UNIT 3

AREA OF STUDY 1

CHAPTER 1 Choosing fuels
CHAPTER 2 Energy calculations
CHAPTER 3 Converting chemical energy to electrical energy

AREA OF STUDY 2

CHAPTER 4 Electrolysis
CHAPTER 5 Rates of reactions
CHAPTER 6 Equilibrium systems
Fuels are burned to produce heat energy. The energy evolved from this combustion is used to heat our homes and for transport and industrial processes. It can also be converted into electrical energy, and, as such, can be conveniently transported over long distances and used to power many machines and appliances. The challenge to our society is to meet its increasing energy demands with a reliable supply of energy from clean, efficient and sustainable sources.

You will examine:
- the definition of a fuel
- how fuels and energy sources may be classified as renewable and non-renewable
- use of the joule as the SI unit for measuring energy
- energy transformation
- the concept of efficiency as it applies to energy transformations
- how fossil fuels and biofuels may be compared according to a range of criteria.

Alcohol and cars are thought to be a bad combination. But what if the alcohol goes into the car instead of the driver? Drivers are increasingly being offered more fuel choices for their cars. In Australia, E10, a blend of 10% ethanol with 90% petrol, is readily available and can be used in most modern cars. Elsewhere in the world, blends with higher proportions of ethanol are available. In Brazil, for example, flex-fuel vehicles can operate on any blend from E20 to E100. Special fuel sensors detect the ethanol to petrol ratio in the fuel and automatically tune the engine for optimum performance. Similar technology is also being introduced throughout Europe. Other fuels for cars include LPG and diesel. While these are non-renewable fuels, diesel can also be made in a renewable way, so there is now a trend for such diesel to be blended with petroleum diesel, as ethanol is blended with petrol. When ethanol and diesel are made as fuels from renewable resources, they are often called bioethanol and biodiesel. While some crops are now being grown specifically for the production of these fuels, new research is developing ways of using plant waste materials instead. It is also investigating plant sources that use less land, so that it does not encroach on land required to grow food crops.
Energy and fuels

What is energy?

We cannot see energy so it is difficult to define. Nevertheless, we can see the effects of energy; we can see things changing because of energy.

Energy is defined as the ability to do 'work.' Whenever something is being pushed or pulled, work is being done. When work is done, energy is used. The unit of energy is the joule; it has the symbol J. One joule is a relatively small amount of energy. It takes about 70,000 J (70 kJ) to boil the water to make a cup of coffee.

Most chemical reactions absorb or produce energy, generally in the form of heat. The study of heat changes in chemical reactions is called thermochemistry. An example of a reaction that produces heat energy is a combustion reaction.

Energy from common fuels

A substance used for producing energy by combustion is called a fuel. Coal, petroleum and natural gas are also known as fossil fuels because they were formed from the decaying remains of plants and tiny marine animals that lived millions of years ago.

Sample problem 1.1

The efficiencies of two fuels, propan-1-ol and butan-1-ol, were tested in a thermochemical experiment. The two fuels were ignited and the heat given out by each flame was measured by recording the change in temperature of a known amount of water heated by each flame. The results of this experiment are shown in table 1.1.

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Mass of alcohol used in experiment (g)</th>
<th>Heat given out (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>propan-1-ol, C₃H₇OH</td>
<td>3.75</td>
<td>126</td>
</tr>
<tr>
<td>butan-1-ol, C₄H₉OH</td>
<td>3.68</td>
<td>129</td>
</tr>
</tbody>
</table>
(a) Write balanced equations for each combustion reaction, given that the combustion products are carbon dioxide and water vapour.
(b) Calculate the energy produced by each fuel as kJ g\(^{-1}\), and thereby determine the more efficient of the two fuels.
(c) Calculate the energy produced by each fuel as kJ mol\(^{-1}\).

**Solution:**

(a) Combustion of propan-1-ol:
\[
2\text{C}_3\text{H}_7\text{OH}(l) + 9\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 8\text{H}_2\text{O}(g)
\]
Combustion of butan-1-ol:
\[
\text{C}_4\text{H}_9\text{OH}(l) + 6\text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 5\text{H}_2\text{O}(g)
\]

(b) Propan-1-ol produces \(\frac{126}{3.75} = 33.6\) kJ g\(^{-1}\)
and butan-1-ol produces \(\frac{129}{3.68} = 35.1\) kJ g\(^{-1}\).

So, in terms of energy per gram of fuel, butan-1-ol is slightly more efficient than propan-1-ol.

(c) Number of moles of propan-1-ol, \(n(\text{propanol}) = \frac{3.75}{60.0} = 0.0625\) mol.
Since 0.0625 mol produces 126 kJ of energy,

1 mol produces \(\frac{126}{0.0625} = 2.02 \times 10^3\) kJ of energy.

Number of moles of butan-1-ol, \(n(\text{butanol}) = \frac{3.68}{74.0} = 0.0497\) mol.
Since 0.0497 mol produces 129 kJ of energy,

1 mol produces \(\frac{129}{0.0497} = 2.60 \times 10^3\) kJ of energy.

So, in terms of energy per mole of fuel, butan-1-ol is more efficient than propan-1-ol.

**Thermochemical equations**

The information in sample problem 1.1 may be neatly summarised by using thermochemical equations. These combine the normal chemical equation with \(\Delta H\) notation (delta \(H\)) to specify the quantity of heat given out when the mole amounts as specified in the equation are burned. For example, the combustion of butan-1-ol in sample problem 1.1 may be summarised as:

\[
\text{C}_4\text{H}_9\text{OH}(l) + 6\text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 5\text{H}_2\text{O}(g) \quad \Delta H = -2.60 \times 10^3\text{kJ mol}^{-1}
\]

By convention, exothermic reactions (such as combustion reactions that give out heat) are assigned negative \(\Delta H\) values.

Thermochemical equations are discussed in detail in chapter 2.

Most of the energy obtained from the combustion of fossil fuels is derived from an exothermic reaction in which the carbon in the fuel is converted into carbon dioxide and the hydrogen in the fuel is converted into water.

Coal is used for generation of electricity. The complete combustion of coal may be represented as:

\[
\text{C}(s) + \text{O}_2(g) \rightarrow \text{CO}_2(g)
\]

Oil, from which petrol is obtained, is mainly used for transport. The complete combustion of octane, a major component of petrol, may be represented as:

\[
2\text{C}_8\text{H}_{18}(l) + 25\text{O}_2(g) \rightarrow 16\text{CO}_2(g) + 18\text{H}_2\text{O}(g)
\]
Natural gas is used both for generation of electricity and directly for domestic and commercial cooking and heating. The complete combustion of methane, found in natural gas, may be represented as:

\[
\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})
\]

**Revision question**

1. The combustion of 3.15 g of methanol was found to yield 71.5 kJ of heat. Calculate the \(\Delta H\) value for this reaction, and write the thermochemical equation.

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**Different forms of energy**

Energy may take a number of different forms. These include:
- mechanical energy
- thermal (heat) energy
- chemical energy
- light energy
- sound energy
- electrical energy
- gravitational energy
- nuclear energy.

However, all of these forms of energy may be classified as either potential energy (energy that is stored, ready to do work) or kinetic energy (energy associated with movement, in doing work).

The total energy of an object is the sum of its potential and kinetic energy.

All objects, from the smallest atom to the largest space rocket, have potential and kinetic energy.

**Energy conversions**

Whatever form energy takes, it is governed by two general laws of thermodynamics.

The first law states that energy is neither created nor destroyed, but simply changes from one form into another. Whenever energy is converted from one form to another, the total quantity of energy remains the same. This is sometimes called the Law of Conservation of Energy.
In any energy conversion, the total quantity of energy remains the same.

The second law states that, although the quantity of energy in the universe may stay the same, the quality or usability gets worse. This is because whenever energy is converted from one form to another, heat is also produced. This is low-temperature heat, which is difficult to use again. It simply warms up the Earth's atmosphere by a small amount. So, after each energy change, less usable energy remains.

**Efficiency**

The efficiency of energy conversion is a concept that follows from the second law. It takes the amount of usable energy obtained into account and is defined as a percentage according to the following formula.

\[
\text{% efficiency} = \frac{\text{energy obtained in desired form}}{\text{energy available before conversion}} \times 100
\]

The efficiency of changing one energy form into another varies.

Energy transformations are not 100% efficient. This is because, when energy conversions take place, heat is also produced. The second law of thermodynamics states that a high quality of energy is transformed to a lower quality of energy and some heat.
Sample problem 1.2

A compact fluorescent light bulb converts electrical energy into light energy. As part of a quality control test, it was found to convert 9.0 kJ of electrical energy into 1.8 kJ of light energy. Calculate its efficiency.

Solution:

\[
\text{% efficiency} = \frac{\text{energy obtained in desired form}}{\text{energy available before conversion}} \times 100
\]

\[
\text{% efficiency} = \frac{1.8}{9.0} \times 100 = 20\%
\]

Sample problem 1.3

The electricity from a coal-fired power station is used to power an electric motor. If the overall efficiency of the power station is 28%, and the efficiency of the motor in producing mechanical energy is 75%, calculate the overall efficiency for the conversion of chemical energy in coal to mechanical energy in this situation.

Solution:

We can answer this by following the fate of 100 J of energy supplied originally by the coal. From the original input of 100 J, the power station produces 28 J of electricity. When this 28 J is fed into the electric motor, the mechanical energy produced can be calculated.

\[
75\% \times \frac{\text{mechanical energy produced}}{28} = \times 100
\]

Mechanical energy produced = \[
\frac{75 \times 28}{100} = 21 \text{ J}
\]

As 21 J of mechanical energy is produced from the original 100 J

\[
\text{% efficiency} = \frac{21}{100} \times 100 = 21\%
\]

Revision questions

Where necessary, use efficiency figures in the diagram at the bottom of the previous page to answer the following questions.

2. A device converts 350 J of mechanical energy into 120 J of output energy. Calculate the efficiency of this device.

3. Calculate the energy input required for a gas heater to produce 72 MJ.

4. Heat energy in steam is used to drive a steam turbine that, in turn, drives an electrical generator. Calculate the electrical energy produced from steam containing 400 000 kJ.
Energy converters

Energy converters enable one form of energy to be changed into another.

Plants

Plants take carbon dioxide from the air and water from the roots to effect the energy change in a process called photosynthesis. In addition to providing food for animals as a result of this process, they provide oxygen as a by-product of the reaction.

![Diagram of energy conversion in plants]

Plants act as energy converters. They change the heat and light energy from the Sun into chemical energy that is stored in the plant.

Power stations

![Diagram of power station]

Key:
1. Coal inlet
2. Air intake
3. Air is preheated by exhaust gases from boiler.
4. Water is converted to steam.
5. Heat energy is converted to mechanical energy.
6. Mechanical energy is converted to electrical energy.
7. Hot water from condenser
8. Steam from turbo-generator is cooled in condenser, then recycled to boiler.
9. Waste products of combustion
When coal is burned, its stored chemical potential energy is converted into heat energy. This heat energy is used to convert water into steam, so heat energy is converted into kinetic energy. The steam flows past a turbine so the kinetic energy of the steam is converted into mechanical energy in the spinning turbine. The turbine is connected to a generator, which converts mechanical energy into electrical energy. Electrical energy may then be used in the home and in industry in a wide range of appliances.

Energy use in society

Global energy use

About 80% of the world’s energy requirements are provided by the fossil fuels coal, oil and gas. Australia has agreed to a pact with five other nations of the Asia–Pacific region (USA, Japan, South Korea, India and China) to collaboratively research more efficient and less polluting methods of generating power using fossil fuels.

Renewable and non-renewable resources

About 95% of our energy requirements are provided by the fossil fuels coal, oil and gas. Australia has a diverse range of energy resources available, but the availability, abundance and relatively low cost of fossil fuels are the reasons that they are in high demand. About 75% of Australia’s electricity generation is provided by black and brown coal, and 16% is supplied by natural gas. Access to these low-priced fuels is important for our manufacturing industry.

There is, however, extreme concern about the future use of fossil fuels. The combustion of fossil fuels releases gases that pose a threat to the environment. Carbon dioxide contributes to global warming, and sulfur dioxide contributes to acid rain. World reserves of fossil fuels are finite, and the fuels are being consumed at a much faster rate than they can be produced.

Projected depletion of world reserves of fossil fuels based on current usage
Energy sources may be classified as non-renewable or renewable.

**Non-renewable energy sources** are those that are used up faster than they can be produced on Earth. Non-renewable energy sources include fossil fuels and nuclear energy sources. There is a limited supply of non-renewable energy sources on Earth.

**Renewable energy sources** are those that can be produced faster than they are used by society. Renewable energy includes solar energy, hydro-electricity, tidal power, wave power and geothermal energy. It also includes a group called biofuels. These are fuels that can be made from biological materials and include bioethanol, biodiesel and biogas.

Attention is increasingly being focused on the development of alternative renewable energy sources to provide our energy needs.
Choosing energy sources

Although energy may be obtained from the direct combustion of fossil fuels, a more convenient form of energy is electricity. It can be carried from one place to another, it can be switched on and off, and it can be used as a source of energy for many different devices.

**TABLE 1.2 Electricity production in Australia by energy source, 2014**

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Production (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>black coal</td>
<td>111 491</td>
</tr>
<tr>
<td>gas</td>
<td>51 053</td>
</tr>
<tr>
<td>brown coal</td>
<td>47 555</td>
</tr>
<tr>
<td>hydro-electricity</td>
<td>18 270</td>
</tr>
<tr>
<td>wind</td>
<td>7 328</td>
</tr>
<tr>
<td>oil</td>
<td>4 464</td>
</tr>
<tr>
<td>solar photovoltaic cells</td>
<td>3 817</td>
</tr>
<tr>
<td>bioenergy</td>
<td>3 151</td>
</tr>
<tr>
<td>geothermal</td>
<td>1</td>
</tr>
</tbody>
</table>

*Source: 2014 Australian Energy Update (Australian Government Bureau of Resources and Economics).*

Electricity is sometimes described as a secondary fuel, since it is not a natural source of power; it is produced from other fuels or energy sources.

At present, most of Australia’s electricity is generated by burning fuel at power stations. Fossil fuels could be made to last longer, and the environmental hazards of fossil fuel combustion could be decreased, if other ways of
generating electricity were used. One way is to use nuclear energy. Others involve wind, moving water, wave motion, falling water, tides and biomass reactions. Electricity may also be generated directly from chemical reactions, as in fuel cells, which are thought to be a possible energy source for the future. Photovoltaic (PV) cells are yet another method. Already these are becoming more and more popular as people install them on the roofs of their houses. PV cells convert solar energy into electrical energy. They can even feed excess electricity produced back into the grid.

**Non-renewable fuels**

**Fossil fuels**

As explained earlier, coal, petroleum and gas are called fossil fuels because they were formed from animals, trees and smaller plants that lived millions of years ago.

Coal was formed from the combined effects of pressure, temperature, moisture and bacterial decay on vegetable matter over several hundred million years. Decaying vegetation progressively became peat (very soft and mushy), lignite (crumbly brown coal), bituminous coal (hard black coal) and anthracite (very hard). Over this period, the moisture content dropped and the carbon content increased, so anthracite is the highest quality coal.

Petroleum and natural gas have their origin in marine life buried in the sediments of the oceans millions of years ago. Heat, pressure and the action of bacteria changed this residue into petroleum and natural gas.

**Coal**

Coal is the world's most plentiful fossil fuel. The main elements in coal are carbon (50–98%), hydrogen (3–13%), oxygen and very small amounts of nitrogen and sulfur. It also contains moisture and inorganic material that remains as ash when coal is burned. As coal was formed, it underwent changes in composition that made it a more efficient fuel.
Victoria generates most of its electricity from brown coal, which has about a quarter of the heat content of black coal. Brown coal can have up to 30% oxygen content, a relatively low carbon content (60–75% when dried), and a high moisture content (30–70%).

By a process called destructive distillation, coal can be converted into many useful products, such as briquettes for heating, coal gas, sulfur, ammonia, benzene, coal tar, and coke. Coke is used in the reduction of Fe₂O₃ to iron.

Traditionally, coal was burned in lumps, but ground coal powder is now used to improve the rate and efficiency of combustion.

In addition to electricity, coal may be converted into gas or liquid fuels. These can be transported and used more cheaply and conveniently than solid coal.

**Petroleum**

*Petroleum* (or crude oil) is a sticky, black substance composed of a combination of many different hydrocarbons. It must be refined before it can be used.

Octane, C₈H₁₈, is the major component of petrol and may burn in air to release energy according to the equation:

$$2C₈H₁₈(l) + 25O₂(g) \rightarrow 16CO₂(g) + 18H₂O(g)$$

However, if the oxygen supply is limited, toxic carbon monoxide gas may be produced instead of carbon dioxide according to the equation:

$$2C₈H₁₈(l) + 17O₂(g) \rightarrow 16CO(g) + 18H₂O(g)$$

Fuels obtained from petroleum include petrol, liquefied petroleum gas (LPG), diesel fuel, heating oil and kerosene. Petroleum is also the raw material for manufacture of a number of useful materials such as plastics, paints, synthetic fibres, medicines and pesticides.

**LPG**

Liquefied petroleum gas (LPG) is a hydrocarbon fuel that consists mainly of propane and butane. It is non-toxic, non-corrosive, lead-free and heavier
than air. LPG is liquefied under pressure but when allowed to vaporise it expands to nearly 300 times its liquefied volume. This is why LPG can be stored as a compact liquid but burns as a dry, gaseous vapour. LPG is popular with many motorists, especially fleet-vehicle owners, because it is an economical energy source. Although LPG conversion costs for cars running on petrol are quite high, more people may make the conversion (or buy new cars designed to run on LPG) as petrol prices increase.

**Natural gas**

Natural gas is an important source of alkanes of low molecular mass. Victoria has large reserves of natural gas in the Gippsland basin. Typically, natural gas is composed of about 80% methane, 10% ethane, 4% propane and 2% butane. The remaining 4% consists of nitrogen and hydrocarbons of higher molecular mass. Natural gas also contains a small amount of helium and is one of its major sources.

Methane is the major constituent of natural gas and it burns with a hot, clean flame.

\[
\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})
\]

Since natural gas is lighter than air, it disperses in air. However, it is explosive in certain concentrations, so a safety measure incorporated by gas companies is to add an odour to natural gas so that leaks may be readily detected. Natural gas itself is odourless.

| **Table 1.3** Typical heat content values of some fossil fuels |
|-----------------|-----------------|-----------------|
| **Fossil fuel** | **Heat content** | **Heat content** |
|                 | **kJ g\(^{-1}\)** | **MJ/tonne**    |
| natural gas     | 54              | 54 000          |
| petrol          | 48              | 48 000          |
| diesel          | 45              | 45 000          |
| black coal      | 34              | 34 000          |
| brown coal      | 16              | 16 000          |

**Coal seam gas**

Coal miners have long been aware of the dangers of methane gas. Released from coal seams during underground mining operations, this gas has been responsible for many explosions and subsequent tragedies over the years. Methane gas, besides being found in association with petroleum deposits, is also a by-product of coal formation. It is often adsorbed onto the surface of coal deposits deep underground.

Coal seam gas (CSG), also called coal bed methane, is extracted by drilling deep wells into underground coal deposits. Such wells are typically 100 to 1500 metres deep and as such are below the level of aquifers used for bore water supplies in inland Australia. The coal seams are nearly always filled with water, which must be pumped to the surface to initiate gas production. This causes a reduction in pressure in the coal seam below and allows the methane to desorb from the coal. It is then brought to the surface along with more of the underground water through the drilled well.

Australia has large deposits of coal seam gas, which are now being extracted from the Bowen and Surat Basins in northern New South Wales and Queensland. The methane produced is relatively free from impurities, often containing only small amounts of ethane, nitrogen and carbon dioxide, and so requires
only minimal processing. It is used in the same way as natural gas and also contributes to a growing LNG (liquefied natural gas) export industry.

Although the coal seam gas industry has shown enormous expansion since 1996, there are concerns from various groups concerning its environmental impact. These include farmers who worry that it may pollute aquifers that supply some of Australia’s most economic farming land. Concerns have also been raised about some of the practices used to increase gas flow in wells using a process called ‘fracking’.

Revision questions

5. An examination of table 1.3 reveals that brown coal has a relatively low energy content. Why do you think brown coal is used on such an extensive scale to generate electricity in Victoria?

6. It is difficult to determine the total world reserves of fossil fuels. Estimates are constantly revised to take into account new discoveries, new information about known deposits and new techniques for extracting them. Conservation strategies will enable us to extend the ‘life’ of fossil fuels.

   Discuss how each of the following factors affects the rate at which fossil fuels are used.
   (a) Population growth rate
   (b) Community awareness of the need for energy conservation
   (c) Alternative technologies and fuel sources
   (d) Fuel pricing policies, nationally and internationally
   (e) Trade relations between nations

7. Fossil fuels took millions of years to form, yet they are likely to be used up within a few hundred years. Draw up a table with two columns.
   (a) In the first column of the table, list the activities you do during a week that require energy from fossil fuels.
Energy can be obtained from biomass (plant or animal matter) either in its unprocessed state or after converting it into gas or liquid fuels.

Bioethanol-blended fuel is more environmentally friendly than unblended petrol.

Bioethanol is obtained by the fermentation of sugar from sources such as waste wheat starch and molasses, which is a by-product of sugar production. Up to about 10% anhydrous ethanol (E10) can be used as an additive to petrol without engine modification. Using ethanol-blended fuel has some advantages in that it reduces some pollutant emissions and is beneficial in reduction of greenhouse gases because production involves the use of a waste product. Environmentally, the presence of oxygen in the ethanol assists the complete combustion of the petrol. Emissions of CO and aromatic hydrocarbons are reduced. There are some disadvantages; for example, the cost of processing compared with petrol will need to be improved, and ethanol produces less energy per gram. Ethanol can contribute to the breakdown of some plastic and rubber parts in vehicles. In some countries there may be a dilemma concerning using land for food or fuel crops. Although burning ethanol puts back into the atmosphere carbon dioxide that was originally absorbed by photosynthesis, some carbon dioxide is released in the production of the ethanol.

Biodiesel is produced from vegetable oil or animal fats combined with an alcohol, usually methanol.

Biodiesel fuels are alkyl esters manufactured from vegetable oil, such as canola, soyabean, sunflower, coconut and cotton seed, animal fats, such as beef tallow, sheep tallow and poultry oil, or used cooking oil. The oil or fat is combined with an alcohol in the presence of a catalyst. About 20% biodiesel (B20) can be blended with petroleum diesel as a transport fuel and so decreases our dependence on imported oil. Biodiesel is biodegradable, produces lower emissions of pollutants such as particulates and SO₂, and requires no engine modification even when used in unblended form. It has significant lubricant properties. On the negative side, it is economically unfavorable to produce and it emits more nitrogen oxides. The higher viscosity of biodiesel makes pure biodiesel (B100) unsuitable in colder climates. Planting of fuel crops requires large areas of land that could be used for food crops or may result in the destruction of natural habitats.

Biogas is produced from the bacterial breakdown of organic material in the absence of oxygen.

Biogas is sometimes called ‘swamp gas’ or ‘marsh gas’ and may contain up to 65% methane. It is a combustible fuel that is produced when animal waste or other organic material rots in the absence of oxygen, such as when rubbish has been buried underground, or in digestive processes of mammals that involve the breakdown of food by bacteria in the gut.

Biogas can be produced on a large scale and used as an energy source to generate electricity, light, heat, motion and fuels such as ethanol. The most common material used for biogas production is livestock manure. The manure is fed into an airtight ‘digester’ where it is allowed to ferment. The biogas produced is then collected and stored in a tank.

In addition to its use as a fuel in powering furnaces, heaters and engines, biogas can be used to generate electricity. Compressed biogas can also be used to fuel vehicles, and the residue from a biogas digester can be used as a fertiliser.
Biogas is a useful energy source.

### TABLE 1.4 Typical heat content of some renewable fuels

<table>
<thead>
<tr>
<th>Renewable fuel</th>
<th>Heat content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kJ g⁻¹</td>
</tr>
<tr>
<td>Bioethanol</td>
<td>30</td>
</tr>
<tr>
<td>E10*</td>
<td>44</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>42</td>
</tr>
<tr>
<td>Biogas</td>
<td>26</td>
</tr>
</tbody>
</table>

*a blend of normal petrol with 10% ethanol

**Revision question**

8. Using criteria such as molecular structure, combustion products, renewability, energy content and environmental issues, compare petrol with ethanol as a fuel for cars. Present your findings as a table.

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**Petrodiesel versus biodiesel — comparing fuels**

After petrol, diesel is the most widely used transport fuel in the world. Traditionally used in larger scale engines such as those in boats, trucks, trains and buses, it is now becoming more and more popular as an alternative fuel for the smaller engines found in cars. Diesel engines, although heavier and initially more expensive, are more efficient than their petrol counterparts, have better fuel economy and tend to last longer. They produce less power than petrol engines of the same size but more torque. This makes them slower to accelerate but they are ideal for hauling heavier loads. Biodiesel can easily be substituted, either straight or blended with petrodiesel, as a fuel for diesel engines and requires little or no modification to the engine.

**Producing petrodiesel**

You may remember from Unit 1 that fuels such as petrol and diesel, as well as many other useful chemicals, are obtained from refining crude oil. One of the most important steps in this process is the first step — separation of crude oil into fractions based on boiling temperatures. As boiling temperature is related to molecular size, this represents a ‘rough sorting out’ according to the sizes of
the molecules that make up the crude oil. This process is known as fractional distillation (or fractionation). Petrodiesel contains alkanes with 12–24 carbon atoms per molecule.

Fractional distillation is performed in tall towers that are cooler at the top than at the bottom. The crude oil is heated and then introduced to the base of the tower. At this point, many of its components vaporise. These vapours rise up the tower, being cooled as they do so. When they reach a point at which the tower’s temperature equals their boiling temperature, condensation occurs. Specially designed trays containing bubble caps are placed inside the tower at strategic intervals. These are designed to allow the vapours to continue rising but stop condensed fractions from dripping back down to lower levels in the tower. The condensed fractions may then be removed from these trays to undergo further processing. The diagram at left shows a simplified outline of this process.

**Combustion**

As crude oil is mostly a mixture of alkanes, so too is the petrodiesel component obtained from it. Its combustion, therefore, follows the typical pattern of an alkane. In the presence of sufficient oxygen, carbon dioxide and water are produced. For example, hexadecane, $C_{16}H_{34}$, burns according to:

$$2C_{16}H_{34}(l) + 49O_2(g) \rightarrow 32CO_2(g) + 34H_2O(g)$$

Other products of combustion include sulfur dioxide (from sulfur impurities), nitrogen oxides, carbon monoxide and particulate carbon (soot). The latter two are produced in situations where insufficient oxygen is present. Soot is often seen as ‘black smoke’ under conditions of heavy acceleration or when engines are poorly tuned. The following equation illustrates how less oxygen is required to make particulate soot.

$$2C_{16}H_{34}(l) + 17O_2(g) \rightarrow 32C(s) + 34H_2O(g)$$

In the past decade, however, considerable advances in both engine technology and fuel quality have led to a significant reduction in all of these emissions. Two such examples are: the introduction of ultra-low-sulfur diesel (ULSD), which not only lowers emissions of sulfur dioxide but also allows for more sophisticated pollution control measures in the engine itself; and the introduction of computer-controlled, self-cleansing exhaust filters designed to remove soot.
Other considerations

Besides the effects on the environment of exhaust emissions, other environmental considerations are associated with the use of petrodiesel (as there is with other petroleum-based fuels). The extraction of crude oil can cause significant degradation to the immediate environment, and its subsequent transportation, especially by sea, has resulted in a number of significant, environmentally damaging spills. The refining process can release hydrocarbons into the air. Vehicle exhaust emissions may also contain unburned hydrocarbons and, under the right conditions, which are often found in large cities, these can react to form photochemical smog. To this must also be added the emissions involved in the transport of both the crude oil and its petrodiesel product.

Biodiesel production

Biodiesel is a diesel alternative that can be made from plant oils and animal fats. Typical sources include canola, palm oil and animal tallow. It can also be made from used cooking oil, such as from restaurant fryers. The CSIRO has estimated that Australia could reduce its petrodiesel demand by 4–8% if all current sources of plant oil, tallow and waste cooking oil were used.

Oils and fats are naturally occurring esters formed between long-chain carboxylic acids (known as fatty acids) and a particular alcohol — glycerol.

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>palmitic</td>
<td>C_{15}H_{31}COOH</td>
</tr>
<tr>
<td>palmitoleic</td>
<td>C_{15}H_{29}COOH</td>
</tr>
<tr>
<td>stearic</td>
<td>C_{17}H_{35}COOH</td>
</tr>
<tr>
<td>oleic</td>
<td>C_{17}H_{33}COOH</td>
</tr>
<tr>
<td>linoleic</td>
<td>C_{17}H_{31}COOH</td>
</tr>
<tr>
<td>linolenic</td>
<td>C_{17}H_{29}COOH</td>
</tr>
</tbody>
</table>

Biodiesel is produced by reacting oils or fats (also called triglycerides) with an alcohol. Although a number of small alcohols can be used, the most common is methanol. Heat and either concentrated sodium or potassium hydroxide, which acts as a catalyst, are used in this process. It can be made on a small scale, using homemade equipment or with specially purchased kits, or on a much larger scale for commercial distribution. The chemical reaction involved turns one type of ester into another and is called transesterification. A typical transesterification is shown on the next page.
The glycerol formed can be sold as a by-product for use in cosmetics and foods and as a precursor for certain explosives. A criticism of this method, however, is that the most economic method currently used to produce methanol requires non-renewable fuels such as coal or natural gas. In this process, steam re-forming is used to produce ‘synthesis gas’, which then undergoes further reactions to make methanol. When natural gas is used as the feedstock, the overall equation for this process is:

$$\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightarrow \text{CH}_3\text{OH}(\text{g}) + \text{H}_2(\text{g})$$

To overcome this problem, a number of methods of producing methanol economically from renewable resources are being investigated. The most exciting of these involves using the glycerol produced in the transesterification reaction as the initial feedstock for producing synthesis gas to feed into the methanol production process. Another method involves using a catalyst to facilitate the direct conversion of glycerol to methanol.

Finally, a number of new, so-called ‘second-generation’ methods are being developed to convert the cellulose in waste or low-quality plant material into biodiesel.

**Combustion**

Although it is a mixture of different esters, rather than alkanes, biodiesel, like petrodiesel, burns to produce carbon dioxide and water. A typical equation for this would be:

$$\text{C}_17\text{H}_{32}\text{COOCH}_3(\text{l}) + 26\text{O}_2(\text{g}) \rightarrow 19\text{CO}_2(\text{g}) + 16\text{H}_2\text{O}(\text{g})$$

---

Biodiesel is produced by reacting plant and animal oils and fats with an alcohol such as methanol. Biodiesel can be considered a renewable fuel, especially if new methods to produce methanol are developed.
Revision questions

9. Name the fatty acid that the biofuel molecule was made from in the equation at the bottom of page 20.

10. Write the formula for biodiesel if it is produced from palmitic acid and methanol.

11. As is the case with petrodiesel, carbon monoxide may be produced if combustion occurs with insufficient oxygen.
   (a) Write the equation for the combustion of the product in question 10 in plentiful oxygen.
   (b) Write the equation for the combustion of the product from question 10 in limited oxygen.

Environmental issues

Biodiesel appears to be an excellent substitute for petrodiesel. It can be used in diesel engines with little or no modification. It also aids in engine lubrication and can clean engines of built-up deposits that result from the long-term use of petrodiesel. Emissions from a biodiesel-fuelled engine are similar to those from a petrodiesel one but are generally lower in quantity, the exception being nitrogen oxides, which may be slightly higher. As manufacturers strive to meet more stringent emission standards, it is anticipated that more petro- and biodiesel blends will be recommended.

Two additional environmental positives of biodiesel are that it is biodegradable, and it can be produced from a waste product, notably used cooking oil. In Australia, the main feedstocks are oil seeds such as canola, used cooking oil and tallow. However, as demand increases, new economical sources will need to be found. Elsewhere in the world, soybeans and sunflower seeds, as well as palm oil, are the main sources being used to meet this demand. However, there are some environmental concerns. There is the debate about land use — should crops be grown for food production or fuel production? In southeast Asia, massive deforestation is occurring to make way for palm oil plantations and is endangering the habitats of many species, the best known of which is the Sumatran orangutan.

Two possible ways of overcoming these issues are the use of algae and the use of seeds from jatropha trees. Research is being undertaken into the development of algae as an oil source. It is envisaged that such algae could grow in low-quality water bodies and maybe even the ocean. Seeds from the jatropha tree are being investigated due to their high oil content. Jatropha trees can be grown in marginal agricultural land and require minimal cultivation and irrigation. Additionally, they do not have to be replanted from season to season. Both of these possibilities would overcome the conflicting issues of whether to use land for food or fuel.

Technical issues

Two major technical issues facing the introduction of biodiesel are that it is hygroscopic and it can gel at low temperatures. To some extent, these also affect petrodiesel, but, due to multiple feedstocks, they have the potential to be a greater problem with biodiesel. If a substance is hygroscopic, it absorbs water vapour from the air. If biodiesel is poorly processed and contains partially converted mono- and diglycerides, this property is enhanced. If significant, this can affect engine life as it allows microbes to grow in the fuel. It also accelerates gelling and reduces the energy liberated upon combustion. Gelling at low temperatures is a major problem but is somewhat dependent on the

<table>
<thead>
<tr>
<th>Oil source</th>
<th>Yield (L/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>algae*</td>
<td>47 000–140 000</td>
</tr>
<tr>
<td>palm oil</td>
<td>5900</td>
</tr>
<tr>
<td>jatropha</td>
<td>1900</td>
</tr>
<tr>
<td>canola</td>
<td>1200</td>
</tr>
<tr>
<td>sunflower</td>
<td>950</td>
</tr>
<tr>
<td>safflower</td>
<td>800</td>
</tr>
<tr>
<td>soy</td>
<td>450</td>
</tr>
</tbody>
</table>

*estimate; depends on species
type of oil used in the original manufacture. Gelling increases viscosity of the fuel, reducing or even preventing its flow along fuel lines and through diesel injectors. A number of potential solutions to this problem are being investigated including blending it with petrodiesel, additives to lower the gel point, special fuel tanks that are heated as the car warms up and special reserve tanks containing petrodiesel for starting and warming up the engine.

**TABLE 1.7 Comparison of petrodiesel and biodiesel**

<table>
<thead>
<tr>
<th>Property</th>
<th>Petrodiesel</th>
<th>Biodiesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>sources</td>
<td>petroleum</td>
<td>• used cooking oil, tallow, oil seed crops such as canola, palm oil, oil from algae is possible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• methanol production requires fossil fuels but production of methanol from glycerol (a by-product) currently under investigation</td>
</tr>
<tr>
<td>chemical structure</td>
<td>alkanes, both straight-chain and branched (typically containing 12-24 carbon atoms per molecule)</td>
<td>• esters from long-chain fatty acids (typically 15-20 carbon atoms per molecule) and methanol</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• other simple alcohols</td>
</tr>
<tr>
<td>combustion products</td>
<td>carbon dioxide, water, carbon monoxide, particulate carbon (soot), sulfur dioxide, nitrogen oxides</td>
<td>• same as petrodiesel but generally lower in quantity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• may be increased emission of nitrogen oxides</td>
</tr>
<tr>
<td>viscosity</td>
<td>hygroscopic, but not generally an issue as seasonal blending allows for changes in outside temperature</td>
<td>hygroscopic and low outside temperatures; can lead to increased viscosity due to fuel gelling</td>
</tr>
<tr>
<td>environmental impact</td>
<td>• non-renewable</td>
<td>• renewable</td>
</tr>
<tr>
<td></td>
<td>• non-biodegradable</td>
<td>• biodegradable</td>
</tr>
<tr>
<td></td>
<td>• spills in transportation of both crude oil and refined products</td>
<td>• issues with growing crops for food versus fuel</td>
</tr>
<tr>
<td></td>
<td>• combustion emissions in transportation chain</td>
<td>• deforestation issues, especially in southeast Asia</td>
</tr>
</tbody>
</table>

**Energy use and the environment**

**The effect of use of fossil fuels on the environment**

Fossil fuels make up over 95% of the energy resources used in Australia today. There is great concern that their use has led to a number of environmental problems, particularly the enhanced greenhouse effect and acid rain.

**Greenhouse effect**

Radiation from the Sun strikes the Earth and warms its surface. The warm surface then radiates heat energy back into space. Gases in the atmosphere known as **greenhouse gases**, including carbon dioxide, CO$_2$, methane, CH$_4$, nitrous oxide, N$_2$O and ozone, O$_3$, absorb some of this heat radiation, so the air warms up. The air may also radiate this energy back into space or down to Earth. This helps to keep the Earth at the appropriate temperature to support life and is called the **greenhouse effect**. Unfortunately, human activities
have led to an increase in the amount of greenhouse gases, so that more heat is absorbed, which has adversely affected weather and climate. This results in an **enhanced greenhouse effect**, causing **global warming**.

Some gases can absorb more energy than others. Such gases are known as greenhouse gases and contribute to global warming in the atmosphere. Carbon dioxide is the major greenhouse gas emitted by human activities in Australia and is generated during transportation, industrial processes, land use change and energy production.

![Greenhouse effect](image1)

When light energy from the Sun reaches the Earth’s surface, it is converted to heat energy, and this is radiated back into the atmosphere. Greenhouse gases absorb some of this heat energy, keeping the Earth’s temperature relatively constant. Life on Earth depends on this heat.

![Enhanced greenhouse effect](image2)

Excess production of greenhouse gases means that the atmosphere retains more heat energy. This increases the average temperature of the Earth, which will affect the Earth’s climate.

Carbon dioxide is essential to life as plants absorb it, enabling them to manufacture their own sugars through photosynthesis. The quantity of carbon dioxide on Earth has remained almost constant for many thousands of years but now we are producing more than can be converted back into oxygen and simple organic molecules. As the quantity of carbon dioxide increases, the amount of heat that is retained by the atmosphere increases, thereby contributing to the greenhouse effect.

When comparing the burning of fossil fuels with biofuels, at first glance it might appear that both contribute to the greenhouse effect as both produce carbon dioxide upon combustion. However, it must be remembered that, when a fossil fuel is burned, it is putting carbon into the atmosphere that has been locked away underground for many millions of years. The carbon in biofuels, however, has been obtained from the atmosphere much more recently via photosynthesis (and perhaps the subsequent eating of plant materials by animals). As such it is merely ‘putting back what it recently took out.’ Theoretically, this carbon dioxide will once again be removed when the next source crops for the biofuel are grown. This is described as being ‘carbon neutral.’

**Acid rain**

**Acid rain** results from the reaction between rainwater and sulfur dioxide that is released into the atmosphere.

Many industrial processes burn coal, oil or some other fossil fuel. Many of these fuels contain sulfur in varying amounts. When sulfur is burned in air, it forms sulfur dioxide, $\text{SO}_2$. This gas is often released into the air in vast quantities.
Sulfur dioxide is released in many natural processes as well. In particular, active volcanoes release a large amount of sulfur dioxide into the air. The atmosphere can cope with large quantities of sulfur dioxide if the gas is given time to disperse. When a large number of industries are all producing the gas over a small area, it cannot disperse in the air fast enough and becomes too concentrated to be safe.

Sulfur dioxide reacts with water to become sulfurous and sulfuric acid. So, when it rains, the rain is no longer a mild carbonic acid solution but contains enough sulfuric acid to make it dangerous to plant and animal life.

\[
\text{SO}_2(g) + \text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{SO}_3(g)
\]

\[
\text{SO}_3(g) + \text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{SO}_4(g)
\]

Other gases contribute to the acid rain problem and many of these are produced by industry.

In heavily industrialised countries, entire forests have been denuded by the effects of acid rain. Our energy use is responsible for more than half of the greenhouse emissions and widespread pollution of land, sea and air. These environmental impacts threaten our quality of life and, perhaps, existence.

**Sustainable energy**

A sustainable energy future means providing for the needs of today’s society without compromising the ability of future generations to meet their own needs. Various responses have been proposed to meet society’s increasing energy demands. These include:

- promoting energy conservation in the domestic, commercial and industrial sectors
- funding research into producing viable alternative energy sources
- decreasing our dependence on coal by using more renewable sources
- increasing the efficiency with which energy is produced from each resource
- developing technologies to reduce emissions when using fossil fuels.

The availability of low-cost, clean and reliable energy will improve land, air and water quality, increase employment and promote health.
<table>
<thead>
<tr>
<th>Energy source</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>natural gas</td>
<td>• high efficiency</td>
<td>• non-renewability</td>
</tr>
<tr>
<td></td>
<td>• some Australian sources</td>
<td>• pollution</td>
</tr>
<tr>
<td></td>
<td>• moderate cost</td>
<td></td>
</tr>
<tr>
<td>oil</td>
<td>• ease of transportation</td>
<td>• non-renewability</td>
</tr>
<tr>
<td></td>
<td>• wide range of uses</td>
<td>• limited world supplies</td>
</tr>
<tr>
<td></td>
<td>• some Australian sources</td>
<td>• pollution</td>
</tr>
<tr>
<td>coal</td>
<td>• large Australian reserves</td>
<td>• non-renewability</td>
</tr>
<tr>
<td></td>
<td>• source of revenue via exports</td>
<td>• contributes to air pollution, acid rain and global warming</td>
</tr>
<tr>
<td></td>
<td>• easily mined</td>
<td></td>
</tr>
<tr>
<td>biogas</td>
<td>• renewability</td>
<td>• energy inefficiency</td>
</tr>
<tr>
<td></td>
<td>• productive use of wastes</td>
<td>• low supplies</td>
</tr>
<tr>
<td>bioethanol and</td>
<td>• renewability</td>
<td></td>
</tr>
<tr>
<td>biodiesel</td>
<td>• less harmful emissions</td>
<td>• possible conflict in land use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• low temperatures can be problematic for biodiesel</td>
</tr>
</tbody>
</table>
Summary

- Energy is the ability to do work.
- The unit of energy is the joule (J).
- Fuels may produce energy through combustion reactions.
- Good fuels have the properties of being easily ignited, releasing significant energy on combustion, having minimal negative environmental impact and being relatively inexpensive, readily available and safe.
- Exothermic reactions release energy to their surroundings and have a negative $\Delta H$ value.
- Thermochemical equations are chemical equations that, besides being balanced with respect to charge and mass, also include a $\Delta H$ value.
- Energy exists in a number of different forms (including mechanical, heat, chemical, sound, light, electrical, gravitational and nuclear) that are interconvertible.
- According to the Law of Conservation of Energy, whenever energy is converted from one form to another, the total quantity of energy remains the same.
- The study of energy changes that accompany chemical reactions is called thermochemistry or chemical thermodynamics.
- The efficiency of changing one form of energy into another form of energy varies.
- Efficiency is defined as a percentage according to the formula
  \[
  \text{% efficiency} = \frac{\text{energy obtained in desired form}}{\text{energy available before conversion}} \times 100
  \]
- Fossil fuels include coal, petroleum and natural gas and are formed from the decaying remains of plants and small marine creatures.
- Electricity, a secondary fuel, is the most convenient form of energy for society.
- Renewable energy sources may be formed faster than they are being used in society.
- Non-renewable energy sources are consumed faster than they are being formed.
- Non-renewable fossil fuels available for use in society today include natural gas, petroleum, coal and coal seam gas.
- Biofuels currently in use include biogas, bioethanol and biodiesel.
- Biodiesel is gradually finding more use as a replacement transport fuel for petrodiesel; both as a straight fuel and in blends with petrodiesel.
- The fuels on which modern society relies are mainly non-renewable fossil fuels.

In future, greater reliance on renewable fuels will be necessary as non-renewable fuels (particularly petroleum and coal) become depleted.

- Our use of energy, whether from renewable or non-renewable sources, affects the environment. Issues such as air pollution and the enhanced greenhouse effect, spills, land degradation, water pollution and habitat damage need to be carefully monitored and improved.
- A significant issue with the increasing use of biofuels is land use. Should land be used for growing fuel crops at the expense of food crops?
- The process of global warming, also known as the enhanced greenhouse effect, arises when the amount of heat striking the Earth’s surface is greater than the amount that is radiated, causing the Earth to warm up.
- The major greenhouse gas emitted by human activities in Australia is carbon dioxide.
- Acid rain results from the reaction between rainwater and sulfur dioxide that is released into the atmosphere.

Multiple choice questions

1. Coal and ethanol are both produced from plants. Which of the following statements about the classification of these two fuels is correct?
   A. Coal and ethanol are both fossil fuels.
   B. Coal is a fossil fuel but ethanol is a biofuel.
   C. Coal and ethanol are both biofuels.
   D. Coal is a biofuel but ethanol is a fossil fuel.

2. Which of the following is not a fossil fuel?
   A. Black coal
   B. Oil
   C. Natural gas
   D. Biogas

3. Which of the following best describes a renewable energy source?
   A. A renewable energy source can be produced at a slower rate than the rate at which it is used by society.
   B. A renewable energy source can be produced at a faster rate than the rate at which it is used by society.
   C. A renewable energy source can be produced at the same rate as the rate at which it is used by society.
   D. The rate at which a renewable energy source can be produced is unrelated to the rate at which it is used by society.

4. Which of the following is a renewable source of energy?
   A. Coal
   B. Bioethanol
   C. Natural gas
   D. Oil
5. Methanol can be burned as a fuel and its heat output can be described by the following thermochemical equation.

\[ 2\text{CH}_3\text{OH}(l) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 4\text{H}_2\text{O}(g) \]
\[ \Delta H = -1.45 \times 10^3 \text{ kJ mol}^{-1} \]

The predicted heat output from the combustion of 3.20 g of methanol would be:
A 72.5 J
B 7.25 kJ
C 72.5 kJ
D 7250 kJ.

6. The energy conversions that occur in a coal-fired power station may be best represented as:
A chemical energy to thermal energy to mechanical energy to electrical energy
B chemical energy to mechanical energy to thermal energy to electrical energy
C chemical energy to mechanical energy to electrical energy to thermal energy
D chemical energy to electrical energy to mechanical energy to thermal energy.

7. One of the criteria for the choice of fuels is the amount of heat released on combustion per gram of fuel. On this basis, which of the following would be the best fuel?

<table>
<thead>
<tr>
<th>Substance</th>
<th>Heat of combustion (kJ mol(^{-1}) of reactant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H(_2)</td>
<td>238</td>
</tr>
<tr>
<td>CO</td>
<td>284</td>
</tr>
<tr>
<td>CH(_3)CH(_2)OH (ethanol)</td>
<td>1371</td>
</tr>
<tr>
<td>C(<em>8)H(</em>{18}) (n-octane)</td>
<td>5447</td>
</tr>
</tbody>
</table>

8. A device converts 85 MJ of input energy into 50 MJ of useable output energy. The efficiency of this device is closest to:
A 50%
B 60%
C 64%
D 85%.

9. The overall efficiency of the photosynthetic process can be as low as 1%. This means that:
A photosynthesis is a very efficient process
B for every 200 J of solar energy received, 1 J of chemical energy is stored in the products
C photosynthesis requires other energy sources in addition to solar energy
D 99% of the solar energy received by plants is not used for photosynthesis.

10. Which of the following lists shows fuels in order of increasing energy output, as measured in kJ g\(^{-1}\)?
A Brown coal, biogas, bioethanol, petrol
B Biogas, biodiesel, bioethanol, natural gas
C Brown coal, diesel, black coal, petrol
D Diesel, biodiesel, petrol, bioethanol

11. In which of the following situations might a biogas generator be built?
A As part of a sewage treatment works
B As part of a piggery
C As part of a dairy farm
D All the above

12. Worldwide, bioethanol is the most widely produced biofuel. It is often blended with petrol as a transport fuel, but it can be used pure in some situations. Which of the following statements is true?
A Bioethanol has a higher energy output than petrol.
B Many of the crops used to produce bioethanol are also food crops.
C Although bioethanol is a renewable fuel, it produces more harmful emissions.
D When blended with petrol, cars get better fuel consumption than with petrol alone.

13. A hygroscopic substance is a substance that:
A absorbs heat
B evolves heat
C evolves water
D absorbs water.

14. When petrodiesel is compared with biodiesel in terms of their chemical components, it can be said that:
A both consist of alkanes
B petrodiesel consists of alkanes whereas biodiesel consists of esters
C petrodiesel consists of esters whereas biodiesel consists of alkanes
D both consist of esters.

15. When biofuels are burned, the carbon dioxide produced:
A puts carbon atoms back into the atmosphere that were only recently removed
B puts carbon atoms back into the atmosphere that were removed millions of years ago
C puts oxygen atoms back into the atmosphere that were removed millions of years ago
D puts carbon atoms back into the atmosphere at a slower rate than when an equivalent amount of fossil fuel is burned.

### Review questions

#### Energy and fuels

1. (a) What is a fuel?
   (b) Give four examples of fuels that you have used in the last week.

2. What are the characteristics of a good fuel for:
   (a) heating the home
   (b) vehicle propulsion?

3. Fuels, and energy sources in general, may be classified as either renewable or non-renewable.
   (a) Define the terms ‘renewable’ and ‘non-renewable’ as they apply to this context.
(b) Are all biofuels renewable? Explain.
(c) Are renewable energy sources always biofuels? Explain.

4. Propane is often used as a fuel for camping stoves. In an experiment to determine its heat content, 2.70 g was found to evolve 135 kJ of heat energy when burned in a plentiful supply of oxygen.
(a) Write a balanced thermochemical equation describing this reaction.

Devices such as these often come with a warning that is only 30% efficient.
(b) Write a balanced equation for the combustion of propane in a limited supply of oxygen.
(c) How would the ΔH value for the equation in (b) compare with the one in (a)? Explain.
(d) Explain exactly why the operation of such a stove in an enclosed space is so dangerous.

Energy transformations
5. A fire is started at a campside fireplace by striking a match and lighting a piece of crumpled newspaper under a pile of dry twigs. Explain the energy transformations in this process.

6. Explain why the overall energy efficiency of a coal-fired power station that generates electricity is said to be only 30% efficient.

7. Describe the energy transformations occurring in each of the following situations.
   (a) Bell ringing
   (b) Battery lighting a torch
   (c) Striking a match
   (d) Inverting an egg timer
   (e) Rubbing hands together on a cold day
   (f) Pendulum swinging
   (g) Thunder and lightning
   (h) Starting a clockwork toy

8. A waste management/energy project near Ballarat uses organic waste from local piggeries to produce biogas (methylene and carbon dioxide). The biogas is then converted to heat and electricity.
(a) Outline the energy changes in the conversion of organic waste to heat and electricity.
(b) Initial proposals for construction of the project were rejected by the local council. On what grounds could the council object to such a scheme?
(c) How could the success of such a scheme be gauged?

9. The Law of Conservation of Energy states that energy can neither be created nor destroyed. Explain how an energy conversion process that is only 85% efficient does not contravene this law.

10. (a) Outline the energy transformations that occur in a fossil-fuel thermal power station.
   (b) Name two fossil fuels that are currently used in fossil-fuel power stations.
   (c) Name one renewable fuel that is currently used in some thermal power stations.

11. A power station using brown coal as its fuel consumes 40 000 tonnes of coal per day. If it generates an average of 27.8 GWh of electricity per day, calculate its overall efficiency. (Heat energy evolved by 1.000 tonne brown coal = 6.7 GJ; 1 kWh = 3 600 kJ)

Fuel choices
12. (a) What is a fossil fuel?
   (b) Give at least three examples of fossil fuels.

13. ‘Coal, gas and oil should be made more expensive to deter people from wasting them.’ Discuss this statement, offering at least two arguments for and against the proposal.

14. (a) What is a biofuel?
   (b) Give three examples of biofuels.

15. Search the internet and any other suitable resources to find the advantages and disadvantages of ethanol and petrol as transport fuels. Present your findings in the form of a table.

16. Repeat question 15 for petrodiesel and biodiesel.

17. Coal seam gas has become a significant energy source in Australia since the year 2000.
   (a) Is coal seam gas a renewable or non-renewable energy source?
   (b) Describe how coal seam gas is obtained.
   (c) Which gas is the main component of coal seam gas?
   (d) List two environmental concerns associated with the production of coal seam gas.

Energy use and the environment
18. Fossil fuels may be used to produce electricity.
   (a) Explain how energy waste may occur in the conversion of fossil fuels to electricity.
   (b) Explain how energy waste may occur in the use of electricity in the home.

19. (a) Assuming that each kilowatt hour of electricity produces about 1.44 kilograms of carbon dioxide, examine your family’s electricity bills and determine how much carbon dioxide your family produces annually.
   (b) Explain why the production of carbon dioxide may lead to environmental problems.
   (c) Suggest three ways in which your family could decrease electricity use to contribute to the minimisation of carbon dioxide release into the atmosphere.
20. In a fuel efficiency test, the percentage of petrol wasted due to incorrect handling techniques and altered car conditions was calculated for a particular car.

<table>
<thead>
<tr>
<th>Altered variable</th>
<th>Percentage use</th>
</tr>
</thead>
<tbody>
<tr>
<td>speeding</td>
<td>14</td>
</tr>
<tr>
<td>overloaded car</td>
<td>15</td>
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<tr>
<td>roof rack</td>
<td>10</td>
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<tr>
<td>soft tyres</td>
<td>5</td>
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<tr>
<td>poor tuning</td>
<td>28</td>
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The car has a fuel consumption of 15.0 km per litre of fuel. Assuming that the fuel costs 130 cents per litre, calculate how much money would be wasted on a 100 km trip, assuming that a driver exceeded the speed limit for a quarter of the journey and that the car was poorly tuned, overloaded and had soft tyres and a roof rack.

21. Find out about the ‘greenhouse effect’ with respect to the use of different energy sources.

22. You have been invited to debate the statement ‘The world should stop using fossil fuels and replace their use with biofuels’.
   (a) Outline three environmental or societal issues you would argue if you were in favour of this statement.
   (b) Outline three environmental or societal issues you would argue if you were against this statement.

23. Fossil fuels and biofuels all undergo combustion to release carbon dioxide. Explain why the combustion of fossil fuels contributes to the enhanced greenhouse effect, whereas the combustion of biofuels does not.

24. (a) Define the terms ‘biodiesel’ and ‘petrodiesel’.
    (b) State one disadvantage of using biodiesel in cold climates.
    (c) Give one environmental advantage of increasing the usage of biodiesel.
    (d) Give one environmental disadvantage that an increased usage of biodiesel may lead to.
Exam practice questions

In a chemistry examination, you will be required to answer a number of multiple choice and extended response questions.

Extended response questions

1. Methane gas is used as a fuel in many industrial and domestic situations. Sources of methane include biogas, natural gas and coal seam gas.

   (a) Write an equation for the combustion of methane in excess oxygen.  
   1 mark

   (b) Methane may be classified as both a renewable and a non-renewable resource. Explain this using the information provided above.  
   2 marks

   In certain situations, the burning of methane may produce carbon monoxide gas.

   (c) Under what conditions might this occur?  
   1 mark

   (d) Write an equation for the combustion of methane to produce carbon monoxide.  
   1 mark

   (e) Why is the production of carbon monoxide undesirable?  
   1 mark

2. Biodiesel is a fuel that is steadily gaining popularity as an alternative to petrodiesel. It is produced by a process called transesterification. Another chemical is also produced.

   (a) Define the term ‘transesterification.’  
   1 mark

   (b) A sample of biodiesel is analysed and found to consist only of methyl stearate. With the aid of suitable molecular diagrams, show how this would have been made. You should make mention of any special reaction conditions required.  
   6 marks

   (c) Write the equation for the combustion of methyl stearate in excess oxygen.  
   3 marks

   (d) Name the other chemical produced by transesterification.  
   1 mark

   (e) To what class of organic compounds do the majority of molecules in petrodiesel belong?  
   1 mark

   (f) Give one advantage and one disadvantage associated with the use of biodiesel as a fuel.  
   2 marks