human health.

The methods of making water safe vary depending on where you live. Starting with sea water is harder than starting with fresh water. This is because the **energy cost** of removing large amounts of sodium chloride from seawater is greater.



In the UK, our populations' water needs are met through **rainfall**. During the **summer, water levels** in reservoirs **decrease** and local areas are encouraged to reduce their water usage by swapping baths for showers and they are asked to avoid using hosepipes.

In the UK, **insoluble particles** are **removed** from naturally occurring fresh water by passing it through **filter beds**. **Microbes** are **killed** by **sterilising the water**. Several different sterilising agents are used for potable water. These are chlorine, ozone or ultraviolet light. The right amount of chlorine and ozone gas (O_3) must be used as both are harmful to human health.

Desalination of Sea Water

If fresh water supplies are limited, sea water can undergo a process called **desalination**. This process requires **large amounts of energy**, but can be done by distillation or the use of membranes such as **reverse osmosis**.

Distillation involves **heating** the sea water until it reaches **boiling point**. Once the water is boiling, it will begin to **evaporate**. The steam then rises up where it cools and condenses in a condensing tube. The salt is left behind. The **downside** to this process is the **energy cost** of boiling the water and cooling down the steam sufficiently in the condensing tube. Not all of the water evaporates which leaves behind a **salty wastewater** that can be **difficult to sustainably dispose of** without harming aquatic organisms.

Reverse Osmosis of Salt Water

Osmosis, as you will have learnt in biology, is the **movement of particles** from an area of **high** concentration **to** an area of **low** concentration through a **semi-permeable membrane**.

Reverse osmosis involves **forcing water** through a **membrane** at **high pressure**. Each membrane has tiny holes within it that only allow water molecules to pass through. Ions and other molecules are prevented from passing through the membrane as they are too large to fit through the holes.

The **disadvantage** of this method is that it produces **large amounts of wastewater** and requires the use of **expensive membranes**. Due to a large amount of wastewater produced, the efficiency of this method is very small.

Water Treatment

Before the **wastewater** from industry, agriculture and peoples' homes can be released back into the environment, it must be **treated**.

Pollutants such as human waste contain **high levels of harmful bacteria** and **nitrogen compounds** which can be a **danger to aquatic organisms**.

Industrial and agricultural waste may contain **high levels** of **toxic metal compounds** and **fertilisers and pesticides** which may also damage the ecosystem.

Cleaning sewage requires several steps:

Step 1 – The water must be **screened**. This is where material such as branches, twigs and grit is removed.

Step 2 – The water undergoes **sedimentation**; wastewater is placed in a settlement tank. The heavier solids sink to the bottom and form a sludge whilst the lighter effluent floats on the surface above the sludge.

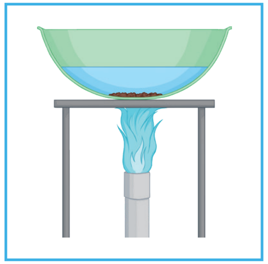
Step 3 - The effluent is then transferred to another tank where the organic matter undergoes **aerobic digestion**. Although not pure, this water can be safely released back into the environment. The sludge is placed in another tank where the organic matter undergoes **anaerobic digestion**. It is broken down to produce fertiliser and methane gas which can be used as an energy resource (fuel).

Required Practical 8 – Analysis and Purification of Water Samples from Different Sources

Analysing the pH of Water Samples

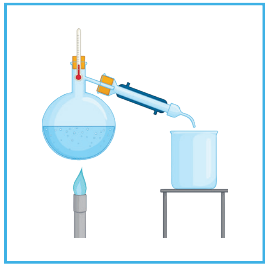
Test the pH of each water sample using a pH meter or universal indicator. If using universal indicator, use a pH colour chart so that you are able to identify the pH of the sample against the colour produced by the indicator.

Analysing the Mass of Dissolved Solids



To measure the mass of dissolved solids in a water sample, measure out $50cm^3$ of the sample using a measuring cylinder. Take the mass of an evaporating basin before heating and record the mass in a table. Place the measured amount of water into an evaporating basin and gently heat over a Bunsen burner until all the liquid has evaporated. Once the evaporating basin has cooled, place it on a top pan balance and record its mass. Calculate the mass of the solid left behind.

Distillation of the Water Sample



To distil a water sample, set up your equipment as per the diagram.

Heat the water sample gently using a Bunsen burner. After a short period of time, distilled water should be produced.

Life-Cycle Assessment (LCA)

Life-Cycle Assessments follow the four main stages of the life cycle of a product.

Stage 1 – Extracting the raw materials needed to make the products and then processing them.

At this stage, the energy and environmental costs need to be considered. For example, if the raw material being used is a finite or renewable resource, the energy to extract and transport the raw material should be considered. Environmental factors also play a large part in stage 1 as the extraction of the raw material can leave scars on the landscape and waste products may be produced that could damage local ecosystems.

Life-Cycle Assessment (LCA) (continued)

Stage 2 – Manufacturing and packaging of the product.

The main consideration is how much energy and resources are needed to manufacture the product. Energy may be used in the form of fuel, electricity or chemicals used in the production of the product. In the manufacturing process, there may be pollution and waste products that need to be considered. Transportation of the goods from the factory to the user will have an environmental impact.

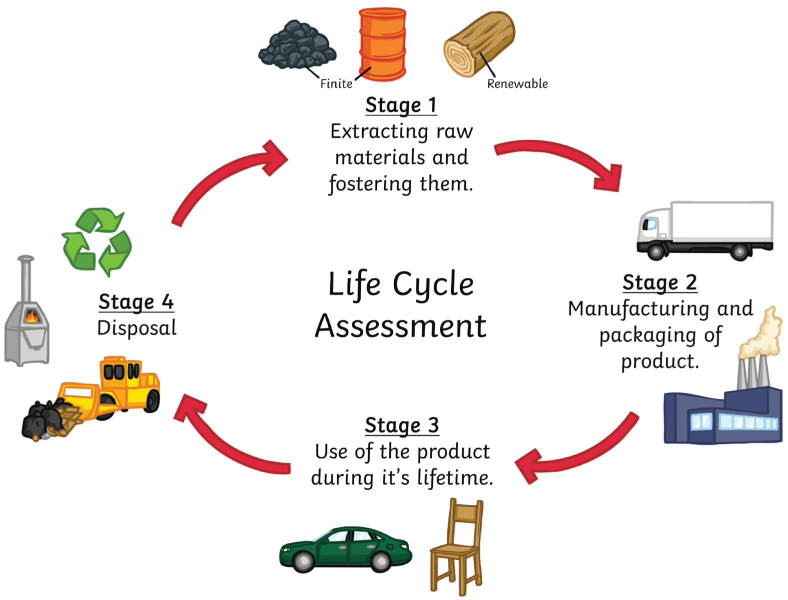
Stage 3 – Use of the product during its lifetime.

The environmental impact of a product during its life depends on the type of product. For example, a car will have a significant impact i.e. it needs to be filled with petrol or diesel, a finite resource, to get to where you are going. A car's engine releases harmful emissions into the atmosphere. On the other hand, a wooden chair may only need minor repairs and is made from a renewable resource.

Stage 4 – Disposal at the end of a product's life.

There are different methods of disposal:

1. Landfill – the product is put in a hole in the ground – high environmental impact.
2. Incineration (organic matter) – burning of the product – low environmental impact.
3. Recycling – for example, batteries contain metal compounds that are not good for the environment. By recycling, it means that no new compounds have to be taken out of the ground.



Comparative LCAs

Comparative LCAs are used to evaluate products and to find which one will have a lower environmental impact.

Stage of Life Cycle	Plastic Bag	Paper Bag
Stage 1 – raw material	Uses a finite resource (crude oil). The processes of fractional distillation, cracking and polymerisation all require energy to make crude oil useful.	Made from trees/recycled paper. Making paper from trees requires more energy than recycled paper because trees have to be chopped down. Still uses less energy than making plastics from crude oil.
Stage 2 – manufacture	Cheap to make.	More expensive to make.
Stage 3 – use	Plastic bags have a low environmental impact as they can be used a number of times. In comparison to paper bags, they are much stronger.	Paper bags can only be reused a limited number of times and so have a short lifetime.
Stage 4 – disposal	The downside to plastic bags is that they do not biodegrade easily in landfill. Recycling options are available. If they are not disposed of correctly, plastic bags can have a detrimental impact on the environment and animal habitats.	Paper bags biodegrade easily in landfill sites.

Disadvantages of Comparative LCAs

The disadvantage of **comparative LCAs** is that some parts of it require certain judgements to be made.

Different people have different opinions and this is dependent on who completes the LCA and whether a certain level of bias is added. For example, if the LCA is completed by a company that is manufacturing a specific product, they may only discuss **some** of the environmental impact of their product in the LCA. Accurate numerical values, for example, show a company how much energy has been used in the **manufacturing process** or how much **carbon dioxide** was produced when the goods were transported.

Recycling

Many materials are made from **natural resources** that have **limited supplies**. Reusing items such as glass bottles that only need washing and sterilising saves energy and reduces the environmental impact. Not all products can be reused, some need to be recycled before reuse.

There are both advantages and disadvantages to recycling materials.

Advantages

- Fewer resources such as **mines** and **quarries** are needed to remove raw, finite materials from the ground. For example, copper.
- Crude oil, the raw material used in the production of plastics, does not need to be extracted. This, in turn, **avoids** high energy cost processes such as fractional distillation and cracking. If more items are recycled, less would end up in landfill sites.
- The amount of greenhouse gases would reduce as the energy cost of recycling is a lot **less** than making a new product.

Disadvantages

- Recycling items require collection and transport of the goods to the organisation. This involves using staff, vehicles and the use of fuel.
- Some materials, such as **metals**, can be **difficult to sort**; the amount of sorting is dependent on the purity of the materials or metals and the level of purity required for the final product. For example, copper used in electrical appliances must have a high purity. To achieve this, the copper needs to be processed and then melted down again to make copper wiring.
- Steel that is used in the construction industry does not require such high purity. Often scrap iron is added to the furnace when steel is made. This reduces the need for as much iron ore and reduces the cost of making steel.

Biological Extraction Methods (Higher Tier Only)

Biological methods of extraction are needed as the resources of **metal ores** on earth are in **short supply**. Large scale **copper mining** leaves **scars on the landscape** and produces significant amounts of waste rock that must be disposed of. Biological methods have a lower impact on the environment and make use of waste containing small amounts of copper. The disadvantages of **biological extraction methods** are that they are **slow**, but they do reduce the need to obtain new ore through mining and conserve limited supplies of high-grade ore.

Phytomining

Phytomining involves the use of **plants**. Plants absorb the metal compounds found in the soil. The plants cannot get rid of the copper ions and it builds up in the leaves. The plants are then **harvested, dried** and then placed in a furnace. The ash that is produced from the burning process contains soluble metal compounds that can be extracted. The ash is dissolved in an acid such as hydrochloric or sulfuric and the copper is then extracted by electrolysis or through a **displacement reaction** with iron.

Bioleaching

Bioleaching uses **bacteria** to produce an acidic solution called **leachate** which contains **copper ions**. The disadvantage of bioleaching is that it produces **toxic substances** that are **harmful to the environment**. To process the copper, the copper undergoes a displacement reaction with iron. Iron is cheaper and a **more cost-effective** way of producing copper from the leachate.

Corrosion

Metals can corrode when **exposed** to **oxygen**; they oxidise and can form metal oxides. Some metals oxidise more quickly than others, like sodium, and some such as gold are very unreactive and do not oxidise at all.

Corrosion occurs when a metal continues to oxidise and the metal becomes weaker over time until it eventually becomes a metal oxide.

Rusting occurs when **iron or steel** reacts with **oxygen** in the **air or water**. Rusting is an example of corrosion.

iron + oxygen + water ⟶ hydrated iron(III) oxide

$4Fe + 3O_2 + 6H_2O \longrightarrow 4Fe(OH)_3$

How Can Rusting Be Prevented?

To prevent rusting, oxygen and water must be kept away from the iron or steel.

Storing the metal in an atmosphere containing unreactive argon prevents it from reacting with oxygen.

A substance such as calcium chloride can be used to absorb water vapour and keep the metal dry.

Barriers to Prevent Rusting

There are several different methods that are used to prevent rusting.

1. painting
2. coating with plastic
3. oiling and greasing

Electroplating

To improve the appearance of metal or to prevent corrosion, a thin layer of a metal can be applied to an object using electrolysis. This process is called **electroplating**.

In electrolysis, there are two electrodes – the **positive anode** (plating metal) and the **negative cathode** (the iron or steel object). The **electrolyte** is the solution that contains the metal ions needed to plate the metal. For example, cutlery made of steel can be electroplated with silver.

Sacrificial Protection

Metals such as iron can be **prevented** from rusting if they are put into contact with **more reactive metals** such as zinc. The reactive metals will react more readily with oxygen whilst iron does not corrode.

We say that the more reactive metal has **'sacrificed'** itself. Once the more reactive metal has corroded away, it can simply be replaced.

Galvanising

Galvanisation is the process of coating iron with zinc. The purpose is to **prevent** oxygen and water reacting with iron and so prevents **rusting**. Zinc acts as a **sacrificial** metal.

Alloys

Name of Alloy	Component Metals	Uses
bronze	copper and tin	bells coins statues
brass	copper and zinc	locks taps instruments door hinges door knobs
gold	Alloyed with other metals such as silver, zinc and copper.	jewellery

Steel Alloys

Steel is an **alloy** made up of **iron** mixed with certain amounts of **carbon**. Different steels have different properties and this determines their use.

- **High-carbon steel** contains a **high proportion of carbon**. This type of steel is **strong and brittle** and is used in the construction industry.
- **Low-carbon steel** contains a **low proportion of carbon** and is softer and more **easily shaped**. This makes it useful for making car body panels.
- **Stainless steel** is made up of **iron** but also the elements **chromium** and **nickel**. It is used for making **cutlery** as it does not rust.

Glass

Glass is made by **melting** a mixture of **sand** (silicon dioxide), **limestone** and **sodium carbonate**. Once it has melted, the molten liquid then cools and solidifies. Glass made with this mixture of ingredients is called soda-lime glass. **Soda-lime glass** is used for window panes, glass jars and bottles.

Glassware that is used in **baking** and in the **laboratory** contains boron trioxide. **Borosilicate glass** has a **higher melting point** than soda-lime glass which makes it better suited to its function where high temperatures are often used.

Ceramics

Ceramics made from **clay** include china, porcelain and brick. Wet clay is shaped and then placed into a furnace where it is heated to a **high temperature**. Crystals form in the clay and join it together.

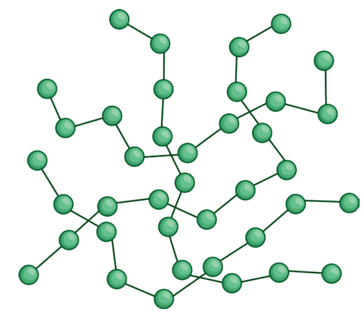
Dinner plates and bowls are made from clay ceramics. Once taken out of the furnace, the ceramics are allowed to cool and are coated with a glaze. This glaze hardens over time and forms a waterproof layer.

Polymers

Polymer properties are dependent upon the **monomer** that it is made from and the conditions in which it was made. For this reason, different polymers have different jobs. For example, **low-density** (LD) and **high-density** (HD) poly(ethene) are made from the monomer ethene using different catalysts and reaction conditions. Low-density poly(ethene) LDPE is flexible and is commonly used in carrier bags and bubble wrap. High-density poly(ethene) HDPE is much stronger, flexible, resists shattering and chemical attack. It is commonly used in plastic bottles, pipes and buckets.

Thermosetting and Thermosoftening Plastics

The polymer chains in **thermosetting plastics** are held together by strong **covalent bonds**. This means that plastics in this group can withstand **higher temperatures** and do not melt when heated – they have **high melting points**. Thermosetting plastics are used to make electrical plugs. Even if there is a fault and the wiring becomes hot, the plastic casing will not melt.



Composite Materials

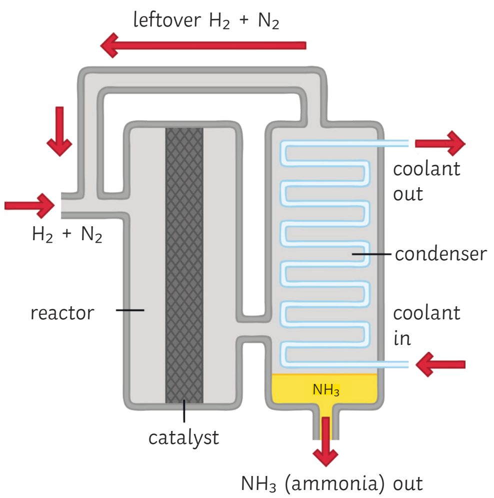
Composites are made up of two materials: a **reinforcement** and a **matrix** which binds the reinforcement together.

Wood is a natural composite. The matrix is **lignin** which is a material that can be found lining the xylem vessels of plants. Wood is reinforced with **cellulose**; in wood, the cellulose fibres are lined up next to each other and this makes the wood stronger in one direction than another. **Chipboard** is a material that can be used for kitchen worktops and doors. Chipboard is made up of **wood chips** (reinforcement) that is randomly arranged and held together by **resin glue** (matrix). This makes it **strong in all direction**s.

Fibreglass and carbon fibre reinforced polymer (CFRP) contain fibres that are strong under tension. Fibreglass contains glass fibres and CRFP contains **carbon fibres**, both of the fibre types are used as **reinforcement**. The fibres themselves are flexible but do not easily stretch. The fibres in each of these composite materials are held together by **polymer resin** (matrix) which helps to bind the fibres together making them stiff.

Concrete is such a versatile material and is often used in the construction industry. The strength of concrete can be increased by **reinforcing** it with other materials such as **wire mesh or steel rods**. The compressive strength of **concrete** (matrix) is greater than its tensile strength. This means that it can withstand more force from crushing than it can force under tension. **Steel** (reinforcement), on the other hand, has greater tensile strength. This means that by combining the two materials, one is created that is both strong under tension and strong under compression. This makes reinforced concrete an important material in the construction of large buildings.

Haber Process



The Haber process is used by the chemical industry to synthesise **ammonia**. Ammonia is used in the production of fertilisers, dyes and explosives.

The reaction is a **reversible** one and involves nitrogen reacting with hydrogen to produce ammonia. As the reaction is reversible, some of the ammonia will decompose back into nitrogen and hydrogen.

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

The reaction mixture is cooled, the ammonia liquifies and is then removed. The hydrogen and nitrogen that has not reacted is recycled to increase the efficiency of the process. The reaction reaches **dynamic equilibrium** and this is where the rate of the forward reaction occurs at the same rate as the backward reaction.

In the Haber process, nitrogen and hydrogen are pumped through pipes at a pressure of **200 atmospheres**.

Nitrogen is obtained by extraction from the air and hydrogen is obtained from natural gas. The gases are passed through a tank containing a **catalyst** (iron); catalysts speed up the rate of a chemical reaction without getting used up themselves. The gases are heated to **450°C** as they pass through the tank.

The reaction mixture is allowed to cool and this allows the ammonia to turn from a gas to a liquid. Once this has happened, the ammonia is removed. Any unreacted nitrogen and hydrogen is then recycled.

Fertilisers

Fertilisers contain lots of **mineral ions** that are key to the growth of healthy crops. Plants absorb these minerals through their root hair cells; these mineral ions need to be replaced and so farmers need to add fertiliser to the soil in order to replace the lost mineral ions.

Farmers often use **NPK fertilisers**. These are fertilisers that contain the elements **nitrogen, phosphorus and potassium**.

- Ammonium nitrate - NH_4NO_3 - and ammonium sulfate - $(NH_4)_2SO_4$ - are examples of fertilisers that contain the essential element nitrogen.
- Ammonium phosphate - $(NH_4)_3PO_4$ - contains the elements nitrogen and phosphorus.
- Potassium nitrate - KNO_3 - contains the elements potassium and nitrogen.

Ammonia

Ammonia has the chemical formula NH_3.

Ammonia produces the ammonium ion NH^{4+} when it is involved in neutralisation reactions. Ammonia is an alkali. Oxidation of ammonia produces nitric acid HNO_3; nitric acid is the source of the nitrate ion NO^{3-}.

alkali + acid ⟶ salt

ammonia + nitric acid ⟶ ammonium nitrate

$NH_3 + HNO_3 \longrightarrow NH_4NO_3$

In aqueous solutions:

ammonium hydroxide + nitric acid ⟶ ammonium nitrate + water

$NH_4OH + HNO_3 \longrightarrow NH_4NO_3 + H_2O$

Mining

The raw materials for fertilisers need to be mined. The minerals needed to make fertilisers are extracted from the **earth's crust**.

Potassium chloride and **potassium sulfate** are a source of potassium ions and are used as fertilisers. **Phosphate rock** is **insoluble** and so cannot be used in fertilisers, but it does contain **phosphorus** which when reacted with acid, will produce **soluble compounds**.

Phosphate rock when reacted with **nitric acid** produces calcium nitrate and phosphoric acid.

Phosphate rock when reacted with **sulfuric acid** produces a mixture of calcium sulfate and calcium phosphate which is called single superphosphate.

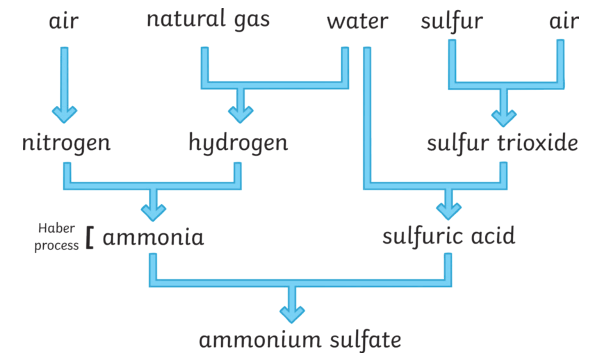
Phosphate rock when reacted with **phosphoric acid** produces calcium dihydrogen phosphate also called triple superphosphate.

Ammonium Sulfate

The salt ammonium sulfate ($(NH_4)_2SO_4$) is used as a fertiliser and is made when ammonia and sulfuric acid react.

ammonia + sulfuric acid ⟶ ammonium sulfate

$2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$



Chemical Industry

To make sulfuric acid, sulfur, air and water are needed.

Sulfur first reacts with oxygen to produce sulfur dioxide. The sulfur dioxide further reacts with oxygen at a temperature of 450˚C to produce sulfur trioxide. This in turn reacts with water to produce sulfuric acid.

In the Laboratory

Ammonium sulfate is produced by reacting ammonia solution with sulfuric acid.

Stage 1 – A measured amount of ammonium sulfate solution is poured into a conical flask.

Stage 2 – Two to three drops of the indicator methyl orange is added. The ammonia solution will turn yellow as it is an alkaline.

Stage 3 – The conical flask is placed under a burette containing sulfuric acid. Slowly the sulfuric acid is added to the flask until the indicator turns orange. If the indicator turns red, this means that too much acid has been added.

Stage 4 – Once the solution turns orange, the volume of acid that was added is recorded and the neutral ammonium sulfate solution containing the indicator is discarded.

Stage 5 – The experiment is then repeated with the same volumes of sulfuric acid and ammonia solution, but this time the indicator is not added. The solution is then heated and the water evaporates leaving behind crystals. The crystals left in the evaporating basin are then placed in an oven.

The Advantageous and Disadvantages of Industrial vs Laboratory Method of Fertiliser Production

Industrial Method

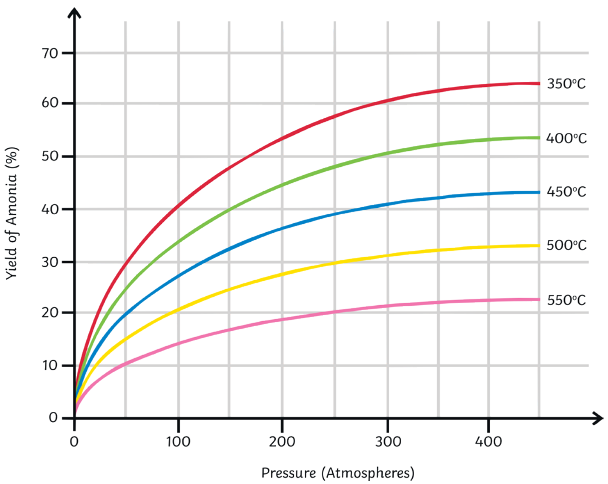
The industrial method of production requires a temperature range between 60-450°C, depending on the stage in the production process. As this is a **continuous method** of production, it requires the use of expensive machinery. The starting materials in this method are acquired from **raw materials** with **large quantities** of fertiliser being made **quickly**. The cost of labour is reduced by using **automated mechanisms** and machines.

Laboratory Method

The laboratory method, on the other hand, is much **slower** and more **labour intensive** and this makes the **running costs high**. The starting materials for this method are purchased directly from a chemical supplier. As this is a batch process, the **equipment** used is **relatively cheap**. A Bunsen burner is used for heating and room temperature is required for the neutralisation stage.

Haber Process – Higher Tier Only

The graph shows that as the temperature increases, the yield of ammonia decreases.



Increasing Temperature

As the temperature increases, the **equilibrium** position moves to the **left** and the **yield** of ammonia **decreases**. Using a low temperature may seem the most sensible option, but if the temperature is too low then the rate of reaction will also be reduced. That is why the temperature that is chosen is a **compromise** between the **yield** and **rate of reaction**.

Increasing Pressure

In a reaction where gas particles are reacting or produced, increasing the pressure will **shift** the **equilibrium** position to the side with the **fewest moles of gas**.

In the Haber process, the right-hand side of the equation has the fewest number of molecules; if the pressure is increased, then the equilibrium position will shift to the right and the yield of ammonia will increase. The disadvantage to using higher pressures are that more expensive equipment is required to cope with the increased pressure and this increases energy costs. The decision here is a **compromise** between **yield** and **cost**.

Catalysts

Catalysts are useful in the Haber process as they **speed** up the rate of reaction in both directions. The time taken for the system to reach **equilibrium** is reduced. A catalyst does not affect the position of the equilibrium or the yield. Using a catalyst allows a low temperature to be used whilst also keeping the yield high.

Reducing Cost

Any unreacted hydrogen and nitrogen are recycled back into the reactor and this reduces the cost of making raw materials. Energy is a large cost. Often, exothermic reactions where energy is released are used to heat up other parts of the process.