activities related to industry
for 13 - 16 year olds

CAPTAINS OF INDUSTRY

HYDRO

MAKING USE OF SCIENCE AND TECHNOLOGY

Other units in the MUST series include:

SWEET SUCCESS solves problems at a confectionery manufacturer when there are complaints of glass in sugar mice. Students are involved in a study of solution and rates of crystallisation. Activities include laboratory work, data interpretation, evaluation, oral reporting, small group work and problem solving.

FIT TO DRINK examines the different options for solving the problems of nitrate in drinking water supplies. Water is analysed for the presence of nitrate, chloride and other anions. Activities include hypothesising, laboratory work, evaluation, oral reporting, small group discussion and decision-making.

WEARING JEANS compares processes for manufacturing faded jeans. Enzymes, natural polymers and rates of reaction are studied. Activities include laboratory work, evaluation, oral reporting, small group discussion and poster presentation.

HYDROGEN AS AN ENERGY CARRIER looks into the future at a non-polluting energy economy based on solar power and hydrogen as a transportable fuel. The preparation and properties of hydrogen are central to the study. Activities include laboratory work, data interpretation, evaluation, small group discussion, strategic planning, poster presentation and numerical exercises.

WHAT A GAS ? looks at the foaming and use of expanded polystyrene. Students make an expanded polystyrene sphere and study changes of state and the structure of simple hydrocarbons. Activities include laboratory work, data interpretation, small group work and decision making to identify a suitable blowing agent.

WAR AGAINST PESTS reviews different strategies for pest control.
Predator-prey relationships are studied. Activities include data interpretation, oral reporting, small group work, interviewing, poster presentation and creative writing.

RECYCLING CITIES covers the use and recycling of polymers. Principles of recycling and degradation are related to aspects of manufacturing and economics. Activities include laboratory work, data interpretation, identification, oral reporting, small group work and strategic planning.

FROZEN ASSETS investigates the environmental impact of de-icers. Osmosis, lowering of freezing point, and corrosion of road structures are used as the basis of tests to evaluate different de-icers. Activities include laboratory work, data interpretation, evaluation, oral reporting, poster presentation, small group work and decision-making.

ALUMINIUM, CRADLE TO GRAVE is an analysis of the environmental impact of aluminium through all the stages in the life of products. Extraction and uses of aluminium are covered. Activities include classification, data interpretation, evaluation, oral reporting, small group work and decision making.

HOT CHOCOLATE deals with the effect of both company logo and the design of a van on the ability to keep chocolate in good condition during transport. Students study melting point as well as refraction and reflection of heat at curved surfaces and the effect of colour and texture on the absorption of radiation. Activities include laboratory work, data interpretation, evaluation, oral reporting, small group work, design and decision-making.

MAGNOX deals with the design of a system to store spent nuclear fuel. The reaction of group II metals with water and carbon dioxide, and the operation of a fission reactor are studied. Activities include laboratory work, model-making, oral reporting, small group work, poster presentation and numerical problems.

CAPTAINS OF INDUSTRY

A unit for 14 - 16 year olds

Acknowledgements

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Captains of Industry is one in a series of units entitled **Making Use of Science and Technology**.

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CAPTAINS OF INDUSTRY

Synopsis

The United Kingdom fertiliser industry is faced with stiff competition from abroad, due chiefly to the dual-pricing policies of foreign exporters of energy and raw materials. Students study the manufacture of fertilisers and examine how effectively raw materials and energy are used. Mass and energy balances, and other data, are used to identify opportunities to revive an unprofitable company. Students plan action to rescue the company.

This unit offers opportunities for students to work with other professionals in the classroom. A representative from the commercial section of a local bank, or a local industrialist, could help to give students a very real impression of what it is like to be a captain of industry for the day.

What the students do

- Study the use of raw materials, and the impact of waste products and their management, by constructing a mass balance for the manufacture of fertiliser.
- Construct the use of in the manufacture of fertiliser and ways of recycling waste heat.
- Interpret and present data for a meeting with bankers.
- Evaluate strategies and make decisions about running a major industry.
- Study the outline chemistry of the synthesis of ammonia and the production of nitric and sulphuric acids.
- Decide whether the use of energy to manufacture fertiliser is a good use of a scarce resource.

Key ideas

- Neutralisation and salts
- Exothermic and endothermic reactions
- Haber Process and Contact Process
- Use and recycling of energy by industry
- NPK fertiliser
- Agriculture as a an energy trap
- Raw materials, and waste products versus co-products

Timing

The activities in this unit require could be completed in the equivalent of one lesson of 70 minutes, with homework, and a report back session of 30 minutes. However, practical work on neutralisation or energy changes could be associated with this unit, with activities being completed over an extended period.

Contents

Copy masters

SAG = Student Activity Guide   SIS = Student Information Sheet

Planning ahead

Teachers may wish to invite another professional into the classroom to work with students during parts of this unit. A local bank manager or a manager or engineer from any large scale industry would be a suitable choice for this unit.

Contacting an industrialist

In the absence of personal contacts through local organisations or school governors, the following organisations will be able to help with initial contacts:

Science and Technology Regional Organisations (SATRO's)

Your regional SATRO's location can be obtained from the address below or your own LEA:

Association for Schools' Science Engineering & Technology
1 Giltspur Street
London
ECIA 9DD
Tel: 020 72942431
Email: asset@scsst.uk.com Web: http://www.asset.org.uk

School Curriculum Industry Partnership (SCIP)

Your LEA should be able to put you in touch with the local SCIP.

Chemical Industries Association (CIA)

The CIA will provide free of charge a visitor who will tailor a contribution to meet your needs. For details, write to:

Speak Out! and Listen
Chemical Industries Association
Kings Buildings
Smith Square
London SW1P 3JJ
FAO Jo Townsend
Tel: 020 7963 6792 Fax: 020 7233 6202
E-mail: enquiries@cia.org.uk, townsendj@cia.org.uk
Web: http://www.cia.org.uk/industry/speak.htm

The Engineering Council

The Engineering Council will have details of your local Engineering Council Regional Organisation (ECRO) and Neighbourhood Engineers. Details are available from:

Engineering Council (UK)
10 Maltravers Street
London
WC2R 3ER
Tel: 020 7240 7891 Fax: 20 7379 5586
E-mail: staff@engc.org.uk Web: http://www.engc.org.uk

Visitors to the classroom would need a clear brief so that they can respond positively and constructively to the work that students produce. Information in the Teachers' notes is included for this purpose.

Teachers' notes

These notes include comments on lesson management for the unit outline suggested overleaf and also further background information for the teacher. Corresponding Student Activity Guides (SAGs) and Student Information Sheets (SISs) could be read alongside these notes.

Introduction

Students prepare plans to revive a non-profitable company manufacturing 1000 tonnes per day of NPK fertiliser. The activities allow students to experience what it is like to be a ‘captain of industry’ for the day, making strategic decisions involving huge sums of money. The decisions would affect the wealth of the nation and the employment of thousands of people. However, students will not have to live with the consequences of the decisions they make!

The unit divides conveniently into four parts:

1. Understanding a flow chart for fertiliser manufacture
2. Preparing a mass balance for fertiliser manufacture
3. Investigating the use of energy in fertiliser manufacture
4. Decision-making and preparing plans to rescue the company

This unit could be used as a unifying theme for work on industrial chemistry (synthesis of ammonia and sulphuric acid, etc.) with the four parts being completed one at a time over an extended period, alongside practical work on neutralisation and exothermic and endothermic reactions. The unit could also be used as a justification for studying the chemistry of ammonia synthesis in greater depth.

Other classes might use the activities as the focus for small group work, with the preparation of a mass balance and charts on energy use and energy costs being delegated to group members. The activities could also be used in combination with class discussion and homework, working from overhead transparencies rather than duplicating sheets for students. The notes that follow assume that students will be working in small groups.

A role for an industrialist or banker

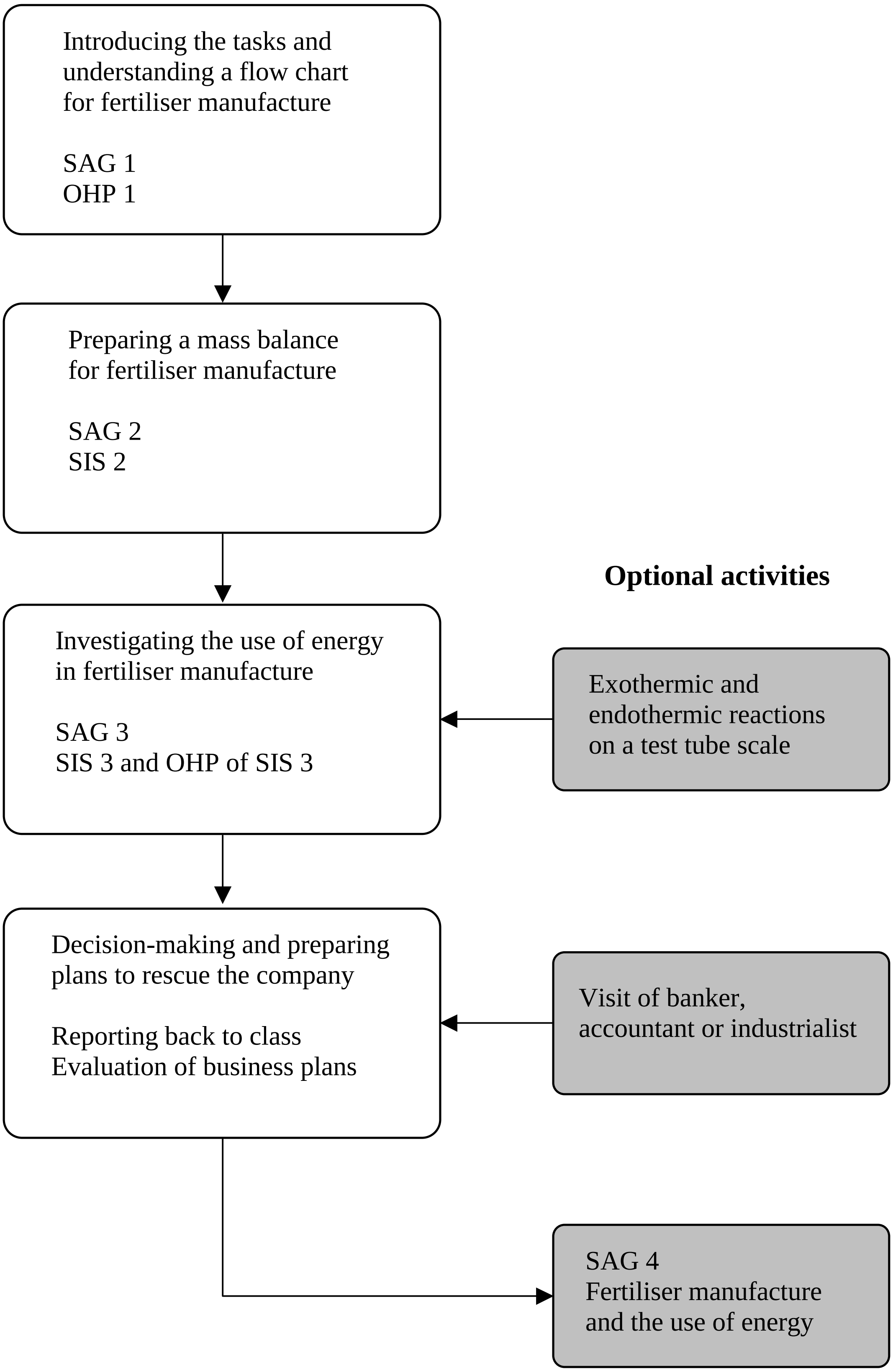
Students could be asked if they would enjoy the challenge of working with a banker, accountant or industrialist, who would help to develop their plans to rescue an unprofitable fertiliser industry. A banker, accountant or industrialist could also make judgements about the amount of money, if any, that they would be willing to risk to finance the students' rescue plans.

The banker, accountant or industrialist could act as a consultant to groups during the decision-making part of this activity, or could lead a report back session where groups of students reveal their plans to the rest of the class and test their impact and credibility on an expert with professional experience.

Careful planning of time and group sizes will be essential to get the best use of a professional from outside the classroom. Teachers could combine decision-making and reporting back in the same session, as an alternative to the unit outline overleaf. In that case, students would have a homework period to study and evaluate the suggestions offered on SAG 1.

If it is not possible to bring another professional into the classroom, the teacher could play the role of banker or the school/college accountant may help.

A suggested unit outline



Lesson management

1. Understanding a flow chart for fertiliser manufacture (20 minutes)

Student Activity Guide SAG 1 could be issued to students to set the scene for the activities that follow. Students adopt the roles of 'captains of industry'; that is the senior directors whose responsibility it is to ensure that the company runs efficiently. The (optional) visit of a banker or industrialist would also need to be explained at this stage.

Fertiliser manufacture is not profitable anywhere in the European Community, for reasons outlined in Appendix 1, but a viable fertiliser industry is an essential component of a healthy domestic economy. The importance of the fertiliser industry in the United Kingdom may be considered important from two points of view:

- Maintenance of self-sufficiency in terms of arable crops
- The potential of crops to offer a future alternative and renewable supply of the raw materials presently obtained from fossil fuels.

SAG 1 requires students to complete two tasks. The first is the organisation of further information on the use of energy and raw materials – this involves the preparation of a mass balance and also bar charts on the cost of energy used in fertiliser manufacture. This information is required before students attempt the second task, which is an evaluation of the ideas offered by the chief executive. Students should be discouraged from spending time studying these ideas in the first stage.

The flow chart for fertiliser manufacture is next introduced to students using OHP 1. This flow chart is common to all the activities and sufficient time will need to be spent in ensuring that students can understand the layout. It might be helpful to colour the acid plants in red, the ammonia plan in blue and plants where salts are present in green. NPK fertiliser is a mixture of three soluble salts – ammonium nitrate, ammonium phosphate (chiefly $(NH_4)_2HPO_4$, though this need not be mentioned to students) and potassium chloride. Brief revision of major plant nutrients may be required.

Simple questions could be raised in class discussion, so that students are encouraged to find their way around the flow chart and handle terms such as 'plant'. For example, questions of the type:

- How many raw materials are used to make ammonia?
- What are the names of the salts produced?

Questions should be based on the previous knowledge of students and could be chosen to emphasise some of the following points:

- Fertilisers are salts – they are made by neutralisation reactions.
- Raw materials are converted first to acids and bases (intermediate products).
- Some of the ammonia is used as a base and some is converted to nitric acid.
- Nitrogen is obtained from air. Hydrogen is needed to 'fix' the nitrogen in a soluble form, ammonia NH_3. The hydrogen is obtained by using methane, in North Sea gas, to reduce water.
- Sulphuric acid is needed to obtain phosphate in a soluble form.
- Phosphorus and potassium compounds are extracted from mined ores. There are deposits of potassium chloride (sylvinite) ore in northern England. Calcium phosphate ore is imported from North Africa (Morocco and Tunisia), the United States (Florida and North Carolina). The deposits are of sedimentary origin - they are based on animal bones and shells.

In the following activities, teachers could emphasise that the amounts of materials and energy used are quantities that are involved **every day** in what is effectively a small company producing about one tenth of our national fertiliser needs.

2. Preparing a mass balance for fertiliser manufacture (20 minutes)

SAG 1 shows that raw materials account for the highest percentage of manufacturing costs. Their efficient use is vital to a profitable industry. A mass balance shows how well the raw materials are used. It compares the masses of what goes into the manufacturing site with what comes out. The proportions of raw materials that are converted to useful products and waste products are easy to see from a completed mass balance.

Students complete the mass balance on SAG 2. The information needed, provided by the 'company engineers', is set out on SIS 2. For some classes, it may be appropriate to blank out the guide boxes on the right hand side of the mass balance on SAG 2 before sheets are duplicated.

On SAG 2, some initial prompting may be required when students first identify five plants – ammonia, sulphuric acid, phosphoric acid, evaporation, and purification – as the sources of waste products. When matching waste products to plants, students could be asked to check that choices based on arithmetic are confirmed by a careful study of the elements present in the raw materials and waste products. For example, the carbon dioxide waste is associated with the North Sea gas (chiefly methane CH_4), which is the only significant source of carbon. Some care will be needed when adding the five arrows to SIS 2, to avoid overlapping the flow chart lines.

A completed mass balance is included in Appendix 3. This may be copied onto an OHP transparency so that groups can more easily check their answers. The completed mass balance should be available for the decision-making part of this unit, which is the second task on SAG 1.

Students could be asked if the quantities of waste products are more or less than they expected. If, later on, students decide that the waste products are a valuable asset, rather than an unwanted and costly component of waste management, they could be asked if the term ‘co-products’ might be more appropriate. The term ‘waste product’ will acquire a very precise legal meaning within EC environment legislation. The anticipated financial penalties of generating waste products is therefore further motivation for industry to make efficient use of raw materials.

Completeness of information on SIS 2

Quantities of water (steam) used for heat transfer are not included on SIS 2. To keep SIS 2 as simple as possible, the supplies of air for oxidising 63 tonnes/day of ammonia to nitric acid are not shown separately, but are included in the 2000 tonnes of air shown above the sulphuric acid plant. Perceptive students may therefore report a missing 237 tonnes/day at the sulphuric acid plant, which corresponds to the mass of oxygen required at the nitric acid plant. Similarly, the mass of water produced by oxidation of ammonia is included in the figure given for mass of nitric acid.

The final product contains over 10% impurities, chiefly form the calcium phosphate and potassium chloride ores. Masses of impurities are included in the figures given.

3. Investigating the use of energy in fertiliser manufacture (30 minutes)

Energy could also be regarded as a raw material. It accounts for the second highest percentage of manufacturing costs shown on SAG 1. Concerns over the Earth's limited reserves of fossil fuels, and also global warming, are important justifications for investigating the use of energy, to see how efficiently the industry uses this valuable resource.

Students use SAG 3 to produce their own bar charts to show how the efficient use of energy can lead to substantial cost savings. The information needed, provided by 'company engineers', is set out on SIS 3. The activity is challenging and might best be completed alongside class practical work on endothermic and exothermic reactions. The reaction of ammonium nitrate with water (endothermic, $\Delta H = + 21$ kJ/mole) and the neutralisation of a hydrochloric acid with sodium hydroxide solution (exothermic, $\Delta H = - 57$ kJ/mole) are examples of test tube reactions that gibe good temperature changes. Practical details are available in many text books. Teachers could emphasise that energy has to be supplied to break chemical bonds and energy is released when new chemical bonds are formed. The burning of magnesium ribbon may be a more useful example of an exothermic reaction if teachers wish to mention activation energy.

Students may not be familiar with the *gigajoule* as a multiple unit of energy. *One gigajoule is 1,000,000,000 joules*. It may help to point out that the loudest and most spectacular rock band would use only *3 gigajoules*, GJ, to power all the sound systems, lighting effects, spots, rigging and lasers at a major event (gig !) at National Exhibition Centre or Wembley.

SAG 3 refers to energy escaping to the surroundings as waste heat. Students may have seen maps of industrial sites and populated areas produced by satellites measuring radiation from the Earth's surface. If students are familiar with using 'energy grow' diagrams, it may be an appropriate place to ask them to predict where the energy is going.

Students are asked to draw on SIS 3 the release of energy from exothermic reactions. SIS 3 is kept neat if students are advised to draw all the arrows coming out from the left hand side of the plants. Students may need some guidance in mapping out the recycling of energy on SIS 3.

The sum of exothermic reactions is 7250 GJ per 1000 tonnes of NPK fertiliser. The overall enthalpy change (overall energy released in chemical reactions) is only 5000 GJ. The difference is accounted for by the endothermic reactions (such as the reduction of water by methane) in the ammonia plant. A proportion of the direct energy input into the ammonia plant helps to drive the endothermic processes. With some classes, it will not be appropriate to draw attention to this accounting.

Mapping out the recycling of energy on SIS 3

The recycling of 'concentrated heat' back into the manufacturing process reduces the quantity of direct energy input required. This exercise assumes that all the energy released by exothermic reactions can be recycled. Teachers could ask the class to identify plants that release more energy than is needed to run them (these could be called energy exporters) and those plants that use more energy than they release by way of exothermic reactions (energy importers).

Students should be given some help to begin the mapping by a teacher completing an example on an OHP transparency of SIS 3. For example, the 1900 GJ released from the sulphuric acid plant may be recycled to meet all the 1400 GJ needs of this plant and still leave 500 GJ left over to contribute towards the running of, say, the phosphoric acid plant.

Heat Exchangers

The idea of heat exchange, to get useful heat to where it can be used, could be compared to the heating of a hot water storage tank in a central heating system.

Completeness of information and qualifications to data on SIS 3

The following points may address questions that the teach might have, but the issues should not be raised with students unless they question the data:

The energy figures quoted on SIS 3, and also the cost data on SAG 1, are adjusted to represent a manufacturing plant where there is no recycling of energy. Figures do not include the energy required to mine or to transport the calcium phosphate and potassium chloride ores, nor the energy required to secure supplies of North Sea gas.

The figure quoted for the ammonia plant does not include the energy content of North Sea gas used as feedstock (raw material), because this value will be reflected in the figure for the overall enthalpy change.

The recycling of energy is simplified and in practice it is not possible to recycle all the energy released from exothermic reactions. Also, some of the heat is at too low of a temperature to be useful for heat exchange in the reactors or for pre-heating of reactants. It may be used instead to power steam turbines to generate electricity. The inefficiency of electricity generation results in a yield of only 26% of some of the quoted figures as useful electrical energy.

Answers to questions on SAG 3 are as follows

- Amount of (direct) energy needed to manufacture 1000 tonnes of NPK fertiliser is 10000 GJ. The energy is obtained chiefly by using North Sea gas as a fuel, in addition to that used as a raw material for ammonia production, and electricity.
- Total energy that might escape as waste heat is 15000 GJ. This is the direct energy input of 10000 GJ plus the overall enthalpy change of 5000 GJ when raw materials are converted to 1000 tonnes of 17:17:17 NPK fertiliser and co-products.
- The value of the waste heat is £300000 each day.
  Note that this figure is not the daily energy bill because a significant proportion of waste heat derives from the enthalpy content of the raw materials. The figure of £20 per GJ is based on a domestic electricity tariff of 7.2p per unit (kWh).
- With recycling of ‘concentrated heat’, the smallest amount of (direct) energy that must be supplied to make 1000 tonnes fertiliser is 2750 GJ.
- Money saved by recycling ‘concentrated heat’ is £20 x 7250 = £145000 each day. This is a 72.5% reduction on the daily energy bill of £2000000 for 10000 GJ.
- The energy recovery system would pay for itself in 69 days.
  This figure does not take into account interest charges on the loan, nor the cost of shutting down the plant during installation of the energy recovery system. A more realistic scenario is the design of energy recovery systems in brand new plants, where the recovery of heat is the most vital component in engineering a profitable operation.

4. Decision-making and preparing plans to rescue the company (30 minutes)

Once students have completed a mass balance and produced bar charts on potential energy savings, they should work in groups and use this information, *together with the pie chart on costs on SAG 1*, to plan ways of making the industry more efficient. The suggestions offered by the chief executive should be evaluated. Students should consider whether ideas of their own can be added. The aim is to produce a 'business plan' for the future that will be convincing enough to persuade a bank manager to lend money to finance any investment that is required to recycle waste heat or to rescue the industry. At its simplest, the business plan could be a list of priorities for action selected from the chief executive's ideas.

A representative from a local bank (as a merchant banker), an accountant or a local industrialist, who need not have a background in fertiliser manufacture, could act as consultant to groups during the decision-making phase and might also run an evaluation session if students are asked to present their plans to the rest of the class.

Comments on the chief executive's ideas are offered below for the benefit of the teacher, industrialist, accountant, or banker. Students should make their own judgements on the value of the chief executive's ideas, though information should be provided if requested. Some of the comments could be raised when students' business plans are revealed to the rest of the class, but care is needed to make sure that students' plans are not judged unsuitable on the basis of information that they were not given.

Waste management costs

∗ **Employ scientists to find uses for the waste products. Then sell the waste.**

Huge amounts of waste products are generated. The waste gases shown could be (but are not) released harmlessly and at little expense into the atmosphere. The majority of waste management costs are due to the large bulk of *solid* calcium sulphate and its toxic content. The calcium sulphate is significantly radioactive due to accumulation of U-238 from phosphate rock; it contains harmful cadmium compounds also from the phosphate rock; and it has a pH = 2. If money is invested to clean up the calcium sulphate, it might be used in plaster manufacture or as a white pigment in paints. However, the supply of calcium sulphate already far exceeds demand.

Students may recognise that the carbon dioxide could be sold for use in fizzy drinks or fire extinguishers. They may also suggest that the impure nitrogen from the sulphuric acid plant is purified and recycled in the ammonia plant. Fertiliser plants abroad, but not in the UK, use the carbon dioxide to react with ammonia to make urea fertiliser $CO(NH_2)_2$, which contains the highest percentage of nitrogen by mass of all solid fertilisers. Unlike nitrates or ammonium salts, the nitrogen in urea is only available when bacteria break down the fertiliser. This process may not be sufficiently rapid in the climate of the UK spring. Urea is particularly effective as a fertiliser in rice growing areas.

Nitrogen oxide emissions from the nitric acid plant amount to much less than 0.1% of total nitrogen used. These quantities are insignificant in mass terms for this exercise, though not in terms of environmental impact. They are not shown in the scheme set out.

∗ **Reduce waste management costs – dump the solid waste in the sea.**

This option would greatly reduce waste management costs and result in the appearance in court of the directors.

∗ **Avoid some of the costs of waste management by importing phosphoric acid.**

This would also gratly reduce waste management costs by eliminating the calcium sulphate waste, but the corresponding increase in raw material costs may be greater. This option also transfers the problem of harmful waste into somebody else's back yard. People inclined towards NIMBY (Not In My Back Yard) views may not make the direct connection between difficult waste management issues and the standard of living they enjoy as a result of highly developed industries.

Energy costs

∗ **Make better use of energy. Redesign plants and build heat exchangers to recycle waste heat.**

Huge amounts of energy are used in manufacturing. It makes sense to recycle waste heat where it is cost effective to do so. Only a small proportion of the direct energy input can be profitably recycled with present technology.

Heat exchangers would be costly to incorporate in existing sites, but a good investment in new designs. There are no fully integrated plants currently in operation in the United Kingdom, but at some plants the heat produced in the nitric acid and sulphuric acid plants generates steam to drive electricity generators. However, due to the unavoidable inefficiency of electricity generation, 14500 GJ of heat energy yields only 400 GJ of useful electrical energy.

∗ **Move the industry to a source of cheap hydro-electric power.**

Cheap power appears an attractive proposition. However, hydro-electric power is rarely available close to the centres of fertiliser consumption. Potential savings would be offset by increased distribution costs, not to mention the costs of scrapping and rebuilding of the plant.

Raw material costs

∗ **Find cheaper raw materials - use sulphur dioxide (in emission gases from coal-fired power stations) for the manufacture of sulphuric acid.**

It makes sense to try to use waste materials from other industries as raw materials. Students would have to be satisfied that alternative sources could meet the demands of producing five million tonnes of fertiliser a year.

Emissions of sulphur (as sulphur dioxide) are currently two million tonnes annually in the UK. However, to remove sulphur dioxide gas would be more expensive than importing sulphur. Existing techniques of removing sulphur dioxide using limestone produce calcium sulphate - a product already in excess supply and one that is not useful for economic manufacture of sulphuric acid.

There is no economic alternative to importing phosphate rock. Basic slag from blast furnaces was previously a source of phosphorus, but the import of better quality ores for modern steel making results in waste that now contains much less than 1% phosphorus.

∗ **Manufacture abroad, where the raw materials are cheaper.**

Moving abroad could result in a return to profits for the company, but at the expense of jobs, national wealth and the balance of payments.

Running costs

∗ **Employ fewer people and save money.**

Reducing the workforce may result in increased costs if maintenance is neglected.

* **Most fertiliser is used in spring. Reduce storage costs by selling fertiliser at a discount from June to February. We could earn interest on money that is paid.**

Production is continuous, but supply of fertiliser is highly seasonal. 80% of fertiliser has to be made available to farmers in the 6-8 week peak growing period in spring. It is expensive for manufacturers to tie up money in stock. Discounting is a good idea to sustain cash flow for the purchase of raw materials. Interest payments would also be reduced.

* **Run the industry at a loss to save jobs.**

This option can not be sustained without government aid. The company must make profit for shareholders as well as products for the market.

Others

* **Quit the fertiliser industry and find other uses for ammonia and acids.**

Students may identify other uses for ammonia (synthetic fibres, dyestuffs, explosives) and acids (detergent manufacture), but the size of the markets is very much smaller than the current capacity to manufacture fertiliser.

* **Quit manufacturing. Import fertiliser and act as a wholesaler.**

The huge capital cost of £200000000 invested in plant would be wasted.
The impact on the balance of payments of importing 5000000 tonnes of fertiliser would be very significant. Importing all our fertiliser needs would make every family in the UK worse off by approximately £100 per year.

Bringing the lesson to an end

The form of the final reporting back by groups will depend on whether or not a banker or industrial representative is working with students in the classroom. The business plans may be written up for homework, or presented to the class at the beginning of the following lesson. 30 minutes should be allowed for the reporting back and de-briefing session.

5. Optional activity - SAG 4
Is fertiliser a good investment of scarce energy resources?

Students may wonder if the huge investment of energy in fertiliser manufacture is worthwhile. The teacher could pose the question, “Could better use be made of scarce energy resources?” In SAG 4, which may be used as an additional and optional homework or class exercise, sets out data that allows students to reach a decision based on the effect of straight nitrogen fertiliser on the yield of winter wheat - the main arable crop in the UK.

Teachers may wish to make the distinction at this point between NPK fertilisers and straight nitrogen. Appendix 2 gives background information for the teacher on the nutrient requirements of winter wheat and the timing of fertiliser application.

The figures for yield of winter wheat on SAG 2 are averages for the UK. The yield of wheat in the absence of fertiliser varies from less than 1 to more than 7 tonnes/ha depending on previous cropping, soil type, climate and use of animal manures. Application of straight nitrogen at 200 kg N/ha (approximated to 0.5 tonnes ammomium nitrate fertiliser/ha) gives a yield **increase** that can vary from zero to 7 tonnes/ha depending on climatic and agronomic conditions. The energy value for harvested grain is quoted at 85% dry matter.

Teachers may wish to emphasise the dominance of manufacturing in the total energy costs of using fertiliser.

The main source of energy in agriculture is the sun. Plants may be regarded as energy traps - they capture and use the sun's energy, which is later harvested in the form of a crop. Agriculture involves an energy input (labour, fuel, fertiliser) as an investment in order to obtain the crop. The data on SAG 4 will show that the optimum use of straight nitrogen fertiliser on winter wheat results in the trapping by the crop of four times as much energy from the sun as the amount of (largely) fossil fuel energy invested in manufacturing and using the fertiliser. This very favourable ratio is not always the case. Cereal crops and root crops usually give a net gain in useable energy, whilst fruit and some vegetables give a net loss. The table below shows for different crops the approximate ratio of harvested energy to total energy input (labour, fuel, etc as well as fertiliser).

Crop	Ratio
Sugar beet	3.5
Wheat	3.0
Maize	3.0
Oats	2.5
Rice	2.0
Potatoes	1.5

Crop	Ratio
Brussels sprouts	0.7
Tomatoes	0.6
Apples	0.4
Oranges	0.3
Spinach	0.2

Source: Agriculture and Fertilisers – a report from Norsk Hydro

Where the energy ratio is less than one, students may point out that agriculture is still vital; firstly because we cannot eat coal and natural gas, and secondly because we eat to obtain essential minerals and vitamins as well as energy.

80% of all fertiliser nitrogen ends up in animal feed. Similar arguments could be used to defend the poor efficiency of energy transfer in livestock farming.

The manual work of traditional agriculture in developing nations is more energy-efficient than mechanised agriculture in industrialised nations, but this one measure of success is not related to the ability to produce sufficient food to continuously meet the requirements of the population. If time permits, issues such as these may be raised in class discussion.

Answers to questions on SAG 4

a) 23.4 GJ

b) Extra food is harvested at the rate of 3 tonnes of wheat grain per hectare.
Fertiliser is spread at the rate of 0.5 tonnes per hectare.
The energy value of the extra food obtained is therefore:

$$3 \times 2 \times 15.6 = 93.6 \text{ GJ per tonne of fertiliser}$$

On the basis of data provided, the use of fertiliser on winter wheat appears to be a good use of scarce energy resources.

Profitability in fertiliser manufacture

In the face of increasing competition on a world level, the profitability of fertiliser manufacture in the UK and the rest of the European Community has been poor for many years. Imports of fertiliser account for over 20% of the domestic market and this share is expected to increase. Production capacities in the EC have decreased and companies have sought a return to profitability through the increased efficiency. Changes in agricultural practices and environmental policy indicate a further decrease in fertiliser demand in the EC.

There are two main reasons for the competitive disadvantage of the fertiliser industry in the European Community:

Raw material costs (natural gas and phosphate rock) are unfavourable

The cost of ammonia production is to a large extent dependent on the price of natural gas, for use as raw material and as a fuel. The price of natural gas is, in turn, linked to the price of oil. Many oil producers charge a very low price for natural gas to their own fertiliser industry in relation to their export prices for oil. As a result, the fertiliser industries of oil-exporting countries are in a position to undercut the prices of the EC industry. On average, the price of natural gas to EC fertiliser producers is six times higher than in the Arabian Gulf and twice as high as in the USA.

There are no worthwhile deposits of phosphate rock in the EC. The fertiliser industry is dependent on imports from North Africa, the USA and the CIS. The phosphate-exporting countries also operate dual-pricing policies, charging higher prices for exports than for the phosphate rock that is processed by their own industries. A consequence of this is that much of the phosphoric acid production in the EC has been abandoned.

Increased production capacities in East European and developing countries

The restructuring of East European economies, including the former Soviet Union, and EC political decisions to liberalise trade in favour of these developing economies, places the domestic fertiliser industry at a competitive disadvantage. There have been situations where countries export fertiliser to the EC to earn foreign exchange and at the same time request grain imports from EC aid programmes. East European industry, subsidised by cheaper raw materials and compensation for losses in the form of government aid, is increasing its production capacity and its exports to the EC.

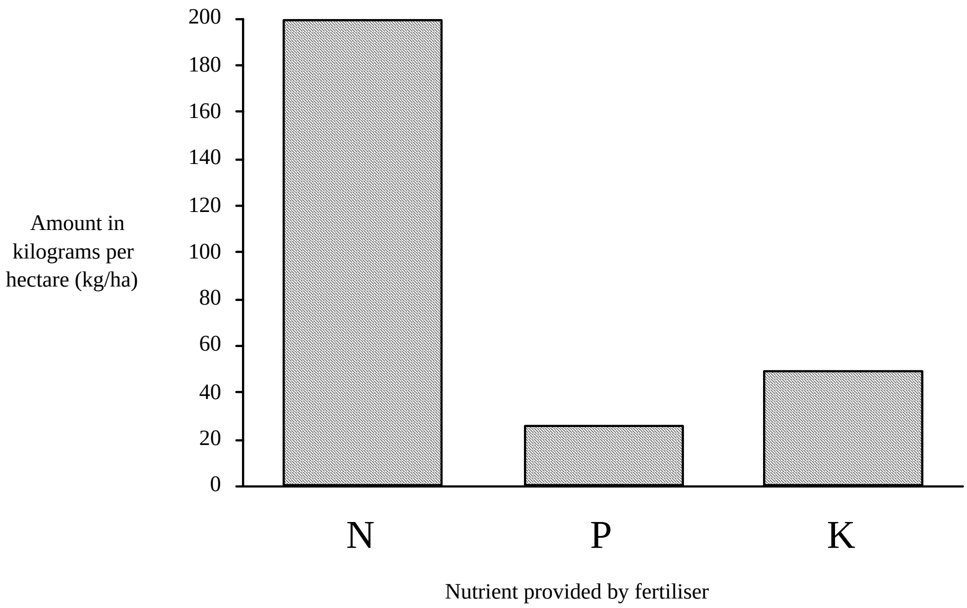
Some of the fertiliser imported into the EC comes from plants that produce high levels of pollution, and these manufacturers are not having to meet the cost of rigorous environmental protection legislation.

The major part of the increase in world fertiliser demand that is forecast in the next ten years is expected to be from the growth of fertiliser consumption in the developing countries. Transport costs of manufactured fertiliser are high and industry is already located in all the main consuming areas of the world. Some of the developing countries have large reserves of phosphates and natural gas, and the fertiliser they produce will be very competitive on the world market.

Fertilisers for winter wheat

The recommended application rates for fertiliser are based on replacing nutrients removed by the crop. Application rates therefore depend on anticipated yield, soil status, the quality of grain required (for animal feed or bread-making), and whether or not straw is to be ploughed back after harvest.

The following figures refer to winter wheat producing on each hectare 7 tonnes of grain of bread-making quality (high in protein content) and 5 tonnes of straw which is ploughed back.



The N is delivered as straight nitrogen (ammonium nitrate, 35% N) in spring. The timing of P and K application is not critical. It is usually spread in autumn in the seed bed. If the wheat straw is harvested, an additional 3 kg/ha of phosphorus and 37 kg/ha of potassium would need to be applied.

The role of N, P and K

Nitrogen is involved in all aspects of growth, such as photosynthesis, leaf development and protein production. Nitrogen fertiliser has the greatest effect on yield.

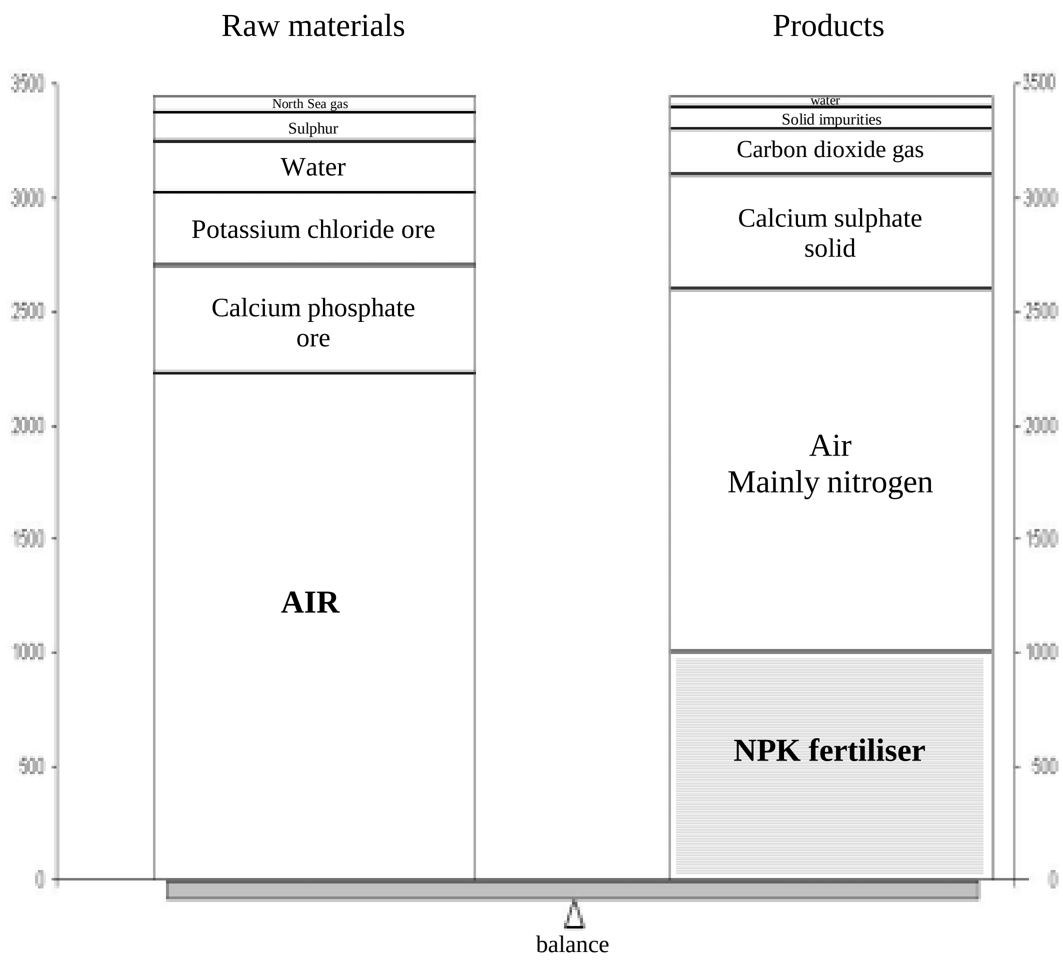
Phosphorus plays a major role in the ripening process and in root development. It also sustains the enzyme reactions in biochemical processes.

Potassium increases the crop’s resistance to drought and low temperature. It also strengthens the stem and plays a role in the ripening process.

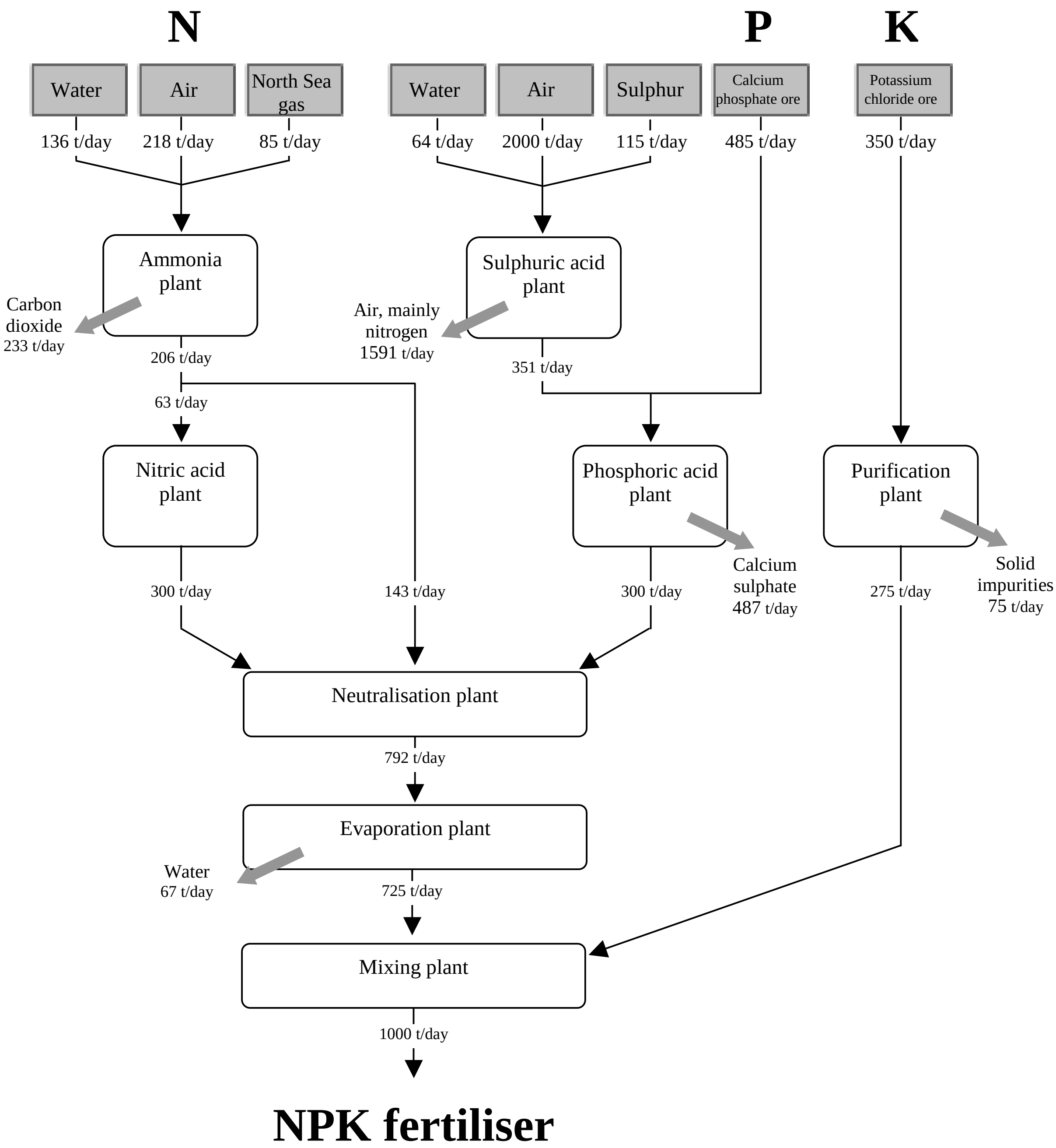
Annual use of fertiliser in the UK

1.4 million tonnes N (equivalent to 4 million tonnes NH_4NO_3)
0.2 million tonnes P as phosphates
0.4 million tonnes K as potassium chloride or potassium sulphate

A completed mass balance

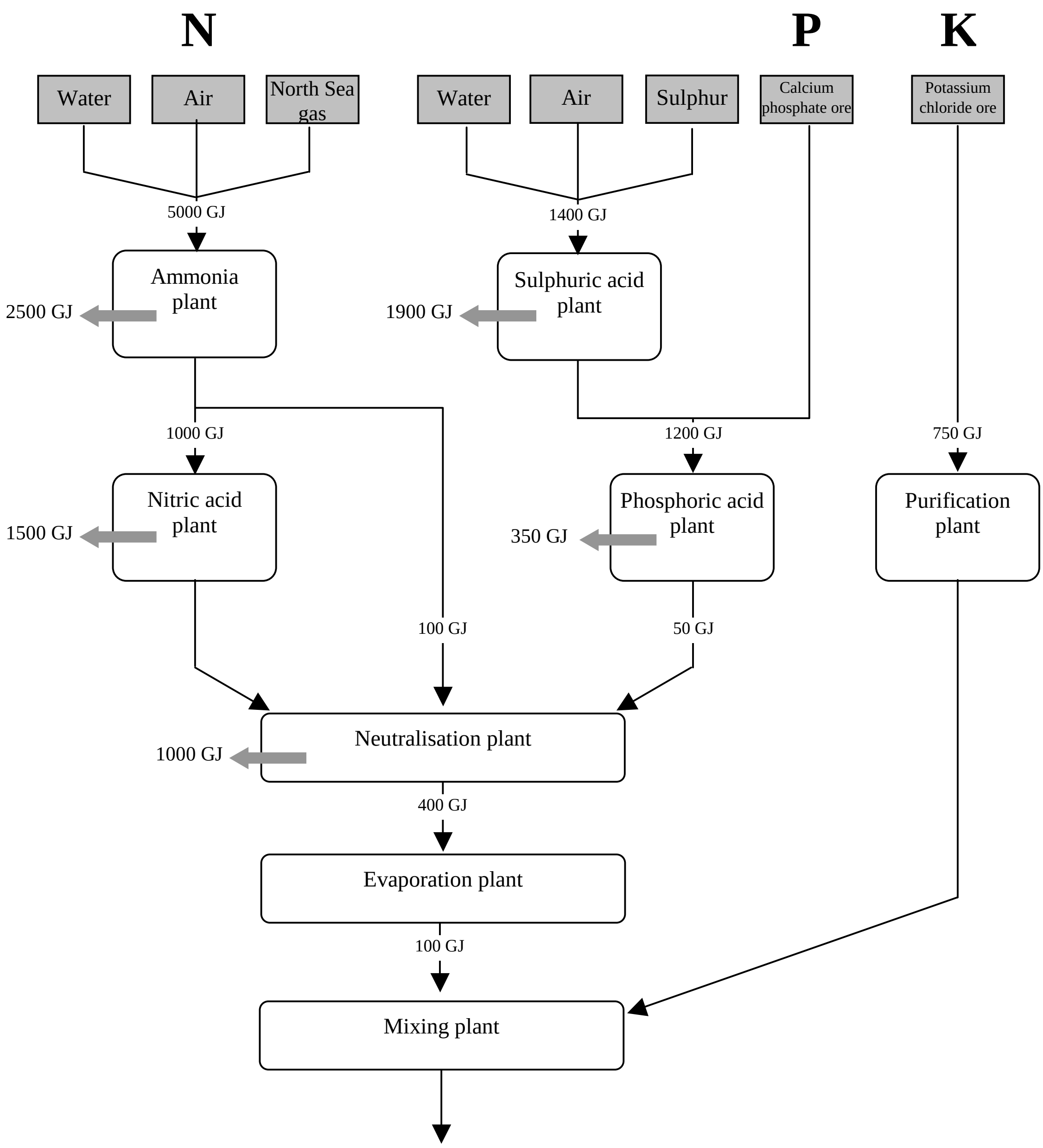


Waste products in fertiliser manufacture (SIS 2)



t/day = tonnes per day

Major release of energy during fertiliser manufacture (SIS 3)



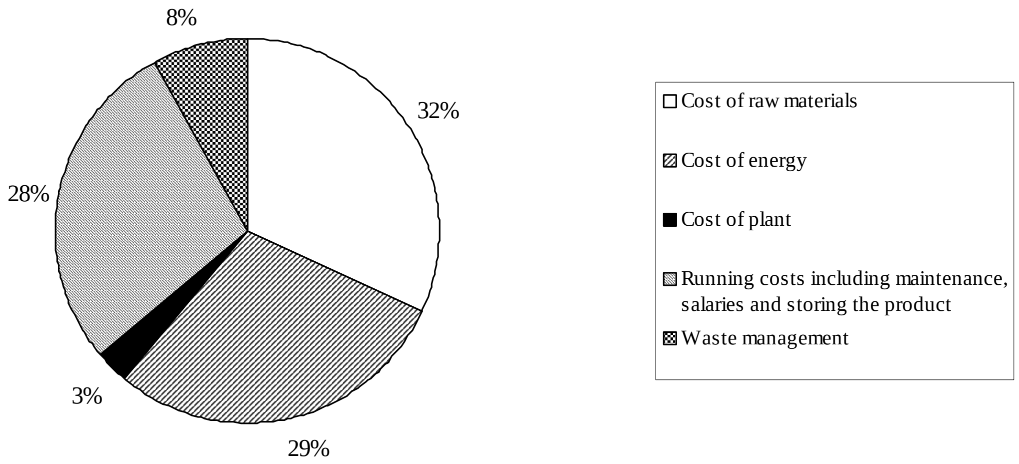
1000 tonnes NPK fertiliser

UK Fertilisers plc

Internal memo

To: Executive directors **From:** Chief executive

Our company is losing money. We must take some action. The chart below shows how our costs are made up.



Next week we have an important meeting with our bankers. We need good Ideas to persuade the banks to lend us money to rescue our company. I want you to:

1. Please prepare charts to show how well we use raw materials and energy. Use the information supplied by our engineers.
2. Decide if any of these ideas are useful and then prepare a plan of action:

Waste management costs
- ✱ Employ scientists to find uses for the waste products. Then sell the waste.
- ✱ Reduce waste management costs - dump the solid waste in the sea.
- ✱ Avoid some of the costs of waste management by importing phosphoric acid.

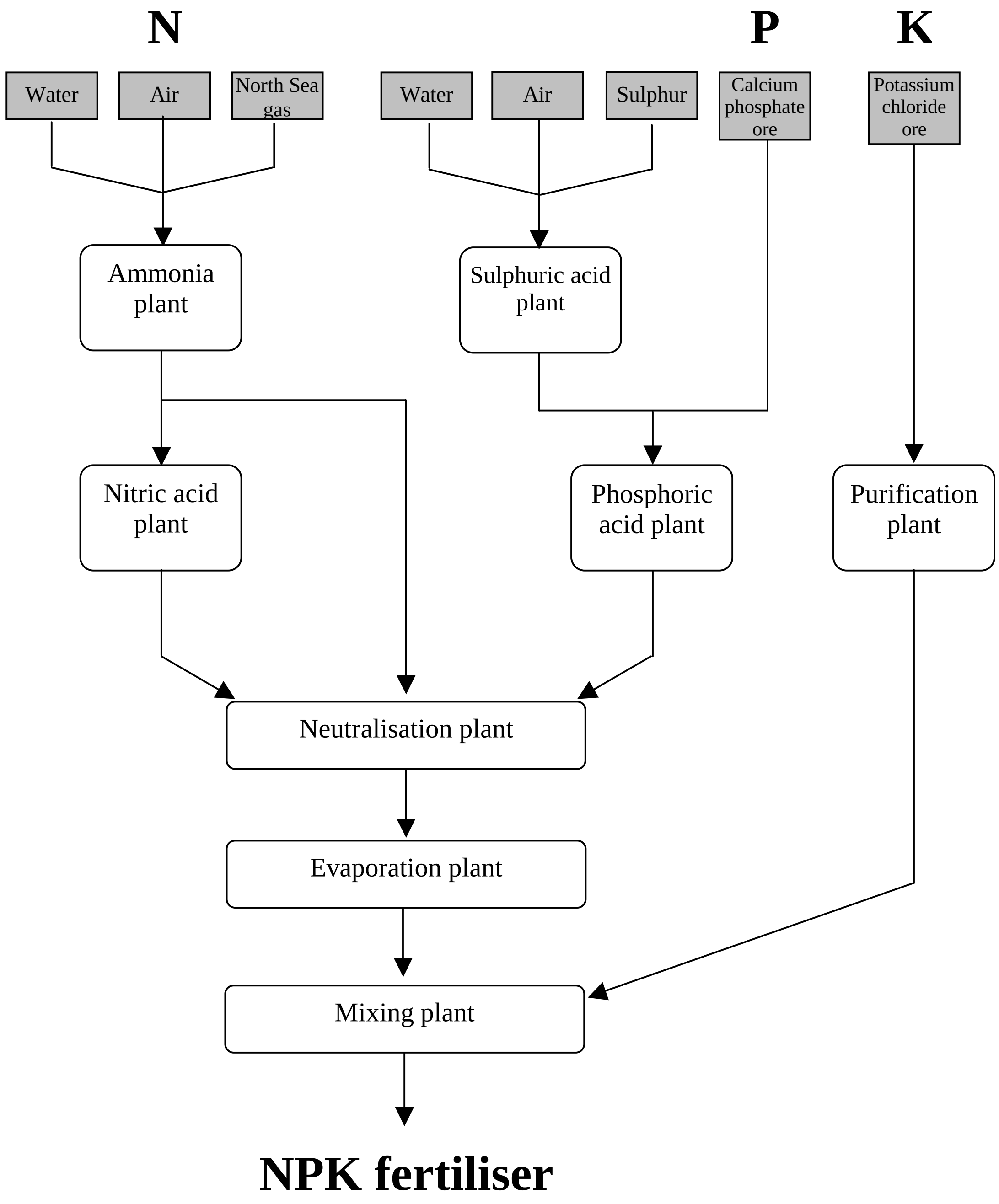
Energy costs
- ✱ Make better use of energy. Redesign plants and build heat exchangers to recycle waste heat.
- ✱ Move the industry to a source of cheap hydro-electric power.

Raw material costs
- ✱ Find cheaper raw materials. Use sulphur dioxide (in emission gases from coal-fired power stations) for the manufacture of sulphuric acid.
- ✱ Manufacture abroad, where the raw materials are cheaper.

Running costs
- ✱ Employ fewer people and save money.
- ✱ Most fertiliser is used in spring. Reduce storage costs by selling fertiliser at a discount from June to February. We would earn interest on money that is paid.
- ✱ Run the Industry at a loss to save jobs.

Others
- ✱ Quit the fertiliser Industry and find other uses for ammonia and acids.
- ✱ Quit manufacturing. Import fertiliser and act as a wholesaler.

Use of raw materials to make fertiliser



A mass balance

The mass of raw materials used to make fertilisers must be the same as the total mass of products. The useful products are shown on SIS 2. Other products, which may be waste products, are not shown.

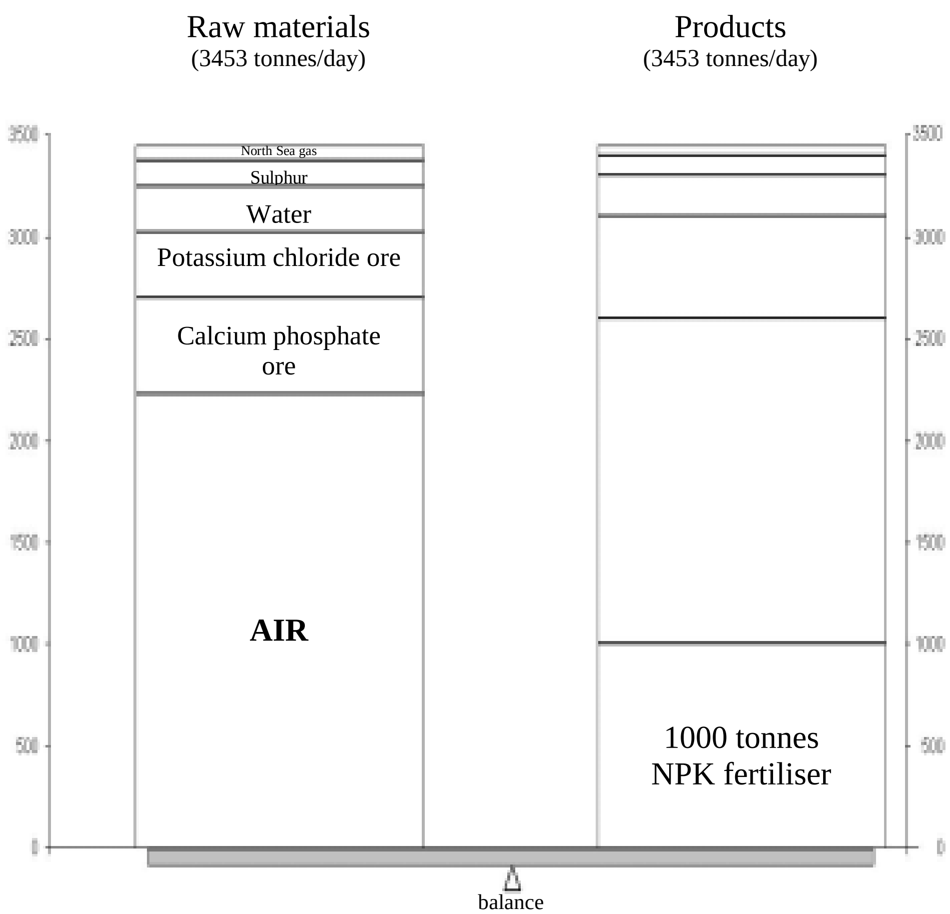
1. Colour in the five 'plants' where waste products are formed. Identify them by looking to see where the mass of useful products is *less* than the mass of raw materials that enter the plant.

2. Match these waste products to the five plants. It may help to check the reactions in a text book.

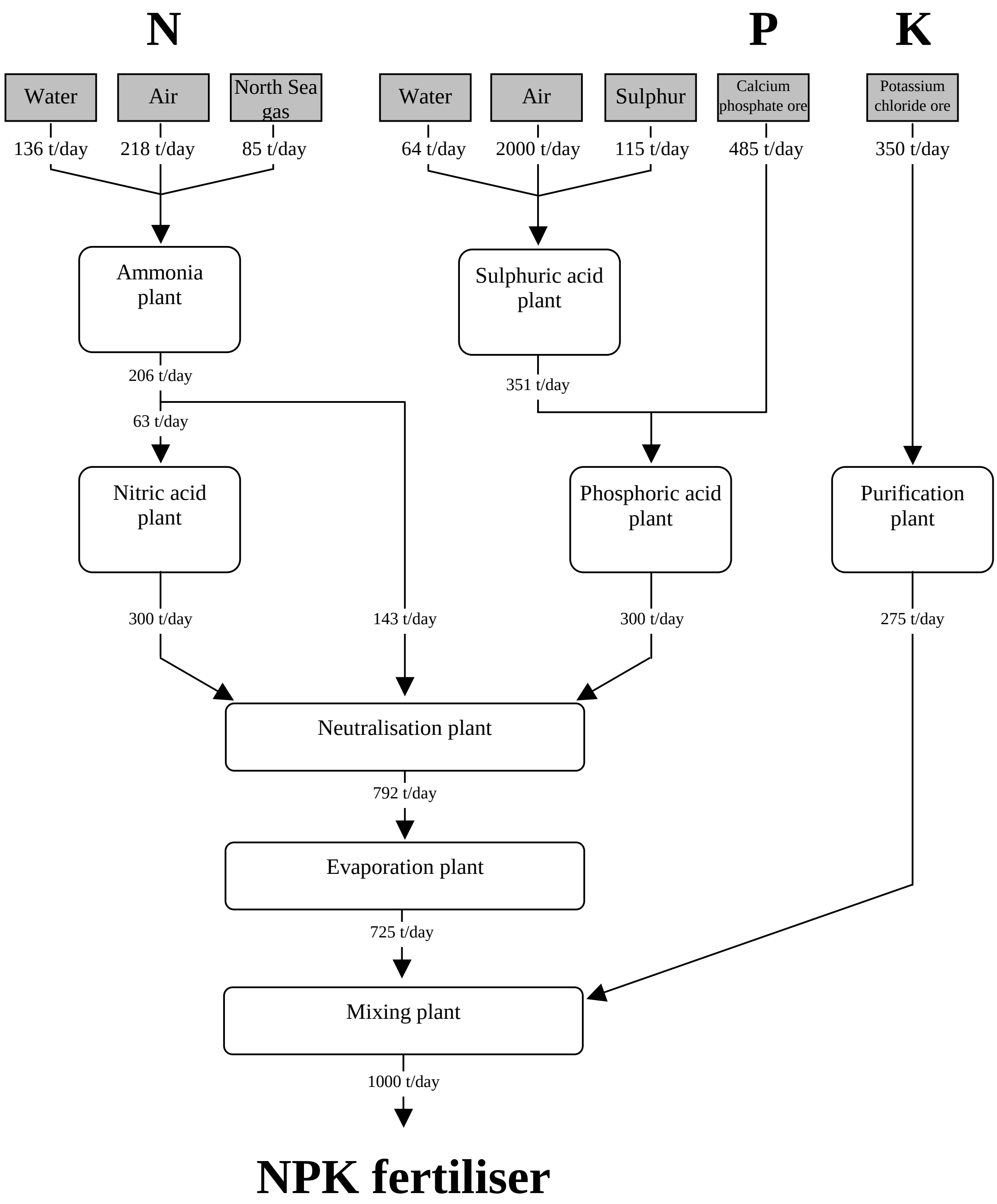
Waste product	Quantity tonnes/day
Water	67
Calcium sulphate solid	487
Solid impurities	75
Air (mainly nitrogen)	1591
Carbon dioxide gas	233

3. Draw arrows coming **from** the five plants, to show the names and quantities of waste products formed.

4. Complete the mass balance below, which is draw to scale, to show how the raw materials end up as the final product (NPK fertiliser) and waste products.



Use of raw materials to make fertiliser



The arrows show the amounts of material, in tonnes per day (t/day), that enter and leave each plant.

Use of energy in fertiliser manufacture

Some uses of energy in fertiliser manufacture are:

- crushing ores and mixing chemicals
- breaking chemical bonds so that raw materials can react
- heating materials to speed up reactions
- compressing gases and pumping materials around
- heating solutions to evaporate water
- illuminating the plant at night

Industry burns North Sea gas and buys electricity in order to supply its energy needs. Use data on SIS 3 to work out the amount of energy needed to make 1000 tonnes of NPK fertiliser.

N.B. GJ means gigajoule – a thousand million joules!

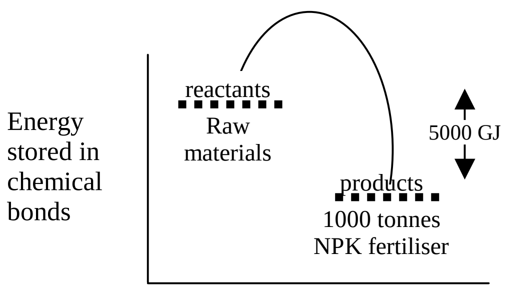
answer = ________________GJ

What happens to this energy?

Machinery and materials get hot. Most of the energy eventually escapes to the surroundings as waste heat. This heat is spread out over a huge site and causes only a small increase in the temperature of the surroundings. It is not easy to make use of this heat.

Is any other energy wasted?

Energy is required to break bonds. All materials have energy ‘stored’ in chemical bonds. Some of this energy may be released when new chemical bonds are formed and some is stored in the new bonds formed. This energy could also be wasted.



Fertiliser manufacture involves many different reactions. Some are exothermic and some are endothermic.

Overall, the process is exothermic. 5000 GJ are released as raw materials react to form 1000 tonnes of fertiliser.

1. What is the total amount of energy that might escape as waste heat each day?

   answer = ________________GJ

2. Householders pay electricity companies £20 for each GJ. What is the value of the waste heat each day?

   answer = £ ________________

Can you make more efficient use of energy?

3. On SIS 3, draw these arrows coming *out sideways* from the plants to show how much energy is released by the exothermic reactions.

2500 GJ ← (at ammonia plant)	1000 GJ ← (at neutralisation plant)	350 GJ ← (at phosphoric acid plant)
1500 GJ ← (at nitric acid plant)	1900 GJ ← (at sulphuric acid plant)	

Energy released by exothermic reactions is 'concentrated heat'. It produces a large increase in temperature in the reaction vessels. Industry could be made more efficient by making use of this concentrated heat.

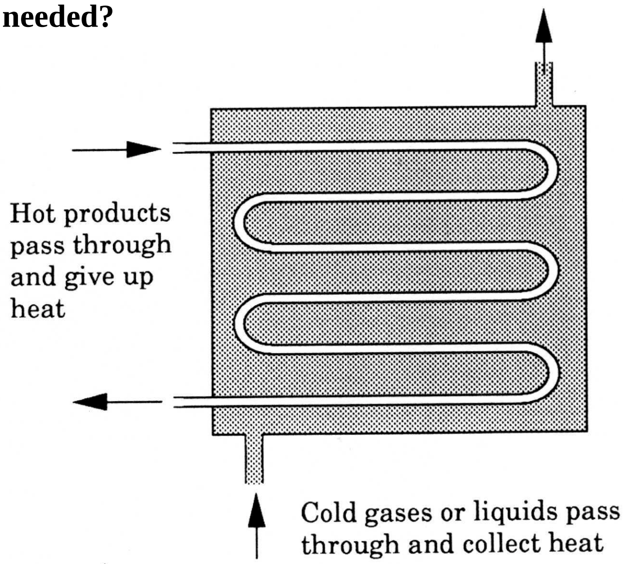
4. On SIS 3, use a coloured pencil to map out how this energy could be put back into the manufacturing process. Now work out the *least* amount of energy that needs to be brought in, as fuel or electricity, to make 1000 tonnes fertiliser.

answer = ________________GJ

How can the energy be moved to where it is needed?

A heat exchanger is one way of moving energy to places where it can be made use of.

You may want to spend money on heat exchangers in order to save money on energy.



Borrowing money from the bank

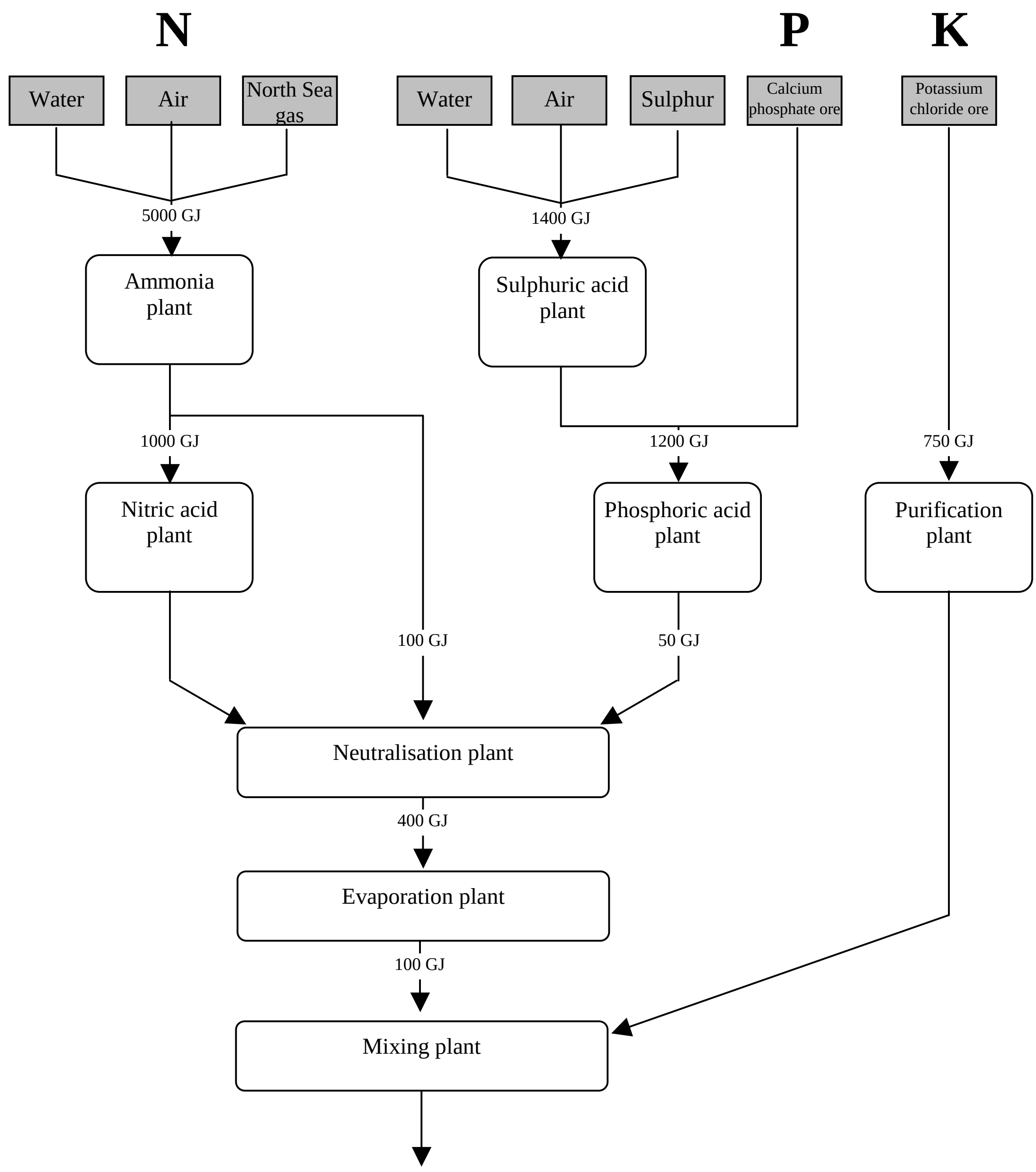
You may wish to borrow £10,000,000 from a bank, in order to build energy recovery systems.

5. Prepare bar charts to show the bank manager how much energy and how much money you could save each day by using energy efficiently.

6. Work out how long it would take for the £10,000,000 energy recovery system to pay for itself.

7. Can you think of other ways of using the waste heat?

Use of energy in fertiliser manufacture



1000 tonnes NPK fertiliser

The arrows show how much energy, in gigajoules, needs to be supplied each day to different parts of the manufacturing process by burning fuels and using electricity.

Fertiliser manufacture and the use of energy

Huge amounts of energy are used to manufacture fertilisers. Most of this energy is obtained by using up limited reserves of fossil fuels.

The effect of fertiliser on the yield of winter wheat

Extra food is harvested when fertilisers are used.

Is it worth it? Is it sensible to use So much energy for making fertilisers?

	Yield of wheat (tonnes per hectare)
No fertiliser	4
Fertiliser	7

To answer these questions, the energy needed to make and use the fertiliser must be compared with the energy value of the extra food harvested.

The energy value of harvested food

Winter wheat is the main arable crop in the United Kingdom. Seed is sown in autumn and the crop survives the winter as green shoots about 10 cm tall. Fertiliser is spread in spring. Approximately **half a tonne** of ammonium nitrate is spread on each hectare (a 100 metre square). When harvested, the wheat grain is used for making flour and bread.

During photosynthesis, the crop traps some of the sun's energy and stores it in the form of food, such as carbohydrates in the grain. Carbohydrates are made when plants combine carbon dioxide from the air with water taken in through the roots. The energy value of grain is 15.6 GJ/tonne. The energy content of bread is printed on the wrapper.

Energy needed to manufacture and spread fertilisers

	Energy in gigajoules per tonne of fertiliser (GJ/tonne)
Manufacturing straight-N fertiliser	22.0
Manufacturing and delivering plastic bags for packing fertiliser	0.4
Transport of fertiliser to farms	0.8
Spreading by tractor	0.2

Use the data above to work out:

a) the total energy involved in making and spreading one tonne of fertiliser
b) the energy value of **extra** food obtained when **one tonne** of fertiliser is used.

Is it a good idea to use energy to manufacture fertiliser for winter wheat?
Explain your answer.

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