

Your visit to a chemical company should enable you to learn some general principles about the way the industry uses chemistry. This activity will help you prepare for your visit to ensure that you get the most out of it.

Preparing for the visit

You may be asked to prepare for the visit in groups. The most appropriate preparation will depend on the exact nature of the industry that you are going to visit and how much you already know about it.

Some of the industries visited by groups of students studying the Salters Advanced Chemistry course are given in Table 1.

Industries that use chemical processes

Heavy chemical industry

You will be familiar with some of the chemicals manufactured at these sites; they include sulphuric acid, ammonia, sodium hydroxide, chlorine, iron, nitrogen, calcium oxide, methanol, poly(ethene), and other petrochemicals.

Fine chemicals

These include pesticides and dyestuffs. Fine chemicals will often be less familiar as they are made in relatively small amounts for special purposes. Many fine chemicals are described as 'building blocks', as they are used for making more complex chemicals.

Pharmaceuticals

The industry provides examples of small-scale research, large-scale development and production.

Other process industries

These include:

- cement production
- brick-making
- other building materials production

Food processing

- breweries
- dairies
- bakeries

Cosmetics, toilet preparations

Glass industry

Metal foundries

- anodising
- electroplating

Polymer processing

Quarrying and mining

Environmental monitoring and analysis

- | | |
|-------------------------|-----------------------|
| ● water treatment | ● sewage treatment |
| ● waste disposal | ● public health |
| ● forensic laboratories | ● hospital pharmacies |

Table 1

The questions on the following sheets are for you to consider or to adapt to fit your specific visit: they won't *all* apply to your visit, for you may see and study anything from work being undertaken in a research laboratory to an industrial plant producing thousands of tonnes of product a day.

1 Products

- a What product or products will you focus upon on your visit?
- b How much of each product is made?
- c Are they made by a batch or continuous process?
- d What are these products used for?
- e What else does the company produce?

2 Personnel

- a What kinds of people should you expect to meet?
- b What proportion of them will be scientists or engineers?
- c What qualifications will these scientists and engineers have?
- d What will be the role in the company of each scientist and engineer?

3 Plant and laboratory location

- a Why are the plant and laboratories located at this site?
- b Was the decision to locate the facilities at this site influenced by any of the following considerations?
 - i Availability of raw materials.
 - ii Availability of a suitable workforce.
 - iii Location of the market for the product.
 - iv Availability of transport for raw materials and products.
 - v The means by which the waste is disposed of.
 - vi Availability of an appropriate energy supply.
 - vii Availability of suitable land.
 - viii Proximity to other sites.

4 Starting materials

- a What are the starting materials (feedstock) for the processes you will see on your visit?
- b Where do these starting materials come from (raw materials)?
- c Are there alternative sources of the starting materials?
- d How is the choice of starting materials made?
- e How are the materials transported to this site?
- f What alternative methods of transport exist?
- g How is the choice of transport made?
- h How much processing have the materials already undergone? Why was this done elsewhere and not on this site?
- i Is material recycled? If so, how?

5 Scale

- a On what scale are the reactions carried out? (This could be millions of tonnes to a few mg.)
- b Are there any chemicals involved which are easy to handle in the laboratory in small amounts, but which may present problems if they are used in bulk?
- c Would it be possible to carry out any of the reactions on a small scale in the laboratory?
- d Would it be possible to carry out small-scale reactions on a large scale?
- e How are large quantities of solid conveyed to reactors?
- f What are the costs and hazards associated with crushing or melting?
- g If powders are converted to slurries to be pumped, what will happen at the next stage to the water (or other liquid) used?
- h How are bulk solid chemicals weighed?
- i How are liquid volumes (or masses) measured (either bulk or small-scale)?
- j How does the apparatus or plant relate to your school laboratory equipment?

6 Rate and yield

- a If a batch process requires a certain time for reactants to be together, how would you monitor the extent of the reaction and so decide when to pass the products on to the next stage or isolate them?
- b If the reaction is carried out as a continuous process, how could you ensure that the reactants stay in the reactor for the right length of time?
- c What is the yield? Using a chemical equation, you can find the yield of a reaction by comparing the mass of product theoretically possible from the given starting amounts with the mass actually obtained.
- d If you are visiting a research laboratory, does yield matter in research?
- e If you have available some information about actual yield, you could consider:
 - i Why isn't it higher?
 - ii How could the yield be increased?
 - iii What difference would a change in the yield make?
- f What conditions of temperature, pressure and concentration are used in the reaction vessels?
- g If any stage of the process involves the use of a catalyst, on what basis has the catalyst been chosen? (Is it the only one available, or the most efficient, or the cheapest?)
- h How does the choice of temperature, pressure or catalyst affect
 - i the rate
 - ii the yield of the process?
- i Does this choice of conditions represent a compromise between rate and yield?

7 Heating and cooling

- a If heating is necessary, what is the energy source?
- b Why is this the most appropriate source?
- c Are alternatives available?
- d If cooling is necessary, how can this be achieved?
- e Is any thermal energy recycled? If so, how is this done?
- f You will be familiar with exothermic reactions taking place in the laboratory – if the reaction is likely to get out of control, the vessel may be cooled in a beaker of ice. As the volume is scaled up from the laboratory to full-size by a factor of L^3 , the area available for cooling increases by a factor of only L^2 . (L is length.)

Explain why this is a potential problem and suggest how it can be overcome.
- g If you can obtain figures for the energy output or input of a particular stage, you could compare these with the output of a typical home central heating boiler ($70\,000\text{ kJ hour}^{-1}$).

8 Other products

- a If you have enough information about the reaction(s), you may be able to answer questions about the *other* products. For example:
 - i What co-products and by-products are formed in the process? Are they undesirable? Why?
 - ii How can their formation be minimised?
 - iii How are they separated from the main product?
 - iv How are they disposed of (or used)?
 - v How pure are the final products?
 - vi How is this purity monitored?
 - vii What are the main impurities?
 - viii Do the final products need to be pure?

9 Construction materials

- a What construction materials are used to make the vessels and pipes on a plant?
- b How is the choice of materials related to the chemicals and conditions involved?

10 Layout

- a What is the logical way to lay out the various parts of the plant or laboratory? Consider:
 - i access to the point at which the starting materials will be delivered
 - ii storage requirements
 - iii hazards associated with the storage and handling of the chemicals involved
 - iv moving chemicals between stages of the process
 - v access to coolants
 - vi access to treatment and disposal areas for wastes
 - vii access to appropriate transport to remove the finished product
 - viii positioning of desks and computers.

11 Names and units

- a You may find that the company uses different names and units from the ones you are used to.
Using whatever information you have available, make a list of all the chemicals which you expect to be used or made by the company. (Check that you have used the correct full names.)
- b For each name, try to find out an alternative name. Many transition-metal compounds and most organic compounds have non-systematic or 'trivial' names which may be used by the company.
- c If you look at literature available from the company, you may be able to anticipate any tradenames or abbreviations for names which the company uses.
- d What units of measurement are used by the company? How do these compare with the units you use?

12 Safety

- a What are the hazards associated with any chemicals which you know the company uses or manufactures?
- b For each hazard involved, suggest how the hazard will affect their use and the design and operation of any plant or laboratory.
- c Will you have to take any specific precautions on your visit because of these hazards?
- d What would happen if there were to be an accident?
- e What waste is there?
- f How does the company dispose of waste?
- g What protective clothing do scientists and operatives wear?
- h How does the company monitor safety?

13 Legislation

- a What legislation will affect the company in its operation of the processes which you are going to visit? For example, consider:
 - i health and safety at work
 - ii environmental practice
 - iii quality control.

14 Environmental matters

- a What stages of the process could put the environment at risk?
- b What are the main environmental problems associated with the process?
- c What emission control procedures are used?

- d Which effluents are likely to be produced?
- e What treatment will be necessary before disposal?
- f How are levels of pollutants in waste monitored?
- g Some chemical companies collect all the rainwater that falls on their site and treat it before allowing it to drain into a river or the sea. Is this a necessary step at the site you are to visit?

15 Costs

- a Do costs matter?
- b What are the major fixed costs?
- c What are the major variable costs?
- d Compare the significance of the scale of these costs.
- e What is the capital cost of the plant at current prices?
- f Where did the capital to build the plant come from?
- g How long did, or will, the initial capital take to be recouped?
- h Over what period of time was it envisaged that the plant would be written off?
- i How will the operation and viability of the plant be affected by:
 - i interest rate changes?
 - ii exchange rate changes?
 - iii inflation rate changes?

The visit

Enjoy it and make the most of it!

Try to talk with as many people as possible during your visit. Ask questions about anything that you do not understand – remember that these people may find it difficult to imagine what you know (or don't know).

Besides your questions about the processes and chemicals, take the opportunity to ask personnel you meet about their jobs and the career paths they followed to get to their present positions.

Remember to thank people who show you round or talk to you.

Report on the visit

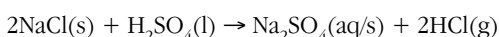
You will need to set aside time for 'debriefing', that is, sharing your findings about the company. Whether you decide to make a written report, a poster display or a 'stand up' presentation, remember that the company which hosted your visit will be interested to have some kind of feedback. There may be others who would be interested in the report you produce.

The siting of the first large scale Solvay process plant for sodium carbonate in Britain provides a good illustration of the factors involved in site selection. This activity also enables you to study a complete production process and relate it to some general principles of industrial chemical production.

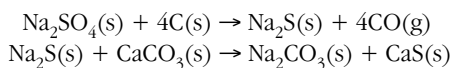
The story of Winnington

In the 1800s, more and more sodium carbonate (Na_2CO_3) known as soda or soda ash was needed, for example, in the manufacture of soaps, glass and paper. All these are commodities that a growing and more affluent population would need as Britain enjoyed the benefits of the industrial revolution. (Details of the current production and range of uses of sodium carbonate are given in **Information Sheet 1a**.)

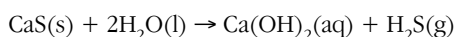
At that time, soda was made by the Leblanc process. First salt was heated in concentrated sulphuric acid:



Then, the sodium sulphate was heated with coal and limestone (calcium carbonate):



In those days the hydrogen chloride was discharged from chimneys and blew across the countryside, rotting trees, destroying crops, corroding machinery, searing lungs. What's more, the residue from the process was a black sludge that contained large amounts of calcium sulphide, CaS . Calcium sulphide hydrolyses readily to produce hydrogen sulphide (H_2S):



Hydrogen sulphide is a poisonous gas with an evil smell of rotten eggs. It was extremely unpleasant for everyone living in the vicinity. Overall, the process led to dreadful pollution of town and countryside. And it was a waste of materials – wasting hydrogen chloride, using up sulphur to make the sulphuric acid, all to make just one useful compound.

A German chemist, Ludwig Mond patented an idea in 1861 to recover some of the sulphur and persuaded John Hutchinson, one of the largest manufacturers of soda, to use it. It was here at Hutchinson's works at Widnes, near Liverpool, that Mond met John Brunner, the company's office manager. Mond and Brunner decided to set up on their own, but to use a newer process, invented by the Solvay family in Belgium. It was a cleaner process that used sodium chloride and calcium carbonate, two plentiful materials, as before. But instead of sulphuric acid, it used ammonia in a clever series of inter-related reactions (these are described in **Information Sheet 1b**). There were no poisonous co-products and no atmospheric pollution from waste hydrogen chloride and hydrogen sulphide.

But where should they site their new factory? Here is the description from a historian, Carol Kennedy.

Looking for a suitable site, the partners went on long country walks around Northwich – then, as now, the centre of the Cheshire salt industry. They needed a source of brine which could be pumped straight into the works, Solvay's process making it unnecessary to convert it first to solid salt. Limestone supplies were nearby in Derbyshire, while railway links to Liverpool and the Midlands provided easy access for supplies of the principal raw material, ammonia. In March 1873 they found what they were looking for, an estate belonging to the distinguished diplomat Lord Stanley at Winnington, with a part-Tudor, part-Georgian mansion from whose windows they could see the Cheshire salt-pans smoking. The house, Winnington Hall, had not been lived in by the Stanley family for about twenty years. It had most recently been used as a girls' school at which Sir Charles Hallé had given recitals and John Ruskin had lectured on art. The whole 627-acre estate, including a railway siding, was bought for £16,108 and, since the land was already mortgaged for £12,000, the partners had ready liquidity. By May, Mond had established an 'office' in the Angel Hotel at Northwich, and on 12 May he sent his first letter on notepaper headed Brunner, Mond & Co., Manufacturers of Carbonate of Soda (Pure Soda Ash), Winnington Park, Northwich.

Mond had at first wanted to demolish Winnington Hall, but John Brunner, unable to find suitable accommodation locally for his large family, persuaded his partner that if repairs were done to the house they could both live comfortably in it. Their first office was the old harness-room, where they sat on opposite sides of a double desk; later, a cowshed was converted to a clerks' office and the loft above it pressed into service as a drawing-office. The partners hoped to start production by September, while the price of soda remained high, but Mond had trouble with suppliers and also with the local workmen, who were hostile to the idea of another soda works fouling the surrounding farmland, and who distrusted this guttural foreigner with his rough black beard, outlandish clothes, dictatorial ways and sudden outbursts of temper. Neighbouring landowners, too, were preparing to use the new Alkali Act to prosecute if they got the chance.

On top of all this, there were troubles with the manufacturing process itself, not yet perfected by the Solvays. 'Everything that could break down did break down,' John Brunner recalled in later years, 'and everything that could burst did burst.' Boilers exploded and one man died of burns. Mond never forgot the experience and for years afterwards refused to allow pressures of more than 100 pounds in his works, or to have steel pipes of more than two inches in diameter, restrictions which hampered a great deal of modernisation.

Brunner, Mond were in full production by the middle of 1874, selling their first soda ash at a loss of £5 a ton. They found it difficult at first to get contracts because customers saw no reason to change from the old Leblanc product with all its impurities: they were simply accustomed to buying the stuff by the bucket, regardless of its purity. To persuade them, Mond, who was a brilliant salesman, demonstrated the economy of the purer product by giving away smaller buckets.



Figure 1 Winnington Hall, Cheshire, Lord Stanley's country estate where John Brunner and Ludwig Mond founded their soda-ash business in 1873. The ladies in their crinolines on the lawn contrast with the life of their near neighbours living in Widnes (Chemical Storylines page 291).

Much later, in 1926, the Brunner, Mond company, with Alfred Mond, the second son of Ludwig at its helm, combined with Nobel Industries (founded by Albert Nobel), and two other British companies to form a single company, Imperial Chemical Industries, the giant ICI, one of Britain's greatest enterprises. Today Winnington still produces sodium carbonate and the site is as well situated as it was in 1873 although ICI have sold the company and it now proudly boasts the names Brunner, Mond.

What you do

1 Use the description of the stages of the Solvay process in **Information Sheets 1a** and **1b** (*The Solvay process*) to answer the following questions.

- Suggest reasons why the Solvay process is operated as a continuous process rather than a batch process.
- Use the Solvay process to help you explain the terms:
raw materials, feedstock, co-products, recycling.
- What are the two main raw materials for the Solvay process?
- Coal, as a source of coke, could also be considered as a more minor raw material but why, theoretically, is the statement in the extract from Carol Kennedy's book referring to ammonia as a raw material not correct?

'... supplies of the principal raw material, ammonia.'

2 Explain why Mond and Brunner chose Winnington (see **Information Sheet 2** *Location of Winnington*) as the site for their company. Then discuss whether Winnington would be any more or less suitable if a location for a Solvay process plant was being sought today.

Information Sheet 1a: The Solvay process

Annual production and uses of sodium carbonate

In Britain the annual production of sodium carbonate is about 1 million tonnes and the world production is about 33 million tonnes.

When it is first made it is called **light sodium carbonate**.

In Britain about 70% of this is converted into a granular form called **heavy sodium carbonate**.

The major uses of the heavy form are as a solid in making glass, where it is used as a flux in the melting of sand (silica, silicon(IV) oxide). For light sodium carbonate the major uses are traditionally those where the chemical is required in solution (Figure 1).

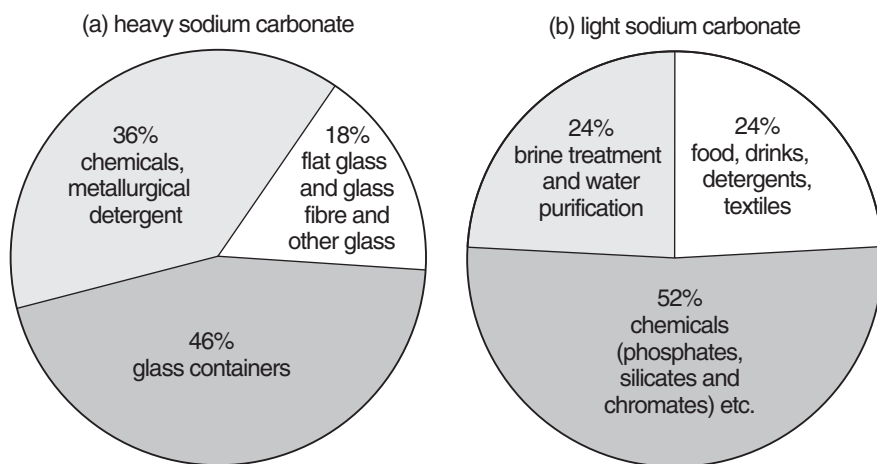
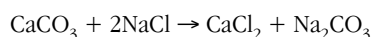


Figure 1 Uses of sodium carbonate

Outline of the process

The overall reaction can be regarded as one between calcium carbonate (limestone) and a solution of sodium chloride (brine):



But it is no use just adding limestone to brine as it is too insoluble to react with the sodium chloride. The Solvay process achieves the overall change by an ingenious roundabout route. Brine is treated with carbon dioxide (made by heating limestone) and ammonia. The ammonia is recovered at a later stage in the process and recycled. The product is obtained by a series of seven stages. The stages are interlinked with some co-products being used in later stages. The Solvay process is made up of a set of *continuous processes* with reactants being continually fed into reactors and products being continually withdrawn. It is represented in Figure 2.

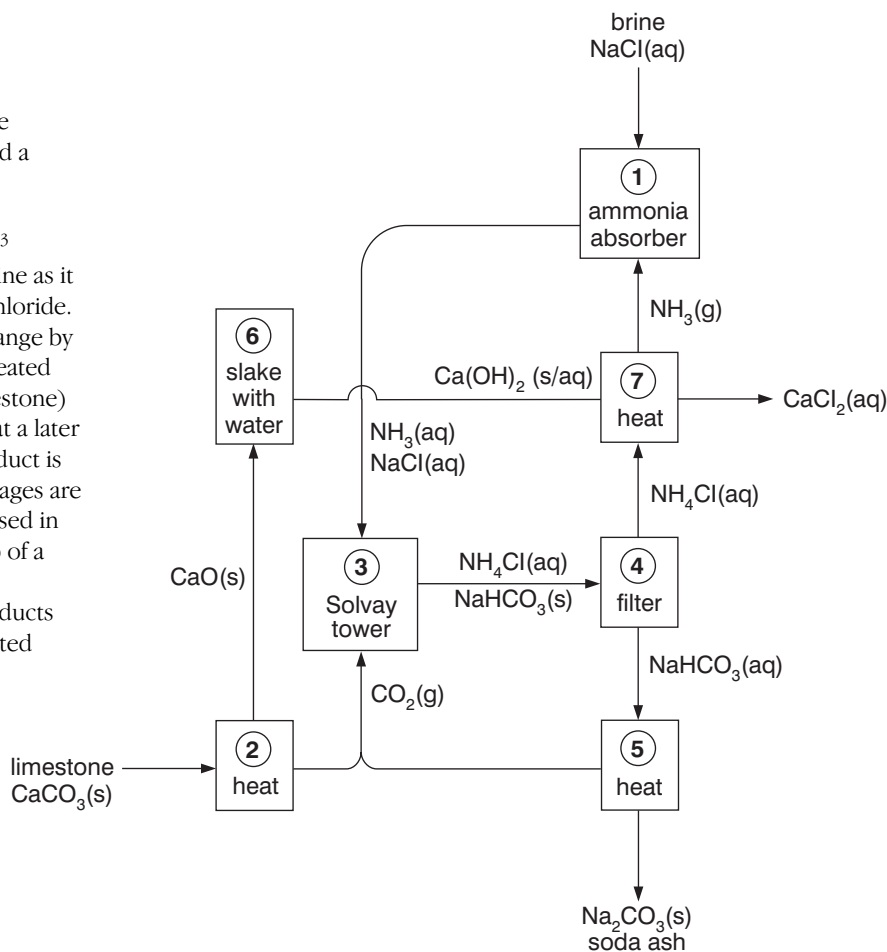


Figure 2 The stages of the Solvay process are linked as shown (descriptions of the stages are given in **Information Sheet 1b**).

Information Sheet 1b: The Solvay process

Stages of the process

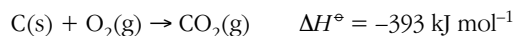
The numbered stages correspond to the numbers in Figure 2 on **Information Sheet 1a**.

① Ammoniation of brine

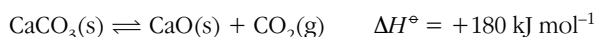
Ammonia gas is absorbed in concentrated brine to give a solution containing both sodium chloride and ammonia. Na^+ , Cl^- , NH_4^+ , OH^- ions and $\text{NH}_3(\text{aq})$ are present.

② Formation of calcium oxide and carbon dioxide

Kilns are fed with a limestone/coke mixture (13:1 by mass). The coke burns in a counter-current of preheated air:



The energy released raises the temperature of the kiln and the limestone decomposes:



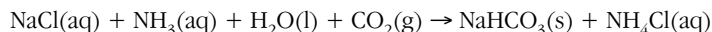
The gas is sent to the carbonating (Solvay) towers. The residue, calcium oxide, is used in ammonia recovery (see steps 6 and 7 below).

③ The Solvay tower

This is the key stage in the process. The ammoniated brine from step 1 is passed down through the Solvay tower while carbon dioxide from steps 2 and 5 is passed up it. The Solvay tower is tall and contains a set of mushroom-shaped baffles to slow down and break up the liquid flow so that the carbon dioxide can be efficiently absorbed by the solution. Carbon dioxide, on dissolving, reacts with the dissolved ammonia to form ammonium hydrogencarbonate:



The solution now contains ions Na^+ , Cl^- , NH_4^+ and HCO_3^- . Of the four substances which could be formed by different combinations of these ions, sodium hydrogencarbonate (NaHCO_3) is the least soluble. It precipitates as a solid in the lower part of the tower, which is cooled. The net process is:



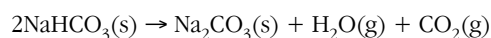
A suspension of solid sodium hydrogencarbonate in a solution of ammonium chloride is run out of the base of the tower.

④ Separation of solid sodium hydrogencarbonate

The suspension is filtered to separate the solid sodium hydrogencarbonate from the ammonium chloride solution, which is then used in step 7.

⑤ Formation of sodium carbonate

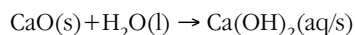
The sodium hydrogencarbonate is heated in rotating ovens at 450 K so that it decomposes to sodium carbonate, water and carbon dioxide:



The carbon dioxide is sent back to the Solvay tower for use in step 3. The product of the process, anhydrous sodium carbonate, is obtained as a fine white powder.

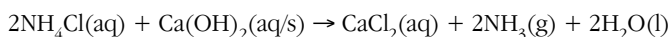
⑥ Formation of calcium hydroxide

The last two steps, 6 and 7, are concerned with the regeneration of ammonia from ammonium chloride (made in step 3). The quicklime from step 2 is slaked with excess water giving milk of lime:



⑦ Regeneration of ammonia

This calcium hydroxide suspension is mixed with the ammonium chloride solution from step 4 and heated:



The ammonia is thus recovered, and sent back to step 1.

The overall process is an elegant one. In theory, the only raw materials are limestone and brine. Inevitably, there are losses of ammonia, and these are made up for by addition of extra supplies, as required in step 1.

Information Sheet 2: Location of Winnington

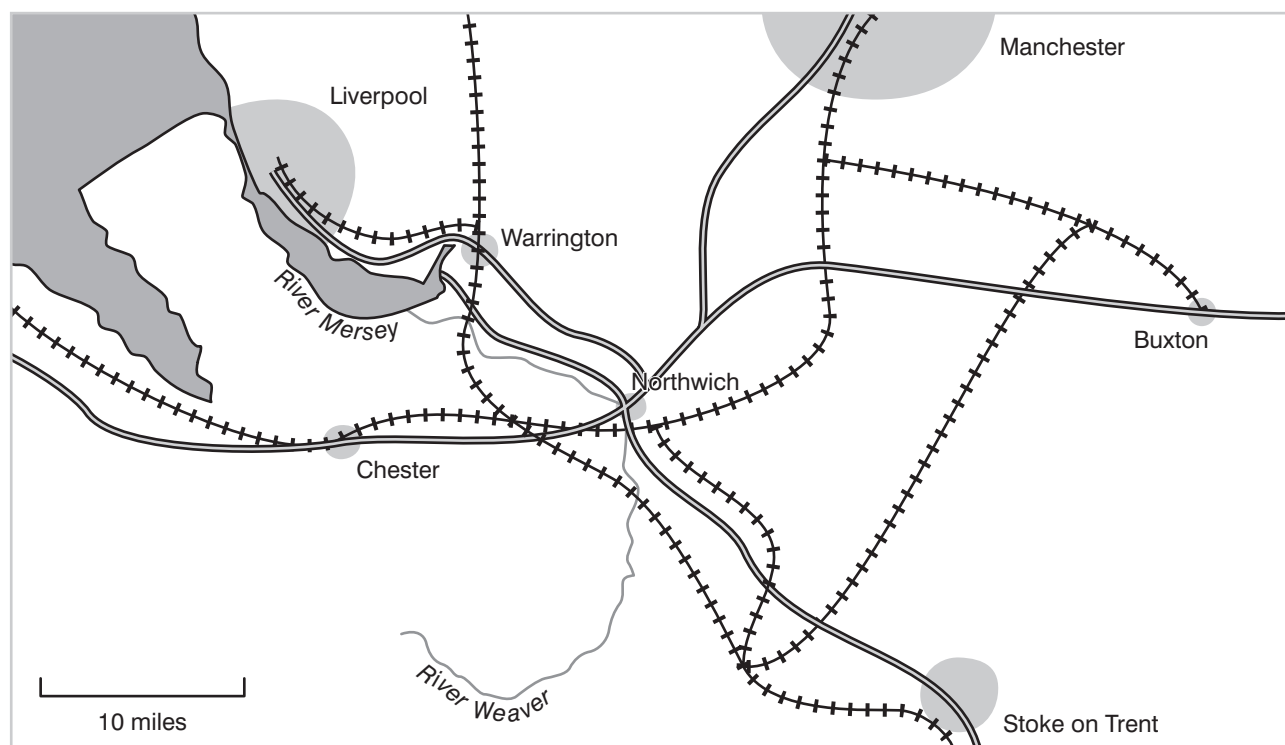


Figure 1 A map showing some of the transport links to and from Northwich prior to the construction of motorways

The Winnington site is situated on the bank of the River Weaver at the northern edge of Northwich. The Weaver was navigable and as can be seen from the map the river, as well as the railway, provided transport routes to the docks at Liverpool.

When the works first began in 1874 the brine needed for the Solvay process was pumped directly from natural subterranean brine streams. A number of shafts for the extraction of brine were located within 5 miles of the site and some were actually on the Winnington Hall land.

The modern method of extracting brine involves sinking boreholes into the rock salt and forming brine by forcing water at high pressure into the rock salt. Once a cavity of a certain size has been created in the rock salt, it is left full of saturated brine. This avoids subsidence problems which was a serious problem with earlier methods.

Limestone came from quarries in the Buxton area and initially it was transported by river and rail but rail became the preferred route and is still used today.

Coal is used for boilers and furnaces but it is also converted to coke to mix with the limestone in the lime kilns. In 1874 there were operating coal fields nearby in Lancashire, Derbyshire, Nottinghamshire and North Staffordshire. In the 1920s Brunner, Mond acquired their own coal mine in Madeley near Stoke on Trent. Both rail and river transport were used but eventually rail became the preferred method until the road took over in modern times.

Although ammonia is recycled in the process it does have to be topped up from time to time. Initially it was obtained as an aqueous solution from gas works in Liverpool and transported by river. Now it is obtained in the forms of a more concentrated liquor by road from Billingham where it is made by the Haber process which was first set up there by Brunner, Mond in 1920.

Water is always a necessary raw material for any chemical works for the production of steam and for cooling. The Weaver was used as a convenient source but it contained too much salt which led to corrosion problems, so later alternative sources were found a few miles from Winnington.

**Check your notes on
Visiting the Chemical
Industry**

This activity helps you get your notes in order.

Use this list as the basis of a summary of the unit by collecting together the related points and arranging them in groups. Check that your notes cover the points and are organised in appropriate ways.

Most of the points are covered in the **Chemical Ideas**, with supporting information in the **Storyline** or **Activities**. However, if the *main* source of information is the Storyline or an Activity, this is indicated.

- The stages in the manufacture of a new product: research, pilot study, scaling-up, production and review.
- The characteristics of effective and successful chemical processes in terms of:
 - raw materials and feedstock
 - batch or continuous process
 - rate, including use of catalysts
 - product yield
 - nature of co-products and by-products
 - waste disposal and effluent control
 - location
 - safety and cost(these points are covered in **Activity VCI 7**).
- The influence of the chemical properties of reactants and products on the selection of suitable materials for the construction of a chemical plant.
- The control of pollution from chemical plants and its economic implications.