53 Biofuels

A **biofuel** is a liquid fuel produced from living or recently living materials such as waste plant and animal matter.

The development of biofuels has been in response to concerns about:

- Pollution caused by the combustion of fossil fuels, especially by transport vehicles which are among the top emitters of greenhouse gases.
- Fears that supplies of fossil fuels are running out as they are a finite resource and non-renewable.
- Lack of availability of fuels due to political unrest.
- Instability in world markets – the cost of importing fuel and its effect on inflation. In Australia we import petrol.

Biomass refers to the materials used. It comes from living or recently living organisms, usually plant matter and can include wood, garbage, waste from industries such as the wood industry, sugar cane (bagasse), corn, sorghum, grasses, hemp, and a variety of trees. Animal fats and oils are also being used and algae are being cultivated for use as biomass.

The two main types of biofuels are bioethanol and biodiesel and these are used for road transport. The European Commission aims to replace 10% of its transport fuels with renewable fuels by 2020.

Bioethanol

Bioethanol is ethanol made by the fermentation of carbohydrates (sugar, starch and cellulose) from biomass such as sugar cane or corn crops.

Ethanol is a carbon compound with formula C_2H_5OH.

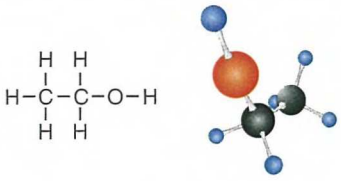


Figure 53.1 Formula and model of ethanol.

As with all compounds, no matter how it is made, ethanol still has the same formula. Ethanol is a member of the homologous group of organic compounds called alkanols, which have a general formula $C_nH_{2n+1}OH$. It is present in alcoholic drinks. Combustion of ethanol in plenty of oxygen produces carbon dioxide and water.

Ethanol + oxygen → carbon dioxide + water

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$

Ethanol is mainly used for blending in low concentrations with petrol in motor vehicles, e.g. E10 fuel. It also acts as an octane enhancer, reducing the pinging in the motor. If used in high concentrations, the vehicle has to be modified. E85 fuel contains 70% to 85% ethanol and is only suitable for vehicles designed for its use. Ethanol to be used as fuel is made unfit for human consumption before leaving the factory.

Table 53.1 Advantages and disadvantages of using ethanol.

Advantages of ethanol	Disadvantages of ethanol
A renewable resource. Can be made by fermenting biomass such as corn and sugar crops. Lignocellulose from waste such as corn stalks and wood chips would be best to use but this is expensive at present as it is difficult to break cellulose down to sugars and costly to set up new factories to do this.	Large areas of land and much water are required for production of raw materials. (But extra land is not needed if waste biomass and cellulose are used.) Waste fermentation products are difficult to dispose of and cause environmental problems.
Using a renewable energy source to produce raw materials and distil the fermented ethanol, will reduce the net levels of: • Greenhouse gases, e.g. CO_2. • CO (combustion of ethanol is more complete).	High cost of: • Distillation or membrane separation. • Removing water from the fuel to prevent problems with the carburettor or fuel injection systems and corrosion of fuel lines.
Burns more cleanly, but you use more to go the same distance than when using petrol.	Lower energy value (about 1/3) than petrol so lower fuel economy and larger fuel tanks or more frequent refilling is needed.
Spills are more easily biodegraded or diluted to non-toxic concentrations.	Spills are difficult to contain and recover as the hydroxyl (OH) group bonds with water and cannot be skimmed off the top.
Higher octane rating, so useful in high performance vehicles (racing cars).	Some ethanol-based fuels are more volatile than petrol and this can cause an increase in the emission of volatile organic compounds.
Eliminates the use of high-octane additives which were used to replace tetraethyl lead in petrol.	Other additives are used.

Two of the biggest producers of ethanol are the USA and Brazil. Ethanol has mostly been used in cars, but work is under way in Brazil to extend its use to trucks, buses and planes, in some cases combined with biodiesel, and also used in conjunction with hybrid vehicles.

Biodiesel

Biodiesel is used as a fuel additive in petroleum-based diesel fuel and is the most commonly used biofuel in Europe. Biodiesel consists of long chain carbon compounds (called esters). These are made from renewable sources such as:

- Vegetable oils (e.g. soybean, flax, coconut, sunflower oils and waste vegetable oils from commercial cooking sources).
- Animal fat (e.g. lard, tallow, chicken fat, waste fish oil).
- Algae and sewage sludge.
- A genetically modified yeast (a fungus) is used in Brazil to ferment sugar cane so it can be used as biomass.

Using biodiesel reduces levels of particulates, carbon monoxide and hydrocarbons released into the atmosphere. It is also renewable, biodegradeable, non-toxic, and has a high flash point making it relatively safe to use.

However, as with bioethanol, the production in large quantities is difficult as sustainable and acceptable raw materials and energy sources are hard to find and it is expensive to start up new industries. With present methods of production, biofuels can only be considered as a supplement to petrol, as it is not yet possible to manufacture nearly enough biofuel to replace petrol in motor vehicles.

Many countries, including Brazil, Australia, the United States, Canada and Sweden have established targets aimed at reducing their reliance on fossil fuels and increasing their consumption of biofuels such as ethanol and biodiesel, or using other sustainable, more environmentally friendly energy sources. Sweden aims to be completely free of fossil fuels by 2020.

QUESTIONS

1. (a) Define 'biofuel' and name two examples.
   (b) Outline three concerns that have led to the development of biofuels.
2. Ethanol can be used as a renewable alternative to fossil fuels.
   (a) Write an equation for the combustion of ethanol.
   (b) Justify the classification of ethanol as a renewable fuel.
   (c) One argument against using ethanol as fuel is that the crops required, and the land needed to grow these crops, could be better used in providing food for starving people. Evaluate this argument.
3. (a) Describe the composition of petrol.
   (b) Describe the composition of bioethanol.
   (c) Evaluate the usefulness of ethanol as a fuel source in comparison to petrol.
4. (a) Distinguish between bioethanol and biodiesel in their sources, composition and uses.
   (b) Biofuels can use biomass in their manufacture. Define biomass.
5. Research the production of ethanol or biodiesel in Australia for use as a fuel and consider if this is a sustainable practice.
   Write a report based on your research. Before you begin, you should discuss the format and length of your report with your teacher.
6. Biofuels are claimed to be 'carbon neutral'.
   (a) What is meant by this term?
   (b) Is it correct to describe biofuels as carbon neutral?
7. Check your knowledge with this quick quiz.
   (a) Recently living plant and animal matter which is used to make biofuels is called ..... .
   (b) Fuels made from biomass are collectively called ..... .
   (c) The two main biofuels are ..... and ..... .
   (d) State the formula for ethanol.
   (e) Name two products of combustion of both ethanol and biodiesel.
   (f) Bioethanol and biodiesel are both made of carbon compounds. Which contains the longer chain carbon compounds, bioethanol or biodiesel?
   (g) Name two substances used to make bioethanol.
   (h) Name two substances used to make biodiesel.
   (i) Which burns more cleanly, ethanol or petrol?

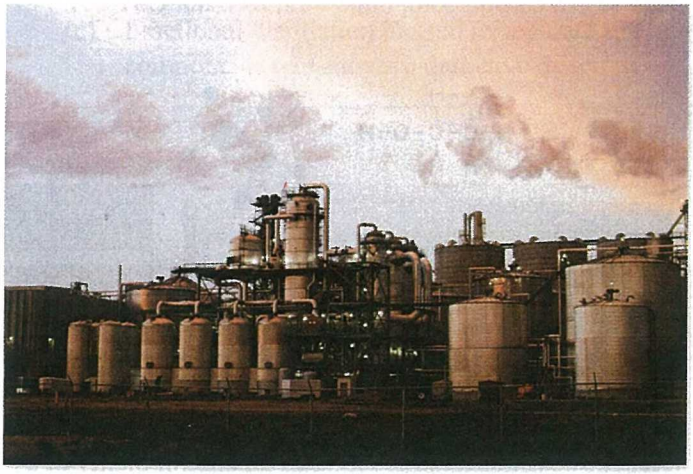


Figure 53.2 Bioethanol refinery.

54 Products of Combustion of Fuels

Some of the products of combustion of fossil fuels and biofuels are pollutants. Fossil fuels and biofuels all contain carbon and hydrogen so they release carbon dioxide, carbon monoxide and water as products of combustion. Most fuels contain sulfur and nitrogen so oxides of these elements are formed during combustion. Also, unburned particles and ash are formed.

Carbon dioxide is a colourless, odourless gas formed by complete combustion of carbon and carbon compounds. Large amounts of carbon dioxide are produced by power plants burning coal (mainly carbon), gas (mainly methane), by motor vehicles burning petrol (e.g. octane) and by burning biofuels (e.g. ethanol).

$C(s) + O_2(g) \rightarrow CO_2(g)$

$2C_8H_{18}(l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$

$CH_4(g) + 2O_2 \rightarrow CO_2(g) + 2H_2O(l)$

$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

Carbon dioxide is acidic. It is a major cause of the enhanced greenhouse effect and it also contributes to acid rain.

Carbon monoxide is a colourless, odourless gas produced by incomplete combustion when the oxygen supply is restricted, e.g. when a car is idling. It is toxic because it combines with haemoglobin in red blood cells in preference to oxygen, reducing the ability of blood to transport oxygen. The use of unflued heaters and barbecues inside homes where there is not a free flow of fresh air can cause carbon monoxide poisoning.

$2C_8H_{18}(l) + 17O_2(g) \rightarrow 16CO(g) + 18H_2O(l)$

$C_2H_5OH(l) + 2O_2(g) \rightarrow 2CO(g) + 3H_2O(g)$

$CH_4(g) + 3/2O_2 \rightarrow CO(g) + 2H_2O(l)$

Carbon monoxide is not acidic, so it does not contribute to acid rain.

Sulfur dioxide is formed by the combustion of sulfur which is present in fossil fuels.

$S(s) + O_2(g) \rightarrow SO_2(g)$

Sulfur dioxide is one of the main causes of acid rain and it also causes respiratory problems such as asthma.

Australian black coal generally has low sulfur content, but unfortunately we export most of our high quality black coal, burning the inferior, polluting coal here.

Nitrogen oxides (e.g. NO and NO_2) are formed by the combustion of nitrogen in fuels and atmospheric nitrogen when they undergo combustion at high temperatures.

$N_2(g) + O_2(g) \rightarrow 2NO(g)$

$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

Nitrogen oxides cause respiratory problems. Nitrogen dioxide is acidic and contributes to the formation of acid rain and photochemical smog.

Particulates are small particles, of solids (such as ash and carbon) and tiny droplets of liquids, that stay suspended in the air. Some coals contain up to 30% mineral matter (e.g. silicates and carbonates) which produces large amounts of ash when the fuel burns.

$2C_8H_{18}(l) + 19O_2(g) \rightarrow 6C(s) + 10CO_2(g) + 18H_2O(l)$

Particulates reduce visibility, cause respiratory problems, damage machinery and contribute to photochemical smog. Some are also carcinogens (cause cancer).

Figure 54.1 Photochemical smog over Sydney, NSW.

Additives in petrol can include a vast array of chemicals including antioxidants, stabilisers, antiknock agents, corrosion inhibitors, lubricants and fuel dyes, all of which can pollute the environment.

Reducing pollution

Steps taken to reduce pollution include the following.

1. Ensure complete combustion.

- Adjust the carburettor/fuel injector of motor vehicles so there is a lean fuel/air mixture to increase engine fuel efficiency and thus reduce exhaust emissions.
- Recirculate the exhaust to burn any fuel that was not burnt initially.
- Use catalysts in the exhaust system to reduce the toxic pollutants emitted. Carbon monoxide and unburned hydrocarbons undergo complete combustion with the help of a catalyst and nitrogen oxides are reduced to nitrogen gas. Catalysts can also be used to remove nitric oxide by increasing the rate of its reaction with carbon monoxide.
  $2NO(g) + 2CO(g) \rightarrow N_2(g) + 2CO_2(g)$
  Ensuring complete combustion not only produces less pollution it also results in more energy being produced per kilogram of fuel.

2. Lower combustion temperatures to prevent the formation of nitrogen oxides – use cooled air, and use multistage combustion.

3. Remove pollution.

- Power stations use filtering devices and electrostatic precipitators to stop particulates being emitted into the atmosphere.
- Water scrubbers are used to dissolve out carbon and sulfur oxides, e.g.

  Carbon dioxide + water → carbonic acid

  $CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$
- Some industries find uses for waste products rather than releasing them into the environment. Sulfur dioxide is used to make sulfuric acid and carbon dioxide is used in fire extinguishers and to make soft drinks.

4. Develop other less polluting energy sources such as wind power, solar energy and tidal generators. Australia has the highest average solar radiation per square metre of any continent in the world. What do you think we should be developing as our main energy source in Australia?

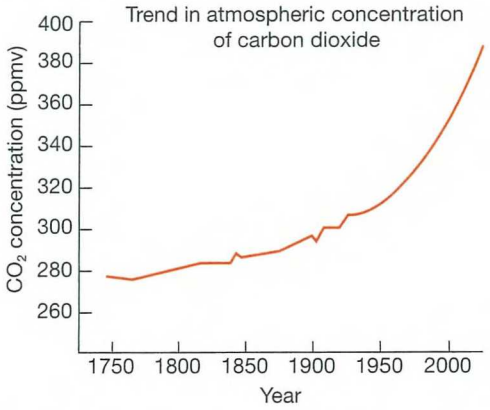
QUESTIONS

1. Write balanced equations to show the incomplete combustion of:
   (a) Methane to produce carbon monoxide and water.
   (b) Methane to produce carbon and water.
   (c) Propane to produce carbon and water.
2. Write equations to show the complete combustion of:
   (a) Butane. (b) Hexane.
3. Copy and complete the following table about the products of combustion of fossil fuels.

Name of product	Formula	Harmful effect
	CO_2	
		Toxic – preferentially combines with haemoglobin.
Particulates, e.g. carbon		
	NO and NO_2	
	SO_2	
Volatile organic compounds (VOCs)		

4. Research photochemical smog and answer the following questions about it.
   (a) Define photochemical smog.
   (b) What causes photochemical smog?
   (c) Account for the concern about photochemical smog.
   (d) What gives the brown tinge to photochemical smog?
   (e) When is photochemical smog most common?
5. Many countries recommend turning off your car's engine if you are stopped for longer than 10 to 60 seconds. Account for the presence of the following road sign placed outside a primary school.

6. For every litre of petrol used in a car, approximately 2.3 kilograms of carbon dioxide is produced.
   (a) If a car uses, on average, 40 L of petrol per week, calculate how much carbon dioxide this car would release in one year.
   (b) Calculate how much carbon dioxide your family produces per year and consider how you could reduce this.
7. Carbon dioxide is present naturally in the atmosphere. The graph below shows changes in atmospheric concentration of carbon dioxide over time.
   (a) Describe the trend shown by the graph.



   (b) Outline the main causes of this change in atmospheric carbon dioxide concentration.
8. Check your knowledge with this quick quiz.
   (a) Name a toxic gas that combines with haemoglobin in blood in preference to oxygen.
   (b) Identify a device used to remove small particles from exhaust gases.
   (c) Name a colourless, odourless gas produced by complete combustion of carbon-based fuels.
   (d) Name an acidic nitrogen oxide.
   (e) Name an acidic gas produced by combustion of sulfur present in coal.

2. (a) Water always enters through the lower end of the condenser so that the condenser jacket fills with water before any can run out. This keeps a jacket of water around the tube through which the vapour is leaving the flask so it is able to cool the vapour more efficiently.
   (b) No, the cooling water does not come into contact with the original mixture or the ethanol produced. The cooling water is in an outside jacket around the tube containing the vapour being condensed.
3. A hot water bath is safer – no flames come close to the distillation flask.
4. (a) Cool it (or put it under pressure) until it condenses from a gas to a liquid.
   (b) Boiling point liquid oxygen is –183°C.
   Boiling point liquid nitrogen is –196°C.
   Nitrogen will be evaporated and distilled off first as it has the lower boiling point.
   (c) They all involve separating a mixture of liquids. The components of these mixtures have different boiling points. In each case the mixture is heated until the boiling point of one component is reached. This component evaporates first, leaves the flask and is collected and cooled so it condenses back to a liquid to be used or stored.
5. Various, for example:
   Fractional distillation made possible the separation of the components of air and crude oil.
   Air – Oxygen is used in medicine to treat patients after surgery, trauma and during illness such as lung disorders. In industry it is used in oxyacetylene welding. Liquid nitrogen is used to snap-freeze vegetables such as peas immediately after harvesting and for cryogenics. Liquid argon can also be separated out from air.
   Crude oil – See next unit for many uses of the fractions obtained from crude oil. They are used extensively for transport.
6. (a) Ethanol.
   (b) Condensation of the vapour to a liquid.
   (c) Boiling points.
   (d) Cool, condense.

52 Fractional Distillation of Crude Oil

1. (a) Organic means containing carbon and carbon compounds. Petroleum is a mixture containing up to 300 hydrocarbons – these are carbon compounds.
   (b) Fractional distillation.
   (c) Fractional distillation is a physical method involving change of state. There is no chemical reaction involved, no new substance is produced so it is not a chemical reaction.
2. Various. Any fractions in Table 52.1, together with the correct use, e.g. kerosene – C10 to C14 – used as aviation fuel.
3. Fossil fuels come from once-living things. Living things contain proteins which are made of carbon, hydrogen, oxygen, nitrogen and sulfur. Thus these elements are present in fossil fuels either as the elements or in compounds.
4. During combustion, nitrogen forms nitrogen oxides and sulfur produces sulfur dioxide.
   Nitrogen + oxygen → nitrogen oxides
   Sulfur + oxygen → sulfur dioxide
   Nitrogen oxides and sulfur dioxide are atmospheric pollutants, causing smog and acid rain.
5. (a) Various, e.g. – a fuel in homes and industry, production of ethene and polymers.
   (b) Various, e.g. ethane, propane, butane, octane.
   (c) Fossil fuel.
   (d) Non-renewable.
   (e) Boiling points.

53 Biofuels

1. (a) A biofuel is a liquid fuel produced from living or recently living materials such as waste plant and animal matter, e.g. bioethanol and biodiesel.
   (b) Various. Biofuels have been developed because of concerns about:
   - The pollution caused by the combustion of fossil fuels, especially by transport vehicles which are one of the top emitters of greenhouse gases.
   - Fears that supplies of fossil fuels are running out as they are a finite resource and non-renewable.
   - The lack of availability of fuels due to political unrest.
   - Instability in world markets – the cost of importing fuel and its effect on inflation. In Australia we import petrol.
2. (a) Ethanol + oxygen → carbon dioxide + water
   $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$
   (b) Ethanol can be made from crops such as sugar cane and corn or their waste products. As the ethanol is used up, more crops can be grown to make more ethanol. Its ability to be replaced when used means it is renewable.
   (c) If food crops are used the argument has validity. However, today there is no need to use edible food; with better production techniques now available, ethanol can be produced from bagasse, the wastes left after the consumable part of the crop (e.g. corn or sugar) has been harvested. This also prevents the burning off, after harvesting, of waste crops, e.g. the stalks, a process which causes considerable pollution. Also, weather-damaged crops and forestry wastes that are unsuitable for human consumption can be used to make ethanol, although this is currently more expensive.
3. (a) Petrol is a mixture of hydrocarbons, mainly C5 to C12.
   (b) Bioethanol is mainly ethanol C_2H_5OH with additives to make it unfit for drinking.
   (c) Present the evidence for each, e.g. see table below, then make a value judgement.

Ethanol	Petrol
Renewable.	Non-renewable.
Spills more easily biodegraded or diluted.	Spills do not biodegrade, so they can cause a lot of damage to living organisms.
But harder to contain and recover.	Spills may be easier to be contained and recovered in some circumstances as petrol does not mix with water.
Combustion is more complete, so it produces CO_2 rather than CO and C.	More pollutants produced during combustion, especially greenhouse gas CO_2.
At present ethanol cannot be produced at a competitive cost or in the volume required to replace petrol.	More readily available at present but supplies will become more expensive and eventually run out and will need to be replaced by some other source of energy.

   Value judgement – various. Your value judgement should reflect the advantages and disadvantages that you have researched and discussed. If you have more facts in favour of a particular fuel then that should be reflected in your value statement.
4. (a) Both bioethanol and biodiesel have both been made from the fermentation of organic sources such as vegetable oil, animal fat, algae, fungi and biomass. They are not made from petroleum. Biodiesel is diesel fuel consisting of long chain carbon compounds. Both are made from similar sources, but diesel contains longer chain, more complex organic chemicals. Bioethanol has traditionally been used in motor cars, whereas biodiesel has been used in large vehicles – trucks and buses. Some scientists are trying to extend the use of ethanol and biodiesel to larger vehicles and aeroplanes.
   (b) Biomass refers to matter which comes from living or recently living organisms, usually plant matter and can include wood, garbage, waste from industries such as the wood industry, sugar cane (bagasse), corn, sorghum, grasses, hemp, and a variety of trees. Animal fats and oils are also being used and algae are being cultivated for use as biomass.
5. Various – Discuss with your teacher the format this report should take and its length.

A report should be informative and based on facts. It should have a formal structure so include subheadings. It should be informative and written in an appropriate style and in the third person. It is acceptable to include bullet points, tables and graphs. A report should be written with a specific audience and purpose in mind and end by offering recommendations for any required action.
In this report you might like to include:

- Define what is meant by the fuel you are researching.
- What are the disadvantages and advantages of using this source of fuel in Australia?
- Describe sources of biomass in Australia suitable to manufacture the fuel, e.g. waste products of sugar cane, starch from wheat and red sorghum. Is biomass waste including cellulose being used?
- How much ethanol is being used as a fuel in Australia? Is this constant, increasing, decreasing? Produce figures/graphs where possible to support your statements.
- Are there any problems involved in its manufacture? For example, is it energy intensive and how can the energy be provided? Are government subsidies paid?
- What would constitute a sustainable practice? Do you think that the manufacture of biodiesel or ethanol is a sustainable process in Australia?

6. (a) Carbon neutral means that the fuel has no net output of carbon dioxide – the amount of carbon dioxide released by combustion of the fuel is the same as the amount of carbon dioxide taken out of the atmosphere for photosynthesis by the growing plant.
   (b) Biofuels are not really carbon neutral, although they can be closer to carbon neutral than petrol. Carbon dioxide is taken out of the atmosphere during the growth of biomass crops. However, not only is carbon dioxide released to the atmosphere by combustion of the fuel, but more is released when producing fertiliser for the crops, and producing energy to make the fuel from biomass, and transport the chemicals. Thus more carbon dioxide is released to the atmosphere than is taken out.
7. (a) Biomass. (b) Biofuels.
   (c) Bioethanol, biodiesel. (d) C_2H_5OH.
   (e) Carbon dioxide and water. (f) Biodiesel.
   (g) Various, e.g. sugar cane, starch production (from wheat and red sorghum).
   (h) Various, e.g. vegetable oils (e.g. soybean, flax, coconut, sunflower, waste vegetable oils), animal fats (e.g. lard, tallow, chicken fat, waste fish oil), algae and sewage sludge.
   (i) Ethanol.

54 Products of Combustion of Fuels

1. (a) $2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(g)$
   (b) $CH_4(g) + O_2(g) \rightarrow C(g) + 2H_2O(g)$
   (c) $C_3H_8(g) + 2O_2(g) \rightarrow 3C(g) + 4H_2O(g)$
2. (a) $2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$
   (b) $2C_6H_{14}(g) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(g)$
3.

Name of product	Formula	Harmful effect
Carbon dioxide	CO_2	Causes enhanced greenhouse effect and acid rain.
Carbon monoxide	CO	Toxic – preferentially combines with haemoglobin.
Particulates, e.g. carbon	C	Can reduce visibility, cause respiratory problems, and photochemical smog. Carbon is also carcinogenic.
Nitrogen oxides, e.g. nitrogen monoxide, nitrogen dioxide	NO and NO_2	Cause photochemical smog, acid rain, and respiratory problems.
Sulfur dioxide	SO_2	Causes acid rain and respiratory problems including asthma.
Volatile organic compounds (VOCs)	A mixture of chemicals	Contributes to problems with eyes and respiratory system. Can be carcinogenic.

4. (a) Photochemical smog is a thick fog which appears as a brown haze and has health risks associated with its presence. It is a mixture of pollutants formed when nitrogen oxides and volatile organic compounds (VOCs) react with sunlight.
   (b) Photochemical smog is caused by reactions in sunlight of nitrogen oxides and volatile organic compounds (VOCs). Nitrogen oxides do occur naturally from bushfires and lightning. However, the problem occurs with the large volumes of nitrogen oxides produced by the combustion of fossil fuels, especially in power stations and from motor vehicles. When nitrogen oxides combine with VOCs they produce harmful secondary pollutants such as ozone and peroxyacetyl nitrate (PAN).
   (c) Photochemical smog contains chemicals such as nitrogen oxides, ozone and peroxyacetyl nitrate (PAN) which can have harmful effects on people's health. They can cause eye irritation, respiratory problems such as coughing, wheezing and asthma, decrease resistance to infection and may be carcinogenic. Smog can also be harmful for plants, reducing photosynthesis and thus growth.
   (d) Nitrogen dioxide gas which is brown in colour.
   (e) The warmer months – October to March.
5. The engine of a car that is idling (the engine is running while the car is not moving) is not operating at its optimum temperature so combustion will be incomplete, releasing pollutants such as carbon monoxide, nitrogen oxides and volatile organic compounds. It also wastes fuel, producing extra pollution. Many parents allow their cars to idle when they are waiting to collect their children after school. The sign is placed outside the school to remind them not to do this.
6. (a) $40 \times 52 = 2080$ L
   $2080 \times 2.3 = 4784$ kg carbon dioxide
   (b) Various. You could calculate the average consumption of petrol by motor vehicles and also gas and electricity bills show how much carbon dioxide is being released. Suggest ways to reduce this such as turning off lights when not needed, not using appliances unnecessarily, only running washing machines and dishwashers for full loads and walking rather than driving where possible.
7. (a) The graph shows that the concentration of carbon dioxide in the atmosphere was stable from 1750 to 1800 at 280 parts per million. It then started to increase, slowly at first and then very rapidly from about 1850 onwards, reaching 395 ppm by 2013.
   (b) The large increase in concentration of carbon dioxide was due to the rapid increase in population at that time and the rise of the Industrial Revolution which required the combustion of huge amounts of fossil fuels to provide energy for new industries.
8. (a) Carbon monoxide.
   (b) A filter or an electrostatic precipitator.
   (c) Carbon dioxide.
   (d) Nitrogen dioxide.
   (e) Sulfur dioxide.

55 Energy and the Greenhouse Effect

1. (a) A greenhouse is a building designed to provide a warm environment where plants can grow. Greenhouses are used to grow fruit, flowers and vegetables in cold climates and to produce crops out of season in a controlled environment. The ceiling and walls of a greenhouse are usually made of glass or plastic. Visible light and infra-red radiation (heat) from the Sun pass through the glass/plastic and warms the contents of the greenhouse. The warmed air and objects inside the greenhouse radiate heat, but this heat has a longer wavelength than the heat from the Sun, so it cannot pass through the glass. Thus the greenhouse becomes warmer inside than the surrounding fields. The greenhouse effect occurs in a similar way. Most of the Sun's radiation passes through the atmosphere warming the atmosphere and the Earth's surface. The warmed-up Earth emits longer wavelength infra-red (heat) radiation that is unable to leave the atmosphere because the Earth's atmosphere acts like the walls of a greenhouse. Gases such as carbon dioxide also absorb this radiation adding to the heating effect – they enhance the greenhouse effect so they are called greenhouse gases.