

Heinemann CHEMISTRY 2

5TH EDITION

VCE Units 3 & 4
Written for the VCE Chemistry
Study Design 2017–2021



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Heinemann
CHEMISTRY **2**
5TH EDITION

VCE Units 3 & 4

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Heinemann CHEMISTRY²

5TH EDITION

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The Chemistry Education Association was formed in 1977 by a group of chemistry teachers from secondary and tertiary institutions. It aims to promote the teaching of chemistry, particularly in secondary schools. The CEA has established a tradition of providing up-to-date text and electronic material and support resources for both students and teachers and professional development opportunities for teachers.

The CEA offers scholarships and bursaries to students and teachers to further their interest in chemistry. The CEA supports STAV with sponsorship for the Chemistry Conference, Science Drama Awards and The Science Talent Search.

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How to use this book

Heinemann Chemistry 2 5th edition

Heinemann Chemistry 2 5th Edition has been written to the new VCE Chemistry Study Design 2017–2021. The book covers Units 3 and 4 in an easy-to-use resource. Explore how to use this book below.

Extension

The extension boxes include material that goes beyond the core content of the Study Design and are intended for students who wish to expand their depth of understanding.

Highlight

The highlight boxes provide important information such as key definitions, formulas and summary points.

Worked example: Try yourself 3.4.3
GAS VOLUME–VOLUME CALCULATIONS

Methane gas (CH_4) is burned in a gas stove according to the following equation:
 $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$

If 50 mL of methane is burned in air, calculate the volume of CO_2 gas produced under constant temperature and pressure conditions.

EXTENSION
Calculations involving excess reactants

As you learned in Unit 2 Chemistry, stoichiometry calculations become more complex if the reactants are not present in their stoichiometric ratio. In these cases, you must determine which reactant is completely consumed in the reaction, the limiting reactant, and which one is present in excess. The amount of limiting reactant determines how much product is formed.

Worked Example 3.4.4 introduces a strategy that can be used to determine the limiting reactant in a reaction.

Worked example 3.4.4
EXCESS REACTANT CALCULATIONS

A gaseous mixture of 25.0 g of hydrogen gas and 100.0 g of oxygen gas are mixed and ignited. The water produced is collected and weighed. What is the expected mass of water produced? The equation for the reaction is:
 $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})$

a Which reactant is the limiting reactant?
b What is the mass of water vapour formed?

THINKING	WORKING
• Calculate the number of moles of each reactant using: $n = \frac{m}{M}$ or $n = \frac{V}{V_m}$ or $n = \frac{PV}{RT}$ as appropriate.	$n(\text{H}_2) = \frac{m}{M}$ $= \frac{25.0}{2.0}$ $= 12.5 \text{ mol}$
	$n(\text{O}_2) = \frac{m}{M}$ $= \frac{100.0}{32.0}$ $= 3.13 \text{ mol}$

CHAPTER
04 Redox reactions

Some of the most colourful and exothermic reactions are classified as redox reactions. This group of reactions includes some that are vitally important for the functioning of the human body and that provide the energy for our modern lifestyle.

In this chapter, you will learn how redox reactions can be defined in terms of electron transfer, and how this definition can be extended by using the concept of oxidation number. You will find out how to write balanced half-equations that describe the transfer of electrons, and then how to combine these half-equations to result in an overall equation for the reaction.

Key knowledge

- Redox reactions with reference to electron transfer, reduction and oxidation reactions, reducing and oxidising agents, and use of oxidation numbers to identify conjugate reducing and oxidising agents
- The writing of balanced half-equations for oxidation and reduction reactions and balanced ionic equations, including states, for overall redox reactions

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Chapter opener

Chapter opening pages link the Study Design to the chapter content. Key knowledge addressed in the chapter is clearly listed.

ChemFile

ChemFiles include a range of interesting information and real-world examples.

CHEMFILE
Fritz Haber

Fritz Haber (1868–1934), seen in Figure 8.7.4, was a German chemist who invented the process for producing ammonia that now bears his name. The reaction produces ammonia from atmospheric nitrogen and hydrogen according to the equation:
 $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$

The Haber process made it possible to produce fertilisers with a high nitrogen content. This allowed for better crop yields in agriculture. Easy access to reasonably priced fertilisers has saved lives and reduced starvation in many areas across the world. This fact was acknowledged when Haber was awarded the Nobel Prize in Chemistry in 1918, following the end of the World War I.

However, Haber's involvement in the production and use of chemical weapons by the German army in World War I meant that the award of a Nobel Prize was seen as controversial by many scientists who considered him to be guilty of war crimes.

FIGURE 8.7.4 Fritz Haber (1868–1934) invented a process for producing ammonia from atmospheric nitrogen and hydrogen. He was awarded the Nobel Prize in Chemistry in 1918.

CHEMISTRY IN ACTION
Improving the catalyst for ammonia synthesis

The effectiveness of the catalyst in the converter in the Haber process is critical to its efficiency. Fritz Haber and his colleague Carl Bosch tested nearly 2000 different materials as catalysts when developing their process for ammonia synthesis. Haber used new elements such as osmium and even suggested uranium as a potential catalyst in his earlier research.

By good fortune, the first one that they tested was from Sweden and contained traces of rhenium. Rhenium compounds that act as promoters, increasing the efficiency of the catalyst. A promoter creates many small pores in the catalyst, exposing more crystals and providing a greater surface area and more sites for reaction. The catalyst widely used today is not very different—iron oxide with a potassium hydroxide promoter.

An alternative catalyst is ruthenium metal supported on high-surface-area carbon. This material began to attract considerable interest from industry in the 1990s. While this catalyst is much more expensive, it is 45 times more active per square metre of surface, allowing the use of a lower operating temperature of about 400°C and 40 atm pressure. It has been involved in a number of ammonia plants.

Even more recently, a Danish company has announced the discovery of a new catalyst based on metal nitrides such as Fe_3N_2 and Co_3N_2 . This catalyst is two to three times as effective as commercial iron-oxide catalysts but less expensive than the ruthenium-based ones.

A dream for many chemists has been to develop a catalyst with the efficiency of nitrogenase, the enzyme found in nitrogen-fixing bacteria in legumes such as

...nitrogenase contains clusters of iron, molybdenum and sulfur. Research is continuing to develop similar artificial clusters that could allow low-cost ammonia synthesis at normal temperatures and pressures. The area of catalysis for the production of ammonia remains an active field; recent research includes the use of photocatalysts developed from osmium-gold nanoparticles.

FIGURE 8.7.5 Factors through soil nodules from broad beans, seen to show the presence of nitrogen-fixing bacteria. Chemists develop new catalysts for the production of ammonia at ambient temperature and produce crops to meet the pathway used by bacteria.

Chemistry in Action

Chemistry in Action boxes place chemistry in an applied situation or relevant context. These boxes refer to the nature and practice of chemistry, applications of chemistry and the associated issues and the historical development of concepts and ideas.

Worked examples

Worked examples are set out in steps that show thinking and working. This enhances student understanding by linking underlying logic to the relevant calculations.

Each **Worked example** is followed by a **Worked example: Try yourself**. This mirror problem allows students to immediately test their understanding.

Fully worked solutions to all **Worked examples: Try yourself** are available on *Heinemann Chemistry 2 5th Edition ProductLink*.

Glossary

Key terms are shown in bold and listed at the end of each chapter. A comprehensive glossary at the end of the book provides comprehensive definitions for all key terms.

Chapter review

Each chapter concludes with a set of higher order questions to test students' ability to apply the knowledge gained from the chapter.

Section summary

A summary is provided at the end of each section to assist students consolidate key points and concepts.

Section review

A set of key questions is provided at the end of each section to test students' understanding and ability to recall the key concepts of the section.

Area of Study review

A comprehensive set of exam-style questions, including multiple choice and extended response questions, are provided at the end of each Area of Study section. The questions are designed to assist students to apply their knowledge and understanding across the entire Area of Study.

9.3 Review

SUMMARY

- Electroplating is an application of electrolysis. It involves the deposition of a thin surface coating of metal over another surface to improve the appearance of an object. Its resistance to corrosion, or leech, is improved.
- The charge passing through an electrochemical cell can be calculated from the formula: $Q = I \times t$ (coulombs), where I is current (amps) and t is time (seconds).
- Faraday's first law states that the mass of metal produced at the cathode is directly proportional to the electrical charge passed through the cell.
- Faraday's second law states that in order to produce 1 mole of a metal, 1, 2, 3 or another whole number of moles of electrons must be consumed.
- The charge on one mole of electrons is called a Faraday (F), where $1 F = 96500 C$.
- The charge on an amount of electrons can be calculated from: $Q = n \times F$, where n is amount of electrons (moles) and $F = 96500 C$.
- Faraday's laws can be used to calculate the mass of a product formed in a cell, given the current and operating time.
- Current passing through a cell, given the mass of product and the operating time.
- Time required for a cell to operate, given the mass of product and the current through the cell.

KEY QUESTIONS

- How many faradays of charge are required to produce:
 - a) 1 mole of silver atoms from a silver nitrate solution?
 - b) 1 mole of zinc atoms from a zinc nitrate solution?
 - c) 1 mole of chlorine molecules (Cl_2) from molten potassium chloride?
 - d) 1 mole of hydrogen molecules (H_2) from molten potassium hydroxide?
- A zinc-plating cell with $NiSO_4(aq)$ electrolyte operates with a current of 10.0 A for 55.0 minutes. What mass of metal is plated on the cathode?
- A car's lights are left on and the battery discharges at a current of 1.2 A. How long would it take, in hours, for 15.6 g of lead to be lost from the anode? The electrode reaction is represented by the half-equation:
 $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-$

Figure 9.3.10 shows an electroplating cell that was devised by a student to plate a silver coating onto a key. An electric current is passed through a solution of 1.0 M silver nitrate ($AgNO_3$) using an inert carbon electrode as the anode.

- Write a half-equation for the reaction that occurs at the electrode connected to the negative terminal of the power source.
- What current is required to deposit 0.050 g silver on the surface of the key when a current is passed through the cell for 7.0 minutes?
- Electrolysis of a molten ionic compound with a current of 0.50 A for 30.0 minutes produces 0.700 g of a metallic element at the cathode. If the element has a relative atomic mass of 136.0, calculate the charge on the metal ion.

CHAPTER 9 | PRODUCTION OF CHEMICALS BY ELECTROLYSIS 257

Chapter review

KEY TERMS

- absorbance
- absorption band
- base peak
- calibration curve
- carbon-13 NMR
- electrochromism
- chemical shift
- dipole
- electromagnetic spectrum
- equivalent

Infrared spectroscopy

- List the bands in a transmission IR spectrum that will absorb the lowest energy infrared radiation to the band that will absorb the highest energy infrared radiation.
- The IR spectra of two liquid samples, A and B, are provided in Figure 12.5.1.

Nuclear magnetic resonance spectroscopy

- Explain the use of TMS in NMR spectroscopy.
- Ethyl methanolate, methyl ethanolate and propanoic acid are isomers with the formula $C_3H_8O_2$. Match each of these compounds with the following spectra.

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neighbour nuclear magnetic resonance (NMR) spectroscopy nuclear magnetic resonance (NMR) spectrum nuclear shielding nuclear spin precession NMR spectroscopy

quantitative analysis splitting patterns transmittance vibrational energy level wavenumber

410 AREA OF STUDY 1: KEY CONCEPTS OF CHEMISTRY AND THE ELECTROLYSIS OF SULPHATE AND CATIONIC

UNIT 3 • Area of Study 1

Refer to the following equation for the reaction between hydrochloric acid and ammonia solution when ammonia gas is formed:

$$HCl(aq) + NH_3(aq) \rightarrow NH_4Cl(aq) \quad \Delta H = -52 \text{ kJ mol}^{-1}$$

- The reaction is:
 - A endothermic, because the energy involved in bond forming is more than that involved in bond breaking.
 - B endothermic, because the energy involved in bond forming is less than that involved in bond breaking.
 - C exothermic, because the energy involved in bond forming is more than that involved in bond breaking.
 - D exothermic, because the energy involved in bond forming is less than that involved in bond breaking.
- Which of the following happens when hydrochloric acid and ammonia solutions are allowed to react in a perfectly insulated container?
 - A The total energy inside the container decreases.
 - B The total energy inside the container increases.
 - C The total energy inside the container is unchanged but there is an entropy (thermal energy) after the reaction.
 - D The total energy inside the container is unchanged but there is more entropy (thermal energy) after the reaction.

The following information relates to Questions 10–12. As a response to rising petrol prices, the Australian Government in 2006 offered car owners a \$2000 incentive to convert their cars from petrol to LPG. Propane is one of the gases in the mixture sold as LPG. The thermochemical equation for the complete combustion of propane is:

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l) \quad \Delta H = -2220 \text{ kJ mol}^{-1}$$

- Which energy profile diagram best represents the energy changes that take place during this reaction?
- When 10.0 g of propane undergoes complete combustion:
 - A 520 J (0.52 kJ) of energy is absorbed.
 - B 5.20 x 10⁴ kJ of energy is released.
 - C 3.92 x 10⁴ kJ of energy is absorbed.
 - D 3.92 x 10⁴ kJ of energy is released.
- When 1 M_l of energy is released in this reaction, the volume of $CO_2(g)$ produced, at standard laboratory conditions (SLC), is:
 - A 3.25 x 10⁴ L
 - B 33.5 L
 - C 1.12 x 10⁴ L
 - D 11.2 L
- Given that the density, d , of a substance is given by the formula: $d = \frac{m}{V}$ and that M represents molar mass, then the density of any gas is given by which formula?
 - A $d = \frac{pM}{RT}$
 - B $d = \frac{pM}{RT} \times 10$
 - C $d = \frac{RT}{pM}$
 - D $d = \frac{pM}{RT}$

- Which of the following lists species arranged with the nitrogen atoms in order of increasing oxidation number?
 - A NH_3 , N_2 , NO , NO_2
 - B NO , NO_2 , NH_3 , N_2
 - C NO , N_2 , NO , NO_2
 - D NO , NO_2 , NH_3 , N_2
- Use the electrochemical series to determine which one of the following would not be expected to occur to an appreciable extent.
 - A $2H^+(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + H_2(g)$
 - B $2Ag^+(aq) + Ni(s) \rightarrow 2Ag(s) + Ni^{2+}(aq)$
 - C $Br_2(l) + 2Fe^{2+}(aq) \rightarrow 2Br^-(aq) + 2Fe^{3+}(aq)$
 - D $2I^-(aq) + Pb^{2+}(aq) \rightarrow I_2(s) + Pb(s)$
- Hydrogen gas (H_2) is bubbled through a solution of $Sr^{2+}(aq)$. Which of the following observations is most likely?
 - A No reaction will occur.
 - B A precipitate of SrH_2 will form.
 - C The pH of the solution will decrease.
 - D Oxygen gas will be evolved.
- The following equations involve ions of the transition metal vanadium. The half-cell potential E° is shown for each equation.
 - $V^{3+}(aq) + e^- \rightarrow V^{2+}(aq) \quad E^\circ = -0.25 V$
 - $VO^{2+}(aq) + 2H^+(aq) + e^- \rightarrow VO^{+}(aq) + H_2O(l) \quad E^\circ = +0.36 V$
 - $VO_2^+(aq) + 2H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l) \quad E^\circ = +1.03 V$Of the ions listed, which are the strongest oxidant and the strongest reductant?

Strongest oxidant	Strongest reductant
A VO_2^+	A V^{2+}
B VO^{2+}	B VO^{+}
C V^{3+}	C V^{2+}
D V^{2+}	D VO_2^+
- Which of the following best describes the features of an anode in a galvanic cell?

Fluoride	Oxidation reaction
Positive	Reduction
Negative	Oxidation
Positive	Reduction

14. An electrochemical cell was made by dipping a copper rod into a solution of 1 M $CuSO_4$ in one beaker and dipping a metal rod into a solution of 1 M $NiSO_4$ in another beaker. The metals were connected with wire and the two solutions were connected by a piece of copper tape that had been soaked in a potassium nitrate solution. The cell is shown in the following diagram.

The solution in beaker 1 was initially colourless blue, owing to the presence of Cu^{2+} ions. The solution in beaker 2 was initially colourless green because of the presence of Ni^{2+} ions. Which of the following changes might it be possible to detect after the galvanic cell has been discharging for a period of time?

- The green colour in beaker 2 has faded and the mass of the copper electrode has increased.
- The blue colour in beaker 1 has faded and the mass of the nickel electrode has increased.
- The green colour in beaker 2 has faded and the mass of the nickel electrode has decreased.
- The blue colour in beaker 1 has faded and the mass of the nickel electrode has decreased.

15. Fuel cells provide an alternative method, often more efficient than direct combustion, of extracting energy from the reaction between a fuel and oxygen. Which of the following are the main energy transformations occurring when a fuel is directly combusted, and when reacted with oxygen in a fuel cell?

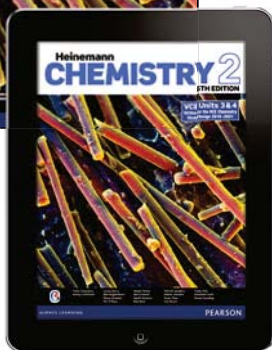
Fuel cell combustion	Fuel cell
A electricity → heat	electricity → enthalpy
B heat → enthalpy	electricity → enthalpy
C heat → enthalpy	enthalpy → electricity
D enthalpy → heat	enthalpy → electricity

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Answers

Numerical answers and key short response answers are included at the back of the book. Comprehensive answers and fully worked solutions for all section review questions, Worked examples: Try yourself, chapter review questions and Area of Study review questions are provided via *Heinemann Chemistry 2 5th Edition ProductLink*.

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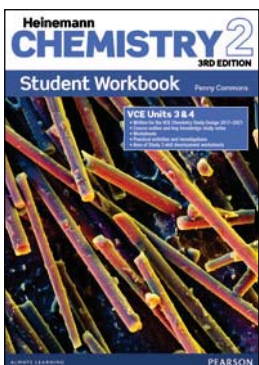


Student Book

Heinemann Chemistry 2 5th Edition has been written to fully align with the VCE Chemistry Study Design 2017–2021. The series includes the very latest developments and applications of chemistry and incorporates best practice literacy and instructional design to ensure the content and concepts are fully accessible to all students.

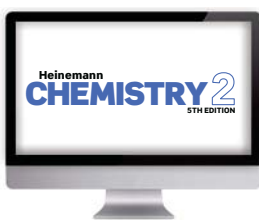
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Student Workbook

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UNIT 3

How can chemical processes be designed to optimise efficiency?

AREA OF STUDY 1

What are the options for energy production?

Outcome 1: On completion of this unit the student should be able to compare fuels quantitatively with reference to combustion products and energy outputs, apply knowledge of the electrochemical series to design, construct and test galvanic cells, and evaluate energy resources based on energy efficiency, renewability and environmental impact.

AREA OF STUDY 2

How can the yield of a chemical product be optimised?

Outcome 2: On completion of this unit the student should be able to apply rate and equilibrium principles to predict how the rate and extent of reactions can be optimised, and explain how electrolysis is involved in the production of chemicals and in the recharging of batteries.

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In this chapter, you will learn how fuels are used to meet global energy needs and you will gain an appreciation of the chemistry that underpins decisions about the use of fuels. Combustion reactions are used to release useful heat energy from the chemical energy stored in fuels. You will explore how fuels vary in terms of the energy that they produce when they are burnt.

You will consider the environmental impact of using different types of fuels, including their carbon emissions as well as the other pollutants they release into the atmosphere. Current research being conducted into the production of renewable fuels and the potential for reducing the harmful impact of fossil fuels will also be discussed.

Key knowledge

- The definition of a fuel, including the distinction between fossil fuels and biofuels with reference to origin and renewability (ability of a resource to be replaced by natural processes within a relatively short period of time)
- Combustion of fuels as exothermic reactions with reference to the use of the joule as the SI unit of energy, energy transformations and their efficiencies
- The comparison of fossil fuels (coal, crude oil, petroleum gas, coal seam gas) and biofuels (biogas, bioethanol, biodiesel) with reference to energy content, renewability and environmental impacts related to sourcing and combustion
- The comparison of the suitability of petrodiesel and biodiesel as transport fuels with reference to sources, chemical structures, combustion products, flow along fuel lines (implications of hygroscopic properties and impact of outside temperature on viscosity) and the environmental impacts associated with their extraction and production

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1.1 Types of fuels

Fuels provide you with energy. They are substances that have chemical energy stored within them. All chemicals contain stored energy. What makes a **fuel** special is that this stored chemical energy can be released relatively easily.

Sugar is an example of a common fuel (Figure 1.1.1). A cube of table sugar (sucrose) can provide your body with 82 kilojoules of energy. This is about 1% of your daily energy needs. If sucrose is burnt, this energy is released as heat. The combustion of 1 kilogram of sucrose releases sufficient energy to melt more than 5 kilograms of ice and then boil all the liquid water produced.

Although sugars provide energy for your body, you do not heat your home, power cars or produce electricity by burning sugar. A range of other fuels such as wood, coal, oil, natural gas, LPG, ethanol and petrol (Figure 1.1.2) are used for these energy needs.

In this section, you will explore the range of fuels available and how they are sourced.

THE NEED FOR FUELS

A fuel is a substance with stored energy that can be released relatively easily for use as heat or power. Although this chapter will focus on fuels with stored chemical energy, the term ‘fuel’ is also applied to sources of nuclear energy, such as uranium.

The use of fuels by society can be considered from a number of points of view, including at a:

- local level (e.g. the type of petrol used in your car)
- national level (e.g. whether Australia’s use of energy resources is **sustainable**)
- global level (e.g. whether the use of **fossil fuels** (coal, oil and natural gas) is contributing to the **enhanced greenhouse effect**).

These are not separate issues. Choices made locally have regional and global effects. The decisions of global and national governments affect how and which fuels are used.

Units of energy

The international system of units (**SI units**) is a widely used system of measurement that specifies units for a range of quantities. The SI unit for energy is the joule, symbol J. As 1 J of energy is a relatively small amount, it is common to see the following units in use:

- kilojoules, $1 \text{ kJ} = 10^3 \text{ J}$
- megajoules, $1 \text{ MJ} = 10^6 \text{ J}$
- gigajoules, $1 \text{ GJ} = 10^9 \text{ J}$
- terajoules, $1 \text{ TJ} = 10^{12} \text{ J}$.

Use of energy in Australia and the world

World energy consumption is around 4×10^{20} joules per year. The United States consumes a quarter of the world’s energy. Australia consumes about one-hundredth of the world’s energy. But energy consumption per person in Australia is only just below that of the United States. Figure 1.1.3 shows the ways in which Australians use energy. As you can see, heating and transportation account for 87% of Australia’s total energy consumption.

In Australia and around the world, most of the energy used for heating, electricity generation and powering vehicles comes from fossil fuels. About 86% of Australian electricity is generated from these fuels, with 73% from coal and 13% from natural gas.



FIGURE 1.1.1 Sugars, such as sucrose, are fuels for your body.



FIGURE 1.1.2 Petrol is just one type of fuel that is used each day to meet our energy needs.

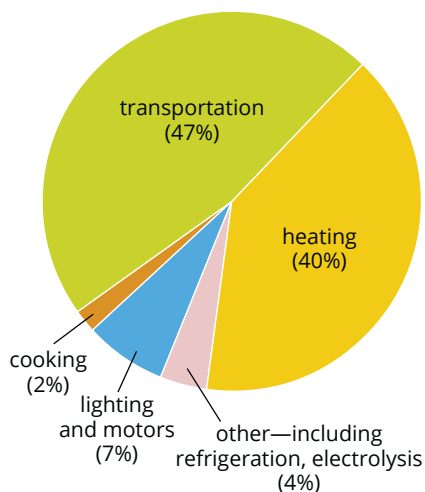


FIGURE 1.1.3 This pie chart shows where energy is used in Australia.

Coal-fired power stations are the dominant source of the world's electricity because they are often the cheapest form of generation. Electricity from coal-fired power stations is reliable and coal is very abundant.

About 14% of Australia's electricity comes from renewable energy sources. Hydroelectricity contributes 7% of total electricity and wind, biofuels and solar energy make up the other 7%.

Future energy needs

Burning wood was the dominant method of obtaining energy up to the middle of the 19th century. Wood supplies once seemed unlimited and, like fossil fuels today, satisfied most of the demands of the time.

Fossil fuels now provide nearly 90% of the world's energy needs. As members of a society that is heavily dependent on fossil fuels as a source of energy, we can find it hard to imagine obtaining energy from elsewhere.

The world first became aware that fossil fuels are a finite energy reserve during the 'oil crisis' of the early 1970s. Several Middle Eastern oil exporters restricted production for political reasons. This dramatically increased the cost of crude oil and caused huge increases in the price of petrol around the world.

Given the limited reserves and concerns about the link between fossil fuels and climate change, there is considerable interest in identifying and developing new energy sources. Many countries are already considering alternative sources of energy. The development of alternative sources for large-scale energy production is not a simple task. Replacement energy sources need to meet a range of requirements, such as being reliable, sustainable and cost-effective. Figure 1.1.4 shows the increase in world energy production from different sources.

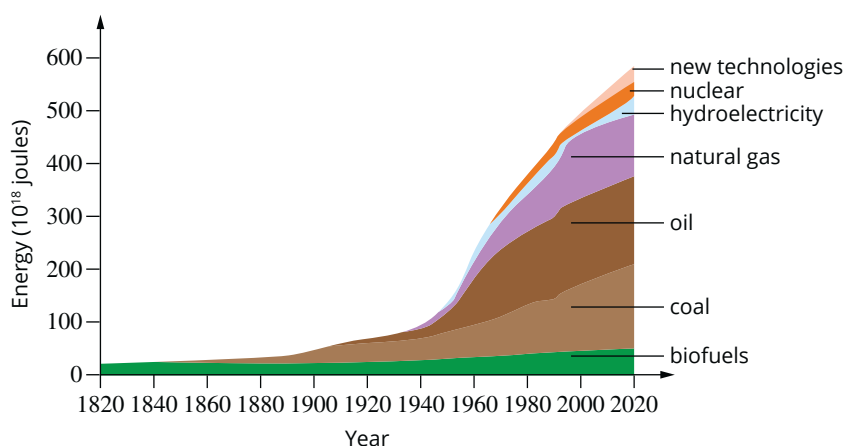


FIGURE 1.1.4 This graph shows the increase in world energy production.

FOSSIL FUELS

Non-renewable resources are those that are used faster than they can be replaced. Coal, oil and natural gas are non-renewable fuels. Reserves of fossil fuels are limited and they could eventually be exhausted.

Formation of fossil fuels

Coal, oil and natural gas were formed from ancient plants, animals and microorganisms. Buried under tonnes of mud, sand and rock, this once biological material has undergone complex changes to become the fossil fuels used by societies today. The organic matter still retains some of the chemical energy the plants originally accumulated by carrying out **photosynthesis**. Chemical energy in fossil fuels can be considered to be trapped solar energy.

Fossil fuel formation occurs over millions of years. This is why these fuels are considered non-renewable. Once reserves of the fossil fuels have been used, they will not be replaced in the foreseeable future.

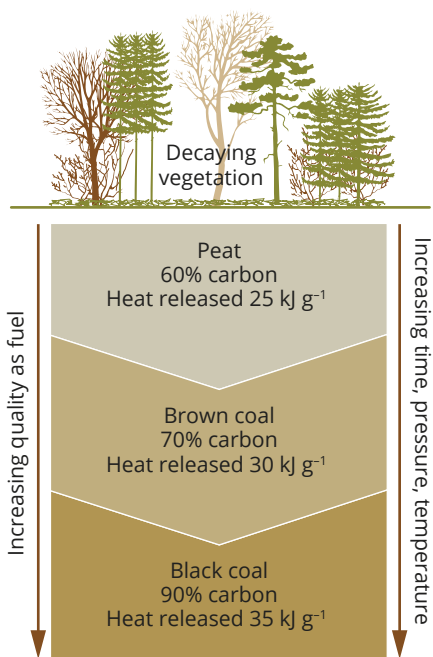


FIGURE 1.1.5 Steps in the formation of coal. Values of the carbon content and heat released upon combustion are for dried coal.

Coal

As wood and other plant material turn into coal, gradual chemical changes occur. Wood is about 50% carbon. As wood is converted into coal, the carbon content increases and the proportion of hydrogen and oxygen decreases. The wood progressively becomes peat, brown coal and then black coal (see Figure 1.1.5). Coal is a mixture of large molecules made from carbon, hydrogen, nitrogen, sulfur and other elements.

The amount of water in coal decreases as these changes occur. When coal is burnt, the energy released causes the water to vaporise, reducing the net amount of heat released. Black coal, which contains the least water and therefore the highest percentage of carbon, is a better fuel than brown coal or peat.

Although black coal is usually buried further underground than brown coal, its higher heat value often makes it economical to mine. Black coal is mined in Queensland and New South Wales. It is used for domestic power generation or exported overseas.

Large brown coal deposits are located in the Latrobe Valley in Victoria (see Figure 1.1.6). The power stations located next to these open-cut mines burn brown coal to generate electricity. Australia is the fifth largest producer of coal and the second largest exporter of coal in the world.



FIGURE 1.1.6 In Australia, brown coal is mined in the Latrobe Valley in Victoria.

CHEMFILE

Forming crude oil

The main deposits of crude oil were formed from small marine animals (zooplankton) and plants (phytoplankton) that lived up to 1 billion years ago. Some crude oil deposits are estimated to be even older, as much as 3–4 billion years old. If a deposit of crude oil was trapped beneath a layer of impermeable rock, then a layer of natural gas would also form.

The first deposits of crude oil were discovered at the end of the 19th century in the United States. Today, the largest crude oil deposits are in Russia, Iran, Iraq and Saudi Arabia. New crude oil deposits are still being found throughout the world. The oldest deposits found so far are in Venezuela, where the oil is estimated to be almost 4 billion years old. However, only about 10% of the oil discovered is profitable to extract.

Permeable rocks contain tiny spaces through which liquid substances can move. Crude oil has a lower density than water, so oil migrates upwards through permeable rocks over time. Large deposits of oil are formed when portions of this migrating oil become trapped under impermeable rocks. To extract the

crude oil, drilling into the impermeable rock has to take place (see Figure 1.1.7). In most cases, the oil flows up by itself under high pressure that has gradually built up from when the oil was formed. As the extraction continues, the overall pressure drops and pumps are needed to extract the remaining deposit.



FIGURE 1.1.7 Operating drill during oil and gas exploration.

Fuels from crude oil

Crude oil (petroleum) is a mixture of hydrocarbon molecules that are mostly members of the **homologous series** of **alkanes**. Crude oil itself is of no use as a fuel, but it contains many useful compounds.

Crude oil is separated into a range of fractions by **fractional distillation**. Fractional distillation does not produce pure substances. Each fraction is still a mixture of hydrocarbon compounds. These fractions can be used as fuels, or treated further to produce more specific products through chemical processes.

The relative amounts of different alkanes in crude oil vary with the deposit. For example, oil from Bass Strait and the Carnarvon Basin, Western Australia, contains relatively few of the larger molecules needed to form lubricants and bitumen.

i Alkanes are hydrocarbons with the general formula C_nH_{2n+2} . Alkanes are commonly found in crude oil.

CHEMISTRY IN ACTION

Fractional distillation of crude oil

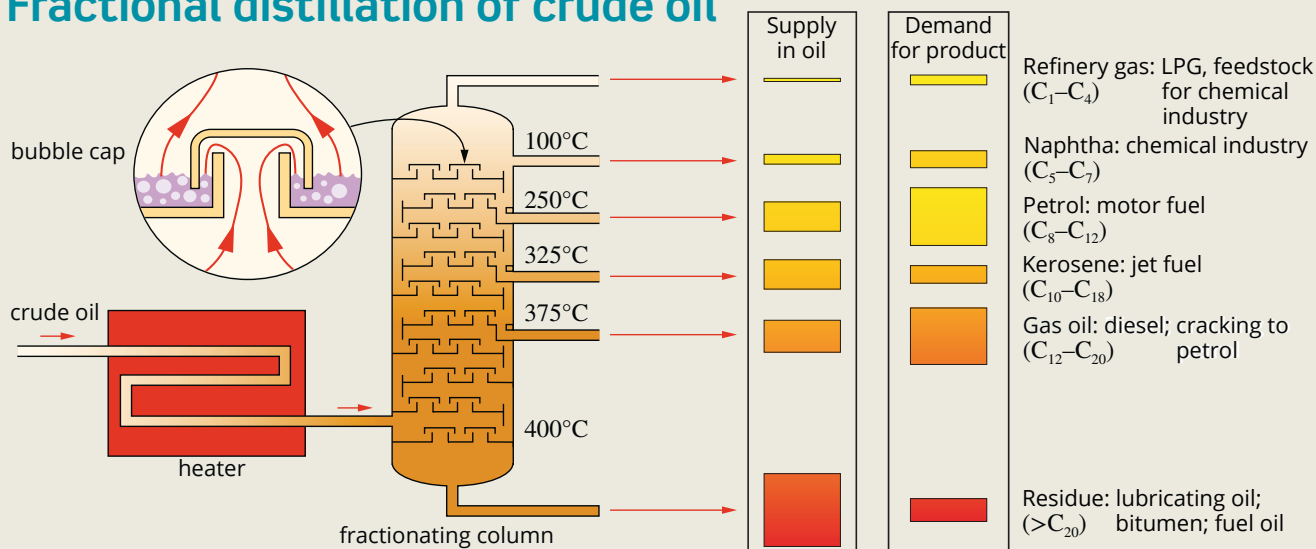


FIGURE 1.1.8 Fractional distillation of oil, and the bubble caps that stop the upward movement of gases.

Fractional distillation uses heat to separate a mixture into a number of different parts or fractions. A number of different temperatures are produced because of the nature of the column in which the crude oil is placed. The temperature of the tower decreases gradually with increasing height. Within the tower are horizontal trays, each containing hundreds of bubble caps. Bubble caps impede (stop) the upwards movement of gases (see Figure 1.1.8). As the vapour rises, it forces the caps up and it bubbles through condensed liquid in the trays. Those substances in the vapour that have boiling points almost equal to the temperature of the liquid in the trays condense and are collected. Consequently, fractions collected from trays higher in the tower will have lower boiling points.

The boiling point of a molecular compound depends on the strength of its intermolecular forces. Attractions between non-polar alkane molecules arise from weak dispersion forces, which are stronger with increasing molecular mass. As a result, each fraction consists of alkanes within a specific mass range. Lighter alkanes condense near the top of the tower, whereas heavier alkanes condense near the bottom. The composition and boiling range of each fraction are summarised in Figure 1.1.8. For example, the petrol fraction that boils (and condenses) between 100°C and 250°C consists of alkanes containing 8–12 carbon atoms; that is, C₈H₁₈ to C₁₂H₂₆.

Oil reserves

Australia's relatively small oil reserves are likely to be exhausted later this century. Figure 1.1.9 (page 6) shows the current locations of Australian oil, gas and coal fields. These reserves are associated with giant offshore gas fields near the northern Western Australian coast, and in reserves in outback South Australia and Bass Strait. Australia already imports over 90% of the crude oil it uses. Importation of large amounts of oil has a significant impact on Australia's economy.

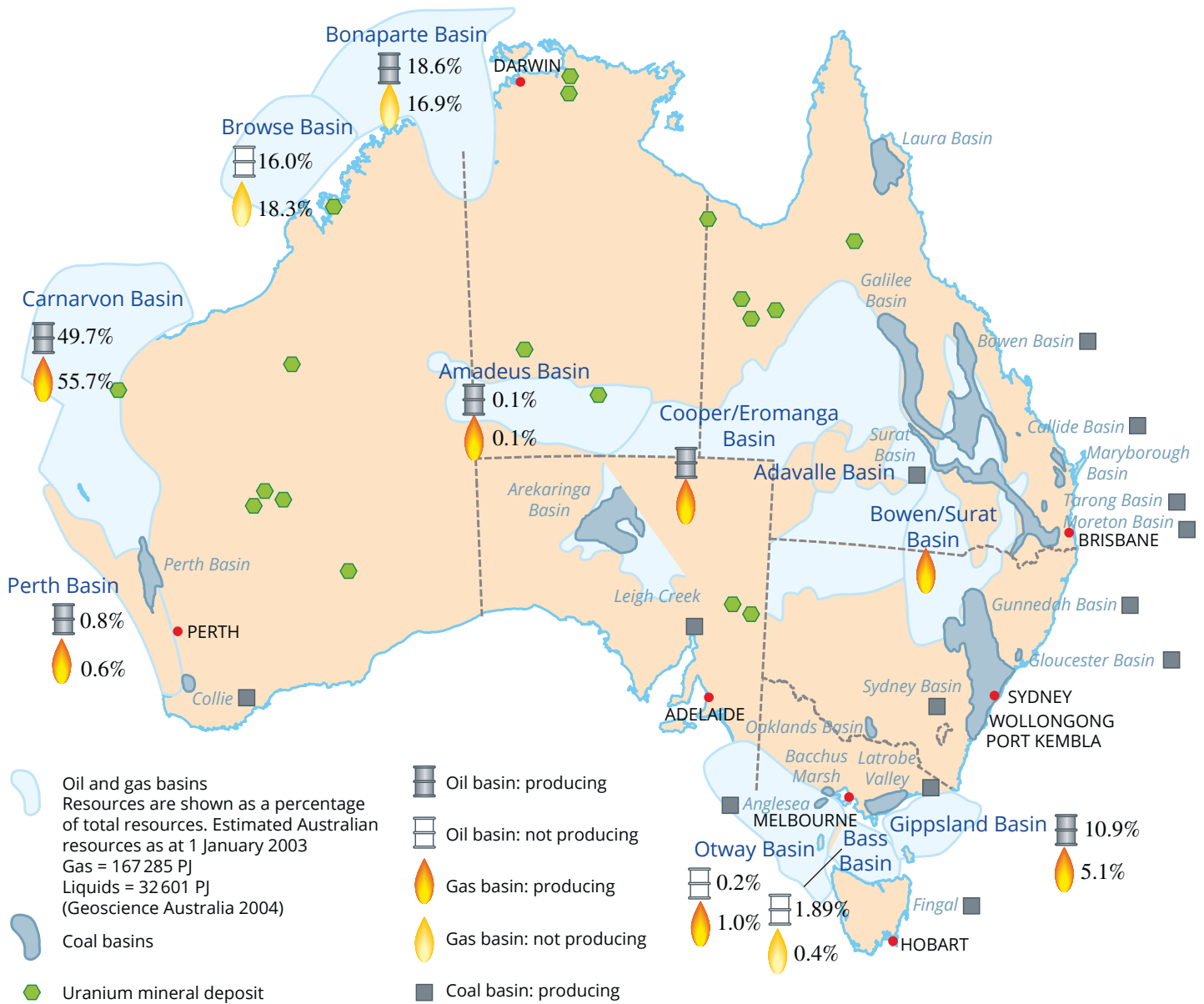


FIGURE 1.1.9 Australian oil, gas and coal fields.

Natural gas

Natural gas is another fossil fuel found in deposits in the Earth's crust. It is mainly composed of methane (CH_4) together with small amounts of other hydrocarbons such as ethane (C_2H_6) and propane (C_3H_8). Water, sulfur, carbon dioxide and nitrogen may also be present in natural gas.

Natural gas can be found:

- in gas reservoirs trapped between layers of rocks
- as a component of petroleum deposits
- in coal deposits where it is bonded to the surface of the coal. Coal seams usually contain water and the pressure of the water can keep the gas adsorbed to the coal surface. Natural gas found this way is known as **coal seam gas** or CSG. It is a major component of the energy supplies of Queensland
- trapped in shale rock, where it is referred to as **shale gas**. Shale gas is mined in many parts of the United States.

Natural gas is accessed by drilling as with crude oil; drilling causes the natural gas to flow to the surface (see Figure 1.1.10).

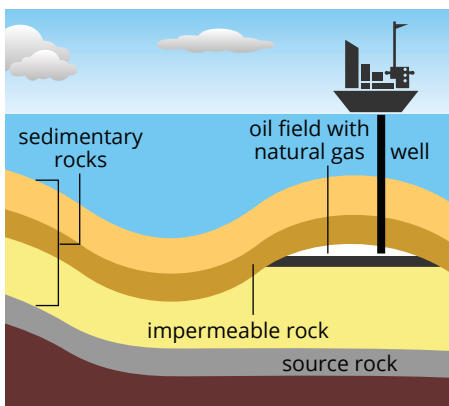


FIGURE 1.1.10 Natural gas deposits are often found trapped above crude oil. Once a well is sunk into the deposit, the natural gas flows to the surface.

Fracking

The extraction of natural gas from coal or shale deposits usually involves a process called **fracking**. Under pressure, the natural gas is adsorbed on the surface of the coal or shale. Fracking is used to fracture the rock or coal to release the natural gas.

Fracking begins with drilling a well into the deposit to access the trapped gas. The well is encased in steel and concrete to prevent leakage into local water supplies. Fracking fluid is then pumped down the well at extremely high pressures. This high-pressure fluid fractures the surrounding rock or coal, creating fissures through which gas can flow. This process is shown in Figure 1.1.11.

Materials used for fracking include sand, water and other chemicals. There are concerns about the potential impact of this process on the local environment and underground water supplies.

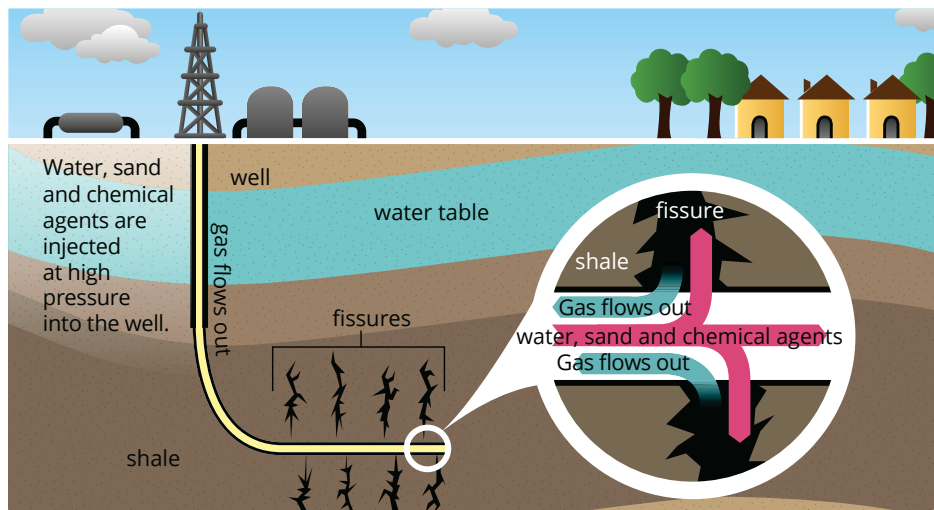


FIGURE 1.1.11 The fracking process: sand, water and other chemicals are injected into the deposit at high pressure to free the gas from the coal or shale.

CHEMISTRY IN ACTION

Debate surrounding coal seam gas

Coal seam gas (CSG) is a natural gas that is extracted from underground coal seams, where it is trapped in pores in the coal. Almost 30% of Australia's natural gas reserves come from coal seam gas. Reserves of CSG are found in New South Wales and Queensland. It is predicted that the reserves of CSG could supply the eastern states of Australia for over 25 years.

Various chemicals have been used as fracking fluids. Fracking fluids increase the permeability of the rock and therefore flow of gas to the surface. Fluids such as benzene, toluene, xylene and ethylbenzene were once commonly used. The use of these fluids has been banned in both New South Wales and Queensland because of concern over their effect on the environment. For example, these potentially carcinogenic compounds may escape and contaminate groundwater.

Water is now commonly used as a fracking fluid. Generally, large amounts of water are not available at the fracking site, so water needs to be transported in, which can have significant economic and environmental costs.

In 2015, there was a moratorium (ban) on coal seam gas exploration and fracking in Victoria. In September 2015, protestors rallied in the streets of Melbourne to express their concerns about the process (see Figure 1.1.12). The Victorian Government agreed to examine the science and impact of the CSG industry and methods while they extended their ban on the process.



FIGURE 1.1.12 Hundreds of protestors against fracking marching towards Parliament House in Melbourne in 2015.

Liquefied petroleum gas

Propane and butane gases can be separated from natural gas by fractional distillation. Propane and butane become liquids under pressure and are sold as **liquefied petroleum gas** (LPG). LPG is used as a fuel in cars and in home gas bottles. The natural gas remaining after the removal of propane and butane is used widely as a fuel for home heating and cooking.

BIOFUELS

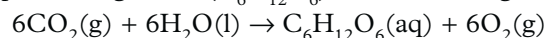
Governments and industry are exploring alternatives to fossil fuels in order to meet our future energy needs and limit the impact of fossil fuels on the environment. Ideally, new sources of energy will be **renewable**. Renewable energy is energy that can be obtained from natural resources that can be constantly replenished.

Biochemical fuels (or **biofuels**) are fuels derived from plant materials such as grains (maize, wheat, barley or sorghum), sugar cane (Figure 1.1.13) and vegetable waste, and vegetable oils. The three main biofuels are **biogas**, **bioethanol** and **biodiesel**. They can be used alone or blended with fossil fuels such as petrol and diesel.



FIGURE 1.1.13 Harvesting sugar cane in Queensland. Sugar cane can be a source of the raw materials for the production of bioethanol.

As well as being renewable, biofuels are predicted to have less impact on the environment than fossil fuels. The plant materials used in the generation of biofuels are produced by photosynthesis, which removes carbon dioxide from the atmosphere and produces glucose ($C_6H_{12}O_6$) in the following reaction:



The plants convert the glucose into cellulose and starch. Although carbon dioxide is released back into the atmosphere when the biofuel is burnt, the net impact should be less than for fossil fuels. You will compare fossil fuels and biofuels in more detail in later sections of this chapter.

Bioethanol

For thousands of years, humans have employed biological catalysts (**enzymes**) from yeasts to convert starches and sugars to ethanol. Enzymes catalyse the breakdown of the starch in grain crops (such as barley and wheat) to glucose. Other enzymes in yeasts then convert glucose and other small sugar molecules to ethanol (CH_3CH_2OH) and carbon dioxide in the **fermentation** reaction:



Bioethanol is used extensively in Australia. This includes E10 petrol, which contains 10% ethanol. This mix can be used by most modern car engines and its use reduces the consumption of petrol derived from crude oil.

Biogas

Biogas is gas that is released in the breakdown of organic waste by **anaerobic** bacteria. These bacteria decompose the complex molecules contained in substances such as carbohydrates and proteins into the simple molecular compounds carbon dioxide and methane. A digester (Figure 1.1.14) is a large tank filled with the anaerobic bacteria that digest (consume) the complex molecules to form biogas.

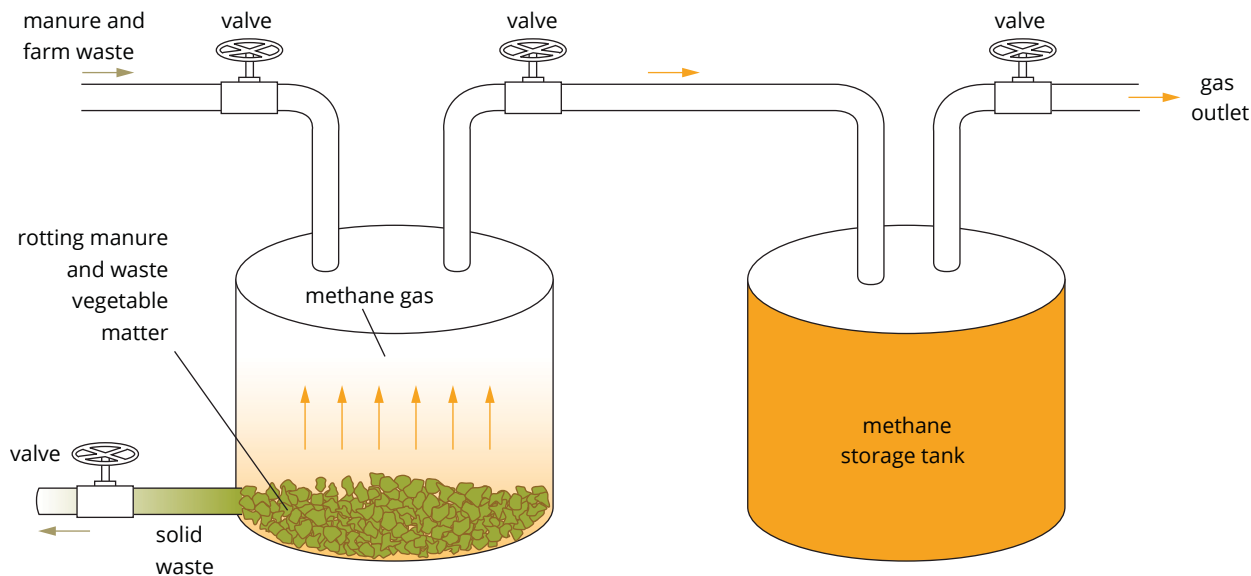


FIGURE 1.1.14 A digester is used in the production of biogas.

A range of materials, including rotting rubbish (such as that seen in Figure 1.1.15) and decomposing plant material, can be used to produce biogas.

The composition of biogas depends on the original material from which it is obtained and the method of decomposition. The typical composition of a sample of biogas is shown in Table 1.1.1.

TABLE 1.1.1 Typical percentage composition of different molecules found in biogas

Gas	Formula	Percentage composition (by volume)
Methane	CH ₄	60
Carbon dioxide	CO ₂	32
Nitrogen	N ₂	4.5
Hydrogen sulfide	H ₂ S	2
Oxygen	O ₂	1
Hydrogen	H ₂	0.5

As you can see from Table 1.1.1, biogas consists mainly of methane and carbon dioxide. Biogas can be used for heating and to power homes and farms. There are more than 7 million biogas generators in China. Biogas generators are particularly suited to farms, as the waste from a biogas generator makes a rich fertiliser.

In the future, it is likely more energy will be obtained from biogas generated at sewage works, chicken farms, piggeries and food-processing plants. Your local rubbish tip also has the potential to supply biogas. The gas can be used directly for small-scale heating or to generate electricity.



FIGURE 1.1.15 Pipes buried in this rubbish tip collect biogas.

Biodiesel

Biodiesel is a mixture of organic compounds called esters. These esters are produced by a chemical reaction between vegetable oils or animal fats and an alcohol (most commonly methanol (CH₃OH)).

The usual raw material for the production of biodiesel is vegetable oil from sources such as soyabean, canola or palm oil. Recycled vegetable oil or animal fats can also be used. The structure of a typical biodiesel molecule is shown in Figure 1.1.16. (The production of biodiesel is discussed in section 1.3 on page 24.)

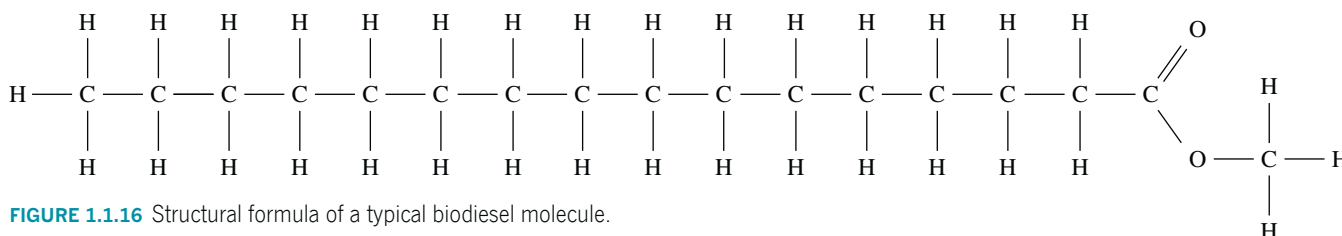


FIGURE 1.1.16 Structural formula of a typical biodiesel molecule.

1.1 Review

SUMMARY

- A fuel is a substance with stored energy that can be released relatively easily for use as heat or power.
- A fuel is considered to be non-renewable if it cannot be replenished at the rate at which it is consumed. Fossil fuels such as coal, oil and natural gas are non-renewable.
- Fossil fuels are produced over millions of years by the breakdown of biomass at high temperatures and pressures underground. Australia has large reserves of coal and natural gas.
- A fuel is considered to be renewable if it can be replenished at the rate at which it is consumed. Biofuels such as biogas, bioethanol and biodiesel are renewable.
- Biogas is formed by the anaerobic breakdown of organic waste.
- Bioethanol can be produced by fermentation of starches and sugars.
- Biodiesel is produced in a reaction between a vegetable oil or an animal fat and a small alcohol molecule such as methanol.
- Some of the non-renewable and renewable fuels in use in Australia are listed in Table 1.1.2.

TABLE 1.1.2 Types of renewable and non-renewable fuels in use in Australia

Non-renewable fuels	Renewable fuels
Coal	Bioethanol
Oil	Biogas
Liquefied petroleum gas (LPG)	Biodiesel
Natural gas	
Coal seam gas (CSG)	

KEY QUESTIONS

- 1 What is the difference between a renewable and non-renewable fuel?
- 2 Give an example of a renewable fuel source and a non-renewable fuel source used in Australia.
- 3 In Australia, which resource is likely to last longer before it is depleted: coal, oil or natural gas? Explain your answer.
- 4 Wood from forests is a renewable resource that supplied global energy needs for thousands of years.
 - a Why is wood no longer sustainable as the major energy source for today's society?
 - b Is it possible to have a non-renewable and sustainable energy source? Explain.
- 5 Why is it necessary to treat crude oil by fractional distillation?

1.2 Fossil fuels and biofuels

Fuels contain stored chemical energy that can be harnessed to perform useful functions. The heat energy released when fuels are burnt provides heat for warmth and cooking, as well as acting as the source of electrical energy and mechanical energy for transport.

In this section, you will look at the different fuels used to produce electricity or power vehicles and compare the environmental impact of these fuels.

ENERGY TRANSFORMATIONS

All substances contain chemical energy. The chemical energy of a substance is referred to as its **energy content**. Fuels are examples of substances with high energy contents.

When fuels are used, their chemical energy is converted to a different form of energy. For example, a competitive cyclist may eat energy bars. Much of the chemical energy of the food is converted in the cyclist's body to mechanical and kinetic energy.

The conversion of chemical energy to kinetic energy in the cyclist is an example of an **energy transformation**—energy is converted from one form to a different form. The use of fuels involves energy transformations. The chemical energy in a log on a fire can be converted to thermal energy to heat a room of a house.



FIGURE 1.2.1 Commercial solar cells convert solar energy to electrical energy with an efficiency of 12–18%.

When energy transformations occur, the total amount of energy is unchanged because energy cannot be created or destroyed. However, not all of the energy is converted to one specific form. In the case of the solar power cells shown in Figure 1.2.1, not all of the energy of the sunlight is converted to electrical energy.

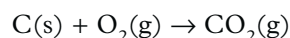
The term **energy efficiency** is used to describe the percentage of energy from a source that is converted to useful energy. For example, if the efficiency of a solar panel on a roof is listed as 17%, it means that 17% of the energy arriving on the panel from the Sun is transformed to electrical energy. The other 83% is converted to other forms of energy. The largest proportion of the Sun's energy reaching the solar cells is converted into heat energy that simply increases the temperature of the cells.

ELECTRICITY PRODUCTION

Chemical energy from most fuels is harnessed through **combustion** of the fuel. In combustion reactions, the reactant combines with oxygen to produce carbon dioxide and water. Thermal energy released from the combustion of fuels can be converted into electrical energy. In Australia, electrical energy is produced from several different fuels.

Electricity from coal

The combustion of coal generates over three-quarters of Australia's electricity. Rather than transport coal to every factory, office and household, the chemical energy is converted to electrical energy at a power station. Electricity is transmitted easily from the power station by metal cables and wires to other regions. The reaction occurring when coal burns can be written as:



The energy released from the combustion of coal is about 32 kJ g^{-1} .

A number of energy transformations occur in a coal-fired power station.

- Coal is burnt—chemical energy in coal is converted to thermal energy.
- Heat from the burning coal is used to boil water—thermal energy from the burning coal becomes thermal energy in steam.
- Steam is passed through a turbine—thermal energy in the steam becomes mechanical energy as the turbine spins. (This is the least efficient energy transformation in the sequence.)
- Electricity is produced from a generator that is driven by the turbine—mechanical energy is converted to electrical energy.

Figure 1.2.2 illustrates how the thermal energy released by the coal is converted to electrical energy.

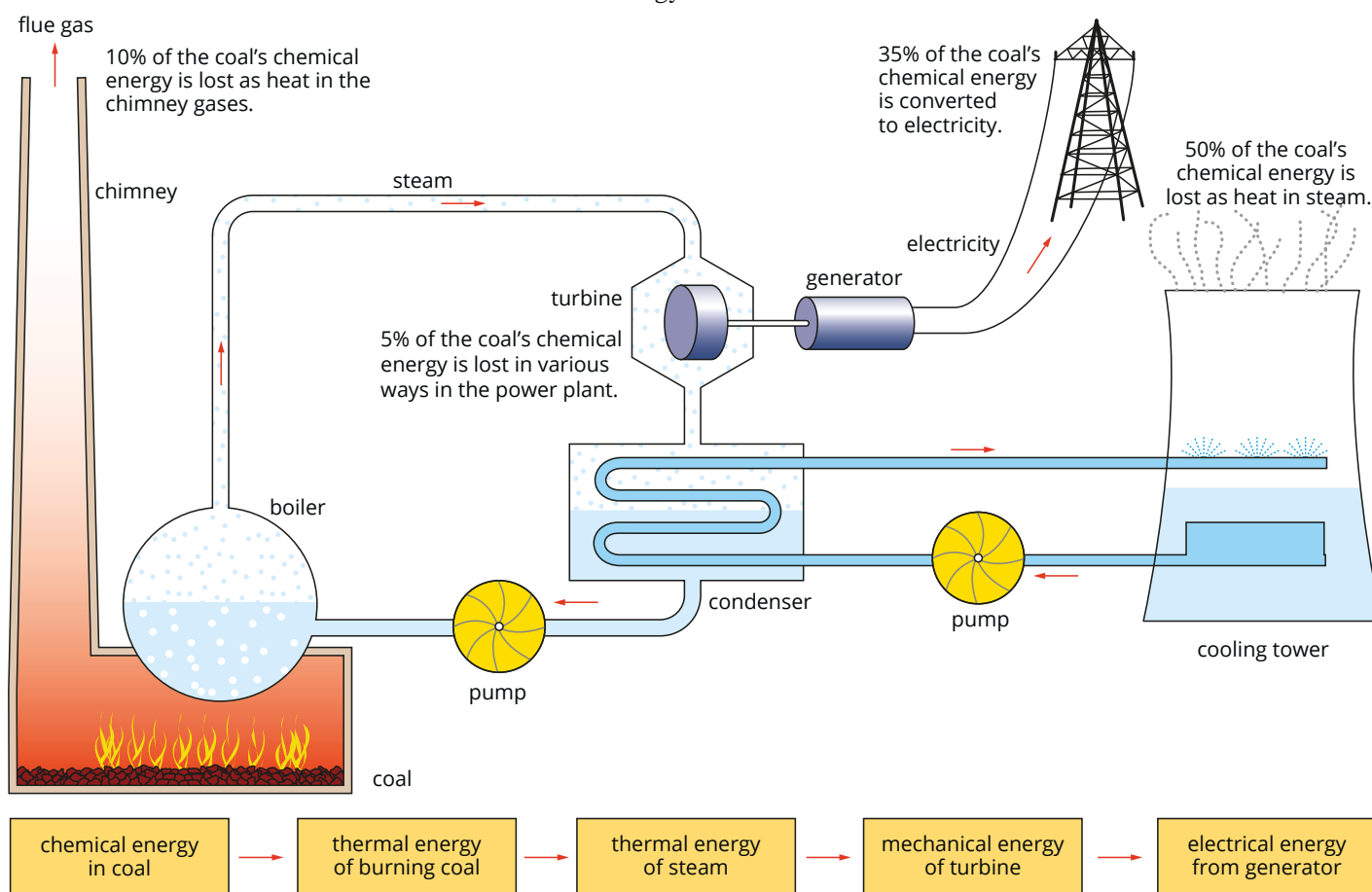


FIGURE 1.2.2 A representation of the process of burning coal to produce electricity. The chemical energy in the coal undergoes several transformations before electricity is produced.

The overall efficiency of a coal-fired power station is 30–40%. The combustion of brown coal is usually at the lower end of this efficiency range. Energy is lost during each step of the process, mainly as heat.

Electricity from natural gas

Natural gas is also used in Victoria to generate electricity for the power grid. In a gas-fired power plant, methane and other small alkanes are burnt to release energy. As shown in Figure 1.2.3, the hot gases produced by combustion cause air to expand in a combustion turbine to generate electrical energy. This is a simpler process than in a coal-fired plant where the thermal energy is used to produce steam.

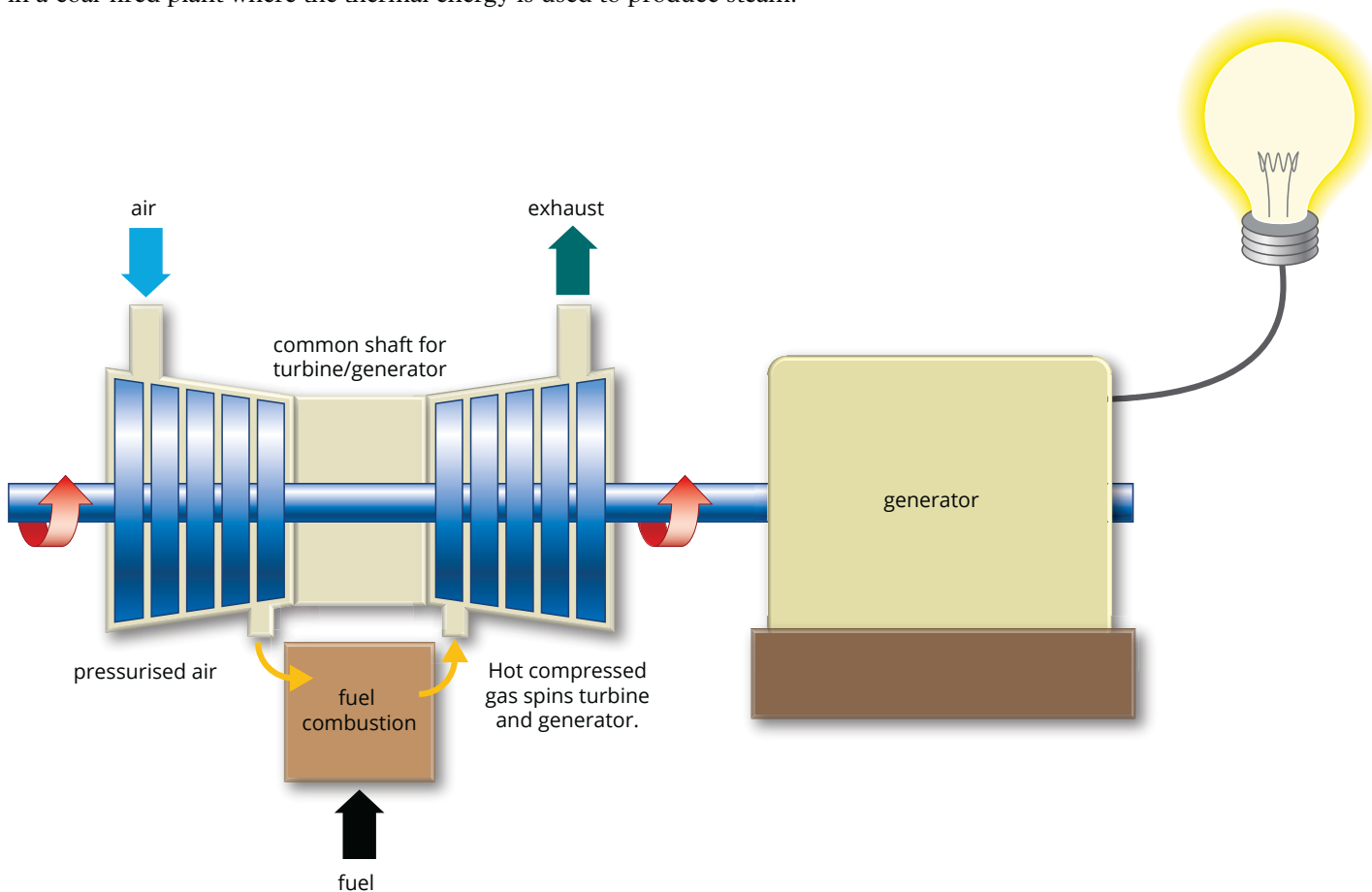
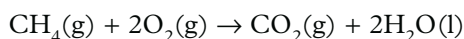


FIGURE 1.2.3 In a gas-fired power plant, the hot gases produced expand air in a combustion turbine to generate electricity.

The composition of natural gas varies but the main combustion reaction involves methane. The equation is:



The combustion of 1 mole of methane releases 890 kJ of energy, equivalent to 55.6 kJ g⁻¹. This is a significantly higher value than that of coal.

A gas-fired plant is more efficient than a coal-fired power station, reaching efficiencies just over 40%. Gas-fired plants also emit less carbon dioxide and particulate matter (small solid particles of solid combustion products) per unit of energy released. An added advantage of gas-fired plants is that the output can be varied at short notice. This allows the operators to adjust to the fluctuating power usage of consumers.

The largest gas-fired power station in Victoria, shown in Figure 1.2.4 (page 14), is operated by Origin Energy at Mortlake in south-west Victoria. The plant uses natural gas collected from off the nearby coast to generate electricity. Most Australian states have gas-fired plants but many of the plants are small-scale ones. Coal seam gas is the source of methane used in some states.



FIGURE 1.2.4 The Mortlake gas-fired power station, 200 km west of Melbourne, was opened in 2012. Natural gas from the Otway Basin is piped to this facility where it is burnt to produce electricity.

Electricity from biogas

Biogas is a renewable fuel that can be used to generate electricity, usually in small-scale electricity generators rather than large power plants. These smaller generators are often located at the site where the biogas is produced. For example, sewage works commonly burn biogas produced in a generator to supply some of their power needs.

The main reaction occurring in the combustion of biogas is the same reaction of methane burning in a gas-fired power station. The energy released per gram of biogas is less than that of natural gas because the methane content in biogas is significantly lower.

Berrybank Farm near Ballarat is an example of the innovative use of biogas. Over \$2 million has been spent on building infrastructure to collect the manure from 20 000 pigs. The manure is fed into a digester that produces two useful products: biogas and fertiliser. The biogas is used to fire generators, like the one shown in Figure 1.2.5, that produce an estimated \$180 000 of electricity annually.



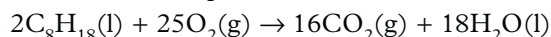
FIGURE 1.2.5 (a) Some of the pigs on the Berrybank Farm near Ballarat; (b) one of the generators that uses the biogas fuel.

FUEL FOR TRANSPORT

Crude oil is the source of most of the fuel we use for transport. Crude oil is a mix of alkanes. The alkanes in crude oil are separated into a series of fractions (parts) by fractional distillation. Some of these fractions are important fuels, such as liquid petroleum gas (LPG), petrol, kerosene and petrodiesel. LPG can also be separated from natural gas.

Petrol

Perhaps the most important of all hydrocarbon combustion reactions are those that occur when petrol is burnt. Petrol is a mixture of hydrocarbons, including octane, and the combustion reactions of these chemicals power most of Australia's 17.6 million motor vehicles. The equation for the combustion of octane is:



The combustion of 1 mole of octane releases 5450 kJ of energy, equivalent to 47.8 kJ g⁻¹. Combustion occurs in the cylinder of a car engine. The hot gases formed push the piston in the engine, enabling the car to move. A typical piston is shown in Figure 1.2.6.

The efficiency of a petrol engine in a new car can be as high as 25%. The operation of a piston in a car engine can be seen in Figure 1.2.7.

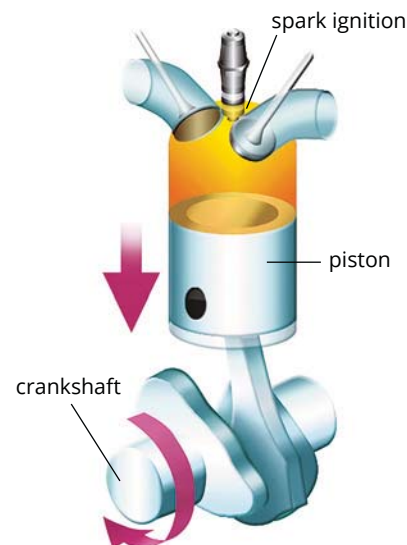


FIGURE 1.2.6 The combustion of octane (C_8H_{18}) and the other hydrocarbons in petrol pushes the pistons in internal combustion engines.

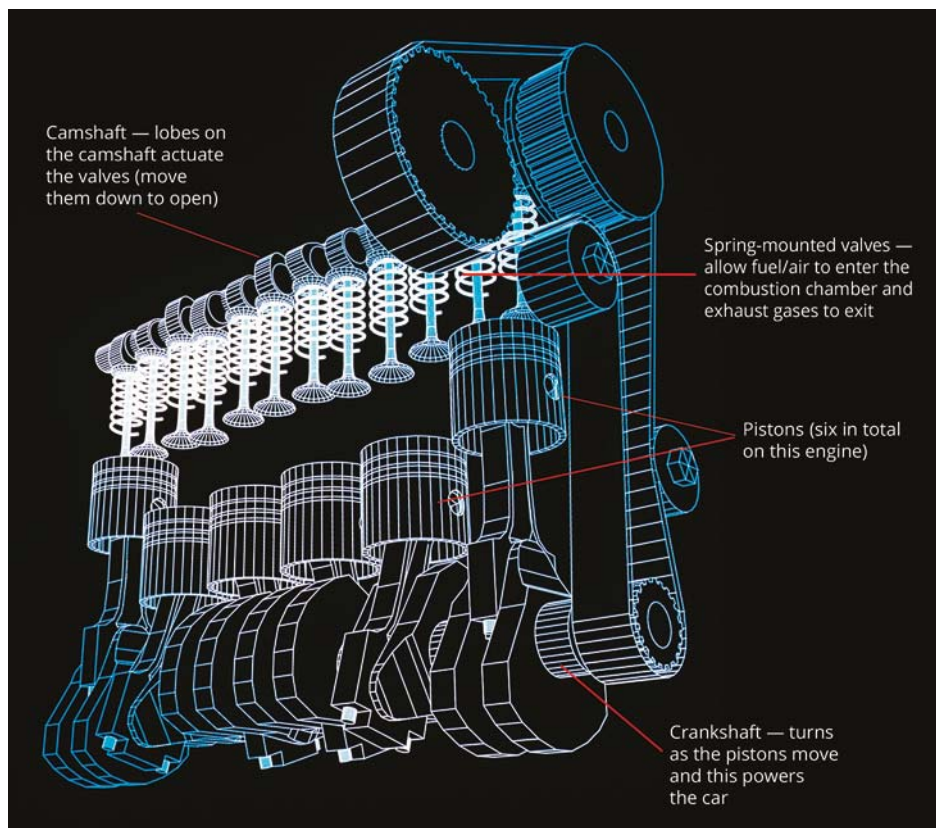
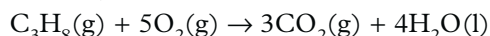


FIGURE 1.2.7 In a standard engine, fuel and air are mixed in cylinders and then compressed, and the mixture is ignited. The explosion drives the piston down, which turns the crankshaft and powers the car. The flow of fuel and exhaust gases is controlled by spring-mounted valves shown in the centre.

Liquid petroleum gas

Liquid petroleum gas (LPG) can also be used in cars. Most of the vehicles that use LPG as a fuel have a standard petrol engine with a fuel tank and fuel injection system modified to suit a gaseous fuel. The equation for the combustion of propane, a major component of LPG, is:



The combustion of 1 mole of propane releases 2220 kJ of energy, equivalent to 50.5 kJ g⁻¹.

In Australia, LPG is a significantly cheaper fuel than petrol, yet its popularity is still limited. Some of the reasons for this are:

- most new vehicles are designed to run on petrol; therefore, the owner has to pay around \$2000 for a conversion
- the LPG fuel tank takes up boot space

- there are fears that LPG cylinders might explode if the vehicle crashes
- the prices of fuels fluctuate, so often it is difficult to do meaningful price comparisons.

Bioethanol

Australia imports over 90% of its fuel requirements. This reliance on other countries, combined with concerns over the greenhouse emissions of fossil fuels, has sparked interest in the production of the renewable biofuels, bioethanol and biodiesel. Biodiesel is discussed in detail in the next section of this chapter.

Bioethanol can be produced from crops such as sugar cane. However, sugar cane is also needed for sugar production so there are limits to the amounts of bioethanol that can be produced in this way. Instead, researchers are trialling less valuable sources of sugar and starch for bioethanol production.

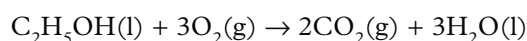
The Manildra plant at Nowra in New South Wales, shown in Figure 1.2.8, is one of Australia's largest ethanol refineries. At this plant, flour and starch are produced from wheat and sold for use in food manufacture. The waste that remains still contains high levels of starch, which is converted to ethanol.



FIGURE 1.2.8 Ethanol refinery in Manildra at Nowra, New South Wales.

Ethanol can be blended with petrol for use in motor vehicles. Australian government regulations limit the proportion of ethanol in petrol to 10%. This petrol blend is labelled E10 and sold at most Australian service stations. The presence of ethanol reduces the emissions of particulates and gases such as oxides of nitrogen, but higher levels of ethanol can damage engines, especially in older vehicles.

The equation for the combustion of ethanol is:



The combustion of 1 mole of ethanol releases 1367 kJ of energy, equivalent to 29.7 kJ g⁻¹. As Table 1.2.1 shows, the energy content of ethanol is about 62% that of petrol, so a larger mass (and volume) of ethanol is required to provide the same amount of energy. At a simple level, the lower energy content of ethanol can be regarded as the result of the carbon atoms in an ethanol molecule being partly oxidised ('partly burnt'). This is due to the presence of oxygen in the ethanol molecule.

TABLE 1.2.1 Energy content and energy density of vehicle fuels

Fuel	Energy content (kJ g ⁻¹)	Energy density (kJ L ⁻¹)
Methane	55.6	23 500 (liquefied)
Propane (LPG component)	50.5	29 400 (liquefied)
Butane (LPG component)	49.6	29 800 (liquefied)
Octane (petrol fraction)	47.8	33 400
Ethanol	29.7	23 400

ENVIRONMENTAL IMPACT

A discussion of the environmental impact of fuels needs to consider both the impact of emissions from the combustion of the fuel, and the impact on the environment of obtaining the fuel in the first place.

Emissions from fuel combustion

Carbon dioxide

Because large quantities of fuel are burnt every day to meet society's energy needs, the level of carbon dioxide production is high. This is a concern because carbon dioxide is a **greenhouse gas**.

Energy from the Sun heats the surface of the Earth. The Earth in turn radiates energy back towards space but greenhouse gases in the atmosphere absorb and re-radiate the energy in a process known as the **greenhouse effect**. The higher the concentration of greenhouse gas, the more energy is trapped.

The greenhouse effect occurs naturally due to the gases present in the atmosphere. However, scientists are concerned that increasing levels of greenhouse gases produced by our use of fossil fuels are causing global warming and triggering consequential shifts in weather patterns and climate. This is referred to as the enhanced greenhouse effect.

Methane, water vapour, nitrogen oxides and ozone are also greenhouse gases. Methane is 21 times more effective at trapping heat than carbon dioxide. The way in which greenhouse gases restrict heat radiation leaving the Earth is shown in Figure 1.2.9.

i The greenhouse effect is caused by heat being trapped in the Earth's atmosphere by greenhouse gases, which causes an increase in temperatures at the Earth's surface. As the amount of greenhouse gases in the Earth's atmosphere increases due to human activities, more heat is trapped, which is predicted to cause global changes in climate.

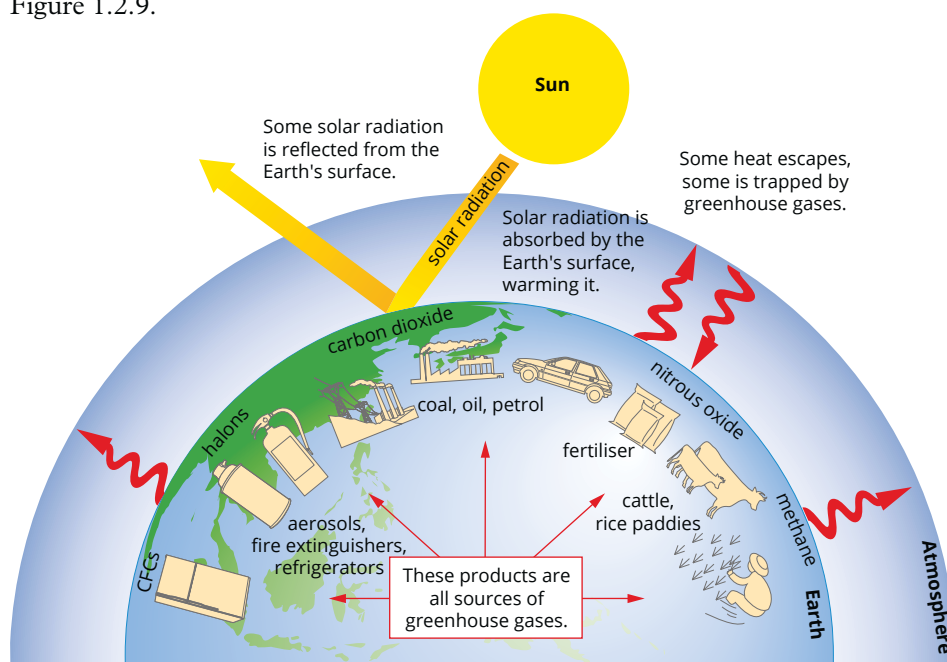


FIGURE 1.2.9 The greenhouse effect. Greenhouse gases help to maintain the temperature at the Earth's surface. Increased quantities of these gases as a result of human activities create an enhanced greenhouse effect.

The graph shown in Figure 1.2.10 supports concerns that the Earth is warming. Many countries are choosing alternatives to fossil fuels to address these fears.

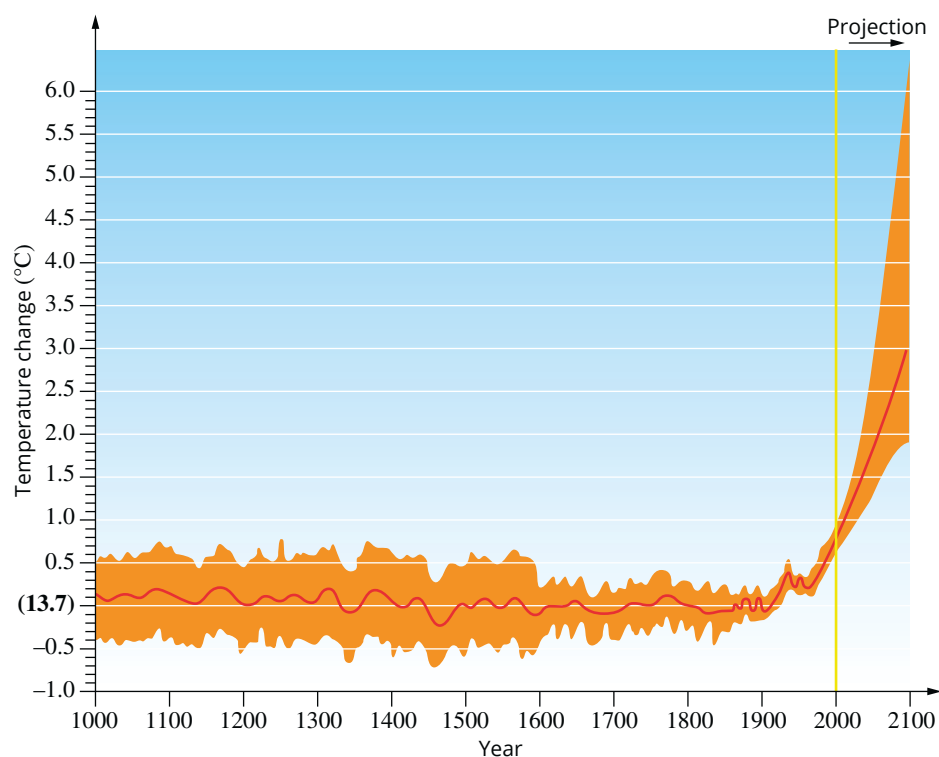


FIGURE 1.2.10 Change in the average surface temperature of the Earth from the year 1000 projected to 2100. Estimates of future temperature increases vary, depending on what assumptions are made.

Each fuel discussed in this section produces carbon dioxide when it burns. Table 1.2.2 compares the theoretical mass of carbon dioxide produced from the complete combustion of 1 gram of each fuel and per unit of energy produced.

TABLE 1.2.2 Mass of CO₂ produced from the combustion of 1 gram of fuel

Fuel	Mass of CO ₂ (g) emitted per gram of fuel	Mass of CO ₂ (g) per megajoule of energy produced (approx.)
Coal	3.7	93
Natural gas	2.8	56
LPG	3.0	65
Petrol	3.1	73
Ethanol	1.9	72

Bioethanol is a renewable fuel derived from plants. Although carbon dioxide is produced when bioethanol burns, carbon dioxide is also absorbed by the plants as they grow. For this reason, the widespread use of bioethanol should lead to a net reduction in the levels of carbon dioxide emitted.

However, bioethanol is not **carbon neutral**. This is because energy is required, and emissions are produced, in the growing, transport and refining of the fuel. Note also that although a relatively low mass of carbon dioxide is emitted per gram of fuel burnt, because bioethanol produces much less energy than the same mass or volume of petrol, a similar mass of carbon dioxide is emitted to produce the same quantity of energy.