SURFING

NATIONAL EARTH AND ENVIRONMENTAL SCIENCE

Unit 3 Living on Earth: Extracting, Using and Managing Earth Resources

• David Heffernan • Rob Mahon •

Science Press

Science Press
Bag 7023 Marrickville NSW 1475 Australia
Tel: (02) 9516 1122 Fax: (02) 9550 1915
sales@sciencepress.com.au
www.sciencepress.com.au

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Introduction

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Use of Non-renewable Earth Resources

1 Non-renewable Resources

Earth resources

Natural resources can be classified in a number of ways, one of which is from an environmental perspective. Water and such living resources as food, natural fibres and wood are **renewable resources** – they can be replaced over a relatively short period of time, like months, years or decades. Non-living resources, such as mineral and energy resources (coal, oil, uranium, metals and fertilisers), are not renewed quickly and are therefore called **non-renewable resources**. For instance, petroleum can take millions of years to be produced.

We can also classify resources according to their economic value. Earth's non-renewable resources fall into two groups – they can be high- or low-value resources. Metals are good examples of **high-value resources**. They are produced wherever they are found. Worth hundreds or thousands of dollars per tonne, they may be transported all over the world.

Figure 1.1 Low-value resources, such as sandmining, occur near to where they are used.

Sand and gravel are good examples of **low-value resources**. They are vital to cities and other construction projects (Figure 1.1). At only a few tens of dollars per tonne, their price means it is not economical to transport them very far – very few sand trucks would carry their loads more than 100 kilometres. Table 1.1 summarises the differences between high- and low-value mineral resources. Table 1.2 lists many high- and low-value resources.

Two terms are commonly used in mining geology. A **resource** is a substance humans need for some use(s) and a **reserve** is an amount of a resource that can be extracted at today's costs and selling prices. The total resource may be much larger than a reserve but may not become a reserve until well into the future. A good example can be seen in the Victorian brown coal resource at Yallourn and Loy Yang, in Gippsland. The brown coal is close to the surface and can be mined by relatively cheap open-cut methods. These reserves are only part of the entire brown coal resource. It may be possible in the future to mine the deeper coal but this is not presently economical.

The process of classifying resources as economic or subeconomic can be quite expensive and time-consuming (Table 1.3). Useful resources are normally found evenly distributed throughout the crust. If we are to mine them, they have to be concentrated in some way. Thus a fossil fuel resource must contain a high enough concentration of a useful material to make it economical to mine.

Table 1.1 Distinguishing between high- and low-value resources.

Feature	Low-value Earth's resources	High-value Earth's resources
Size of deposit	Large	Small
Value per tonne	Low	High
Importance of where it is found as to whether it is extracted or not	High	Low
Import/export trade	Few	Many
How common?	Common	Rare
Processing needed	Little	Complex
Geology of deposit	Simple	Complex

Table 1.2 High- and low-value resources.

Value of the resource	Metallic	Non-metallic
High	Aluminium Titanium Copper Iron Uranium Lead Gold Silver Platinum Zinc	Phosphates Sulfur Coal (certain types) Petroleum
Low		Cement Sand Clay Gravel Gypsum Coal (certain types) Water

Modern technology has dramatically increased the size, accuracy and amount of detail with which geologists can work. Resources such as minerals and fossil fuels have to be found by modern aerial survey, seismic and other geophysical surveys (Figure 1.2). More traditional on-the-ground sampling is involved as well. Eventually, drilling allows the extent of the resource to be determined and the mine or oil well can be evaluated for its economic potential. Unfortunately, all of the easy-to-find resources have already been located by this process.

Locating the mineral or fossil fuel and proving it is economical to mine is only part of the problem. There are also legal considerations. Who owns the land on which the resource is found? What level of royalties will need to be paid? If the ore is discovered in a national park or on Aboriginal land, there are other legal hurdles to cross.

Figure 1.2 During a geophysical survey vehicles are used to create vibrations by hitting the ground. The vibrations are detected by sensors and the patterns produced used to create a view of the geology beneath.

Environmental considerations are also vital. Can the resource be mined without destroying the local environment? Can mine wastes be contained so that they do not pollute the atmosphere or local waterways? Will transport links cause environmental problems?

Table 1.3 Classifying mineral reserves and resources.

Value	Identified – reserves and resources that have been measured	Undiscovered	
		In known districts	In undiscovered districts or forms
Economic	Reserves – can be mined at current costs and prices	Resources – hypothetical as their presence can only be inferred	Resources – speculative resources
Subeconomic	Resources – cannot be mined at current costs and prices		

If the geology of a region is well known, it is sometimes possible to infer the presence of other sources of minerals or fossil fuels that are not readily visible from the surface. Without drilling, the extent of the resource is only **hypothetical**. What about areas where exploration has never been carried out? Any estimates in such regions tend to be highly **speculative**. Part of the process used is based on history – how the rate at which estimated fuel reserves have changed over time. By extrapolating this history, geologists can speculate about future discoveries.

Satellite imagery can give views of remote regions of the world where little or no exploration has taken place. Combined with a knowledge of plate tectonics, the possibility of mineral or fossil fuel resources can be evaluated. Mining companies tend to produce much higher estimates than conservationists!

If we are using more and more of a non-renewable resource, will we run out? That is a difficult question to answer because we have not investigated the geology of the entire Earth in detail. That means we do not really know what is there. The answer also depends on the price we are willing to pay for the mineral or fossil fuel.

There are several ways we can meet our future mineral or fossil fuel needs.

- Find **more sources**. Even though new technology is making geological exploration more efficient, this is becoming harder because the easy-to-find resources are already known.
- We can mine **lower grade deposits**. With better technology and higher prices, it may be possible to mine minerals or coal, or extract petroleum that is not economic at present. Perhaps oil shales can be mined.
- We can make use of **new technology** and mine in new ways. For example, pumping water into oil reservoirs increases the amount of oil extracted.
- We could conserve our minerals and fossil fuels by **reducing the amount we use** by doing without or making **more efficient use** of what we have left. We can do without oil resources by walking. We can reduce the need for fuel by riding a bicycle or using public transport. We can recycle plastics and metals.
- We could find **substitutes** by making use of renewable sources of energy such as solar power, wind power, geothermal power and power from waves and tides. As prices of minerals, coal and petroleum rise, conservation becomes more and more attractive.

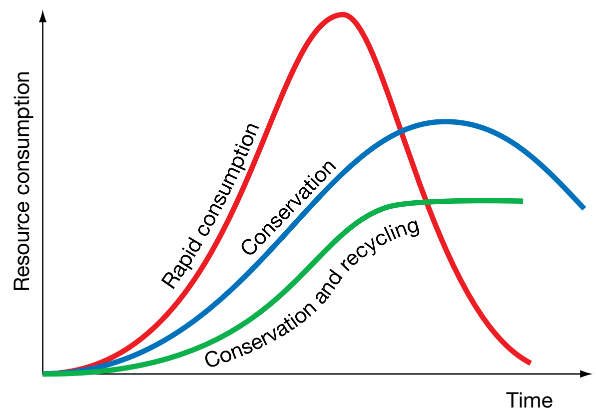

Figure 1.3 Depletion curves illustrate three ways we can use our resources.

Just how long a given resource will last depends on what actions we take in the future. A particular resource can be used in a number of ways – there are economic, political and social factors working in each case (Figure 1.3).

- **Rapid consumption.** Historically, this is what has happened with most resources. They are mined rapidly and are soon depleted. The world's fisheries are a classic example as more and more species are becoming endangered. With resources such as minerals and fossil fuels, their continued availability depends on finding and exploiting resources from other parts of the world. Eventually, they will all be gone.

Table 1.4 Materials in a typical home.

Group	Materials
Building materials	Sand, gravel, stone, brick (clay), cement, steel, aluminium, bitumen, glass
Plumbing and wiring	Iron, steel, copper, brass, lead, cement, glass, ceramic pipes, plastics
Insulating materials	Rock 'wool', wool, fibreglass, gypsum (paster; wallboard)
Paint and wallpaper	Mineral pigments (e.g. iron, zinc, titanium compounds); fillers such as talc; synthetic polymers (paint); paper
Floor coverings	Rock (e.g. slate); plastics (lino and other coverings); wool (carpet)
Appliances	Iron, copper, plastics, a number of rare metals (e.g. manganese and titanium in alloys)
Eating and cooking utensils	Aluminium, iron, copper, plastics; porcelain; china
Furniture	Wool and synthetic fibres in coverings, steel in springs, wood or plastic frames
Clothing	Wool, cotton and the fertilisers and pesticides used to produce them; synthetic fibres from petroleum
Food	Grown with the help of mineral fertilisers and often synthetic pesticides; packaged in plastics by a machine made from metals
Medicines and cosmetics	Mineral and synthetic chemicals; natural chemicals
Other items	What have we missed?

- **Conservation.** More efficient mining and extraction techniques can extend the lifetime of resources. Improved technology allows for better extraction or more efficient use by industry. Wherever possible, renewable resources can be substituted for non-renewable resources.
- **Recycling.** This will lengthen the lifetime of the resource even further. There is already extensive recycling of such metals as copper, lead and aluminium.

With extensive conservation and recycling it may be possible to use resources **sustainably**. This means the resource can continue to be used indefinitely by present and future generations. However, there is always some loss of materials during manufacturing and recycling that will need to be replaced by mining or substitution. The sustainable use of fossil fuels will require extensive use of renewable energy resources in the long term.

QUESTIONS

1. (a) Distinguish between renewable and non-renewable resources.
   (b) Distinguish between a resource and a reserve.
   (c) Compare high- and low-value resources.
2. Describe how the estimates of known reserves of non-renewable resources change with:
   (a) Price.
   (b) Technological innovation.
3. List all of the Earth materials involved in your having breakfast this morning.
4. Describe what is meant by the 'sustainable use' of resources.
5. Identify ways we can overcome problems with declining amounts of non-renewable resources.
6. Use Table 1.5 to answer the questions below.

Table 1.5 Australia's identified mineral resources (Geoscience Australia, 2011).

Commodity	Resources that can be mined economically	Mine production
Bauxite	5665 million tonnes	69.98 million tonnes
Black coal	50 656 million tonnes	461 million tonnes
Brown coal	34 150 million tonnes	66.73 million tonnes
Copper (Cu)	86.7 million tonnes	0.96 million tonnes
Diamond (C)	272.5 million carats	7.6 million carats
Gold (Au)	9112 tonnes	258 tonnes
Iron ore	37 762 million tonnes	488 million tonnes
Lead (Pb)	35.9 million tonnes	0.62 million tonnes
Nickel (Ni)	20.4 million tonnes	0.215 million tonnes
Phosphate rock	945 million tonnes	2.49 million tonnes
Silver (Ag)	87.9 kilotonnes	1.73 kilotonnes
Uranium (U)	1082 kilotonnes	5.967 kilotonnes
Zinc (Zn)	68.3 million tonnes	1.51 million tonnes

   (a) Identify the commodity that has the greatest mine production.
   (b) Identify the commodity that has the greatest economically mineable resources.
   (c) How many tonnes of gold are mined?
7. Explain how recycling can reduce the amount of bauxite that is mined.
8. Diamonds in Australia nearly all come from the Argyle Mine in Western Australia. This mine will be exhausted in a few years. Do you think we have found all the diamonds in Australia? Explain your answer.
9. A carat of diamond weighs 200 milligrams. Calculate the weight of diamonds mined in Australia.
10. Evaluate if fossil fuel resources can be used sustainably in the long term.

2 Fossil Fuels

Coal

Coal is a rock produced from once-living plant material. Coal is a rock that can be burnt! It is composed mainly of carbon (50 to 98 per cent), hydrogen (3 to 13 per cent) and oxygen, with smaller amounts of nitrogen, sulfur and other elements. Some water is always present, together with grains of inorganic matter, such as sand and clay, that form an incombustible residue known as ash.

Figure 2.1 Coal occurs in beds, with thickness ranging from less than a millimetre to many metres thick.

Coal is formed from thick layers of plant matter that have been altered by decay and various amounts of heat and pressure. Between the layers of coal there are often beds of other sedimentary rocks. Coal forms beds that range from less than a millimetre to many metres thick (Figure 2.1). Such a bed, or several beds separated by thin layers of shale, siltstone or sandstone called dirt bands or partings, makes up a **coal seam**.

Coal is classified by **rank**, which is a measure of the amount of change the vegetation has undergone during formation. It gradually changes as it increases in rank, from an initial **peat** stage to **brown coal**, **sub-bituminous coal**, **bituminous coal** and **anthracite**. An increase in rank is caused by a gradual rise in temperature and pressure that results in a decrease in water content and therefore a rise in carbon content. The properties of coal change gradually between these ranks. Table 2.1 summarises the properties of the different ranks of coal.

Figure 2.2 Brown coal occurs in beds which can be tens of metres thick.

Black coal derives its name from its colour (Figure 2.1). It varies from having a bright, shiny lustre to being very dull and from being relatively hard to soft. It has higher energy and lower moisture content than brown coal. Economic resources of black coal occur in most Australian states, particularly New South Wales and Queensland, and most of those mined commercially are of Permian age (about 250 million years old). Permian black coal from New South Wales and Queensland is exported in large quantities to China, Japan, Europe, South-East Asia and the Americas. It includes the ranks of sub-bituminous and bituminous coal.

Table 2.1 Coal and its properties (approximate values).

Rank/grade	Description	Typical water content (weight per cent)	Carbon (weight per cent)	Inorganic material (ash) (weight per cent)	Typical content of volatile matter (weight per cent)	Energy value (MJ/kg)
Peat	Fibrous decomposed material	40	20	5	35	15
Brown coal or lignite	Still contains woody material	35	30	5	30	25
Sub-bituminous coal	Hard blotchy appearance; dark material; slight lustre	20	40	10	30	30 to 35
Bituminous coal	Black; lustrous; strongly banded appearance	5	65 to 45	10	20 to 40	35
Anthracite	Metallic lustre; bands absent	5	80	10	5	35

Sometimes called **lignite**, **brown coal** is a relatively soft material whose heating value is only about one quarter of that of black coal (Figure 2.2). Brown coal also has a much lower carbon content and a higher moisture content. When found near the surface in thick seams, it is economical to mine it on a large scale by open-cut methods. Australian brown coal deposits are Tertiary in age and range from about 15 million to about 50 million years old. Victoria is the only state that produces brown coal. In the Latrobe Valley of Gippsland, 165-metre-thick seams provide coal for Victoria's electric power industry.

Petroleum

Petroleum is a complex mixture of organic compounds divided into crude oil and natural gas. It occurs naturally in the ground and was formed hundreds of millions of years ago. Trapped in sediments, the remains of plants and animals were transformed by heat and pressure of the earth to produce oil and gas.

Crude oil varies from oilfield to oilfield in colour and composition from a pale yellow, low-viscosity liquid to heavy, black 'treacle' consistencies. It is immiscible with and lighter than water; hence it floats. Crude oils are generally classified as **tar sands**, **heavy oils** and **medium** and **light oils** on the basis of their density and relative ability to move between the grains of a rock. Tar sands contain oil that does not flow into a well drilled into the sands. Heavy oils are able to move slowly so that, given time, they can be obtained through a well if given some help (enhanced recovery methods). The medium and light oils are able to move freely through sediments and are easily recoverable through production wells.

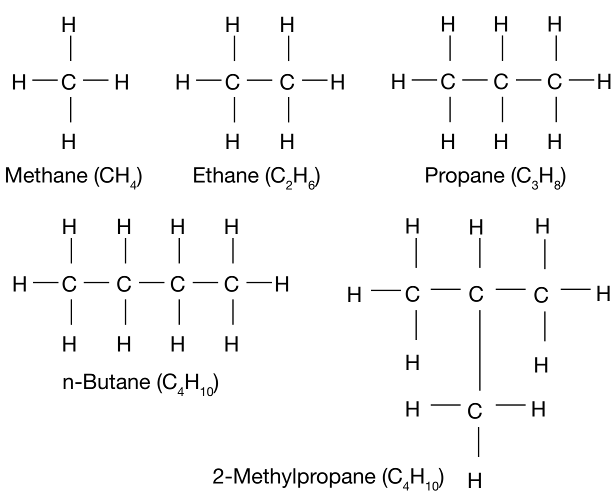

Figure 2.3 Only single carbon-carbon bonds are present in paraffins.

Petroleum consists of three main hydrocarbon groups. **Paraffins** contain straight or branched molecules with only single carbon-carbon bonds (Figure 2.3). The simplest paraffin is methane (CH_4) and, along with ethane (C_2H_6) and propane (C_3H_8), is the main ingredient of **natural gas**. With very few carbon atoms (C_1 to C_4), these are low in density and are gases under normal atmospheric pressure. Paraffins with 5 to around 40 carbons are liquids while those with more than about 40 carbons are solids (Table 2.2). Chemically, paraffins are very stable compounds.

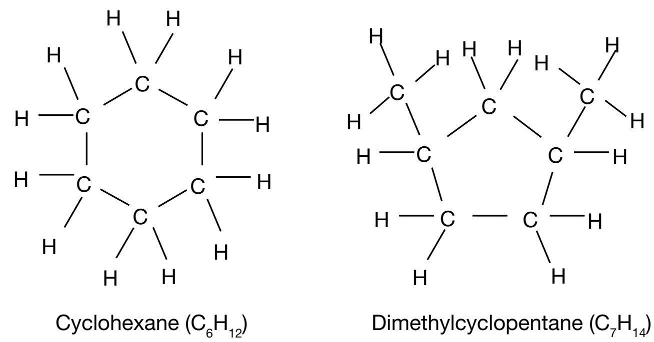

Figure 2.4 Like paraffins, only single carbon-carbon bonds are present in cycloalkanes (napthenes).

Naphthenes (cycloalkanes) are made up of carbon rings, sometimes with side chains, with only single carbon-carbon bonds (Figure 2.4). They are chemically stable, occur naturally in crude oil and have properties similar to paraffins.

Aromatic hydrocarbons are compounds that contain a ring of six carbon atoms, with alternating double and single bonds and six attached hydrogen atoms (Figure 2.5). This structure is known as a benzene ring. Aromatic hydrocarbons occur naturally in crude oil and can also be created by the refining process. The more carbon atoms a hydrocarbon molecule has, the higher its molecular weight and boiling point.

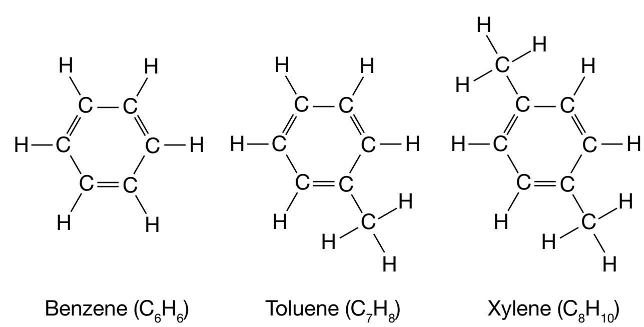

Figure 2.5 Aromatic hydrocarbons are compounds that contain a ring of six carbon atoms, with alternating double and single bonds.

Small quantities of a crude oil may be composed of compounds that contain oxygen, nitrogen, sulfur and metals. Sulfur content ranges from traces to more than five per cent. If a crude oil contains appreciable quantities of sulfur, it is called a **sour crude**. If it contains little or no sulfur, it is called a **sweet crude**.

Energy from gas

There are two major sources of gas that can be used as a fossil fuel. The gas can come from sources associated with coal or with petroleum. The advantage of gas is the high energy density and the fact that less of the greenhouse gas carbon dioxide is released when burnt.

Table 2.2 Petroleum and its properties.

Component	Name	Molecule	Volume (%)	State	Energy value (MJ/kg)
Natural gas	Methane	C_1	Greater than 80%	Gas	55.5
	Propane	C_3	Less than 20%	Gas	50.5
	Butane	C_4	Less than 20%	Gas	49.5
Crude oil	Petrol	C_5 to C_{10}	27	Liquid	48.0
	Kerosene	C_{11} to C_{13}	13	Liquid	52.5
	Diesel	C_{14} to C_{18}	12	Liquid	53.5
	Heating oil	C_{19} to C_{25}	10	Liquid	54.0
	Lubricating oil	C_{26} to C_{40}	20	Liquid	N/A
	Bitumen	Greater than C_{40}	18	Solid	N/A

Gas from coal. A major source of gas is **coal seam gas** (also called **coal methane**). Australia has considerable resources of methane in the black coal seams of the east coast coal basins and is already used in some power stations (Figure 2.6). It is estimated that the amount of methane contained within these coal seams is several times greater than the current reserves for natural gas obtained from petroleum. It has an energy density of around 55 MJ of energy per kilogram of gas burnt.

Figure 2.6 Coal seam gas is extracted from mines beneath ground level and used to supply energy to power stations.

There are cost savings in using methane drained from coal seams as an energy resource. This includes a relatively low exploration cost because the location of the coal seams is known and the methane reserves are often close to major city markets. In contrast, natural gas is piped all the way from Moomba, in northern South Australia, to southern South Australia and to many parts of New South Wales. Another pipeline runs from south-western Queensland to Brisbane and other regions.

Another advantage is that the removal of methane gas helps make coal mining safe. The danger of a methane explosion limits high levels of productivity in underground coal mines.

Methane is produced as a by-product of the coal formation process. The bituminous coals of the New South Wales and Queensland coal basins typically contain gas that consists of over 95 per cent methane, with smaller quantities of carbon dioxide, ethane, higher hydrocarbons, nitrogen and inert gases. About 90 per cent of this gas is within the coal itself.

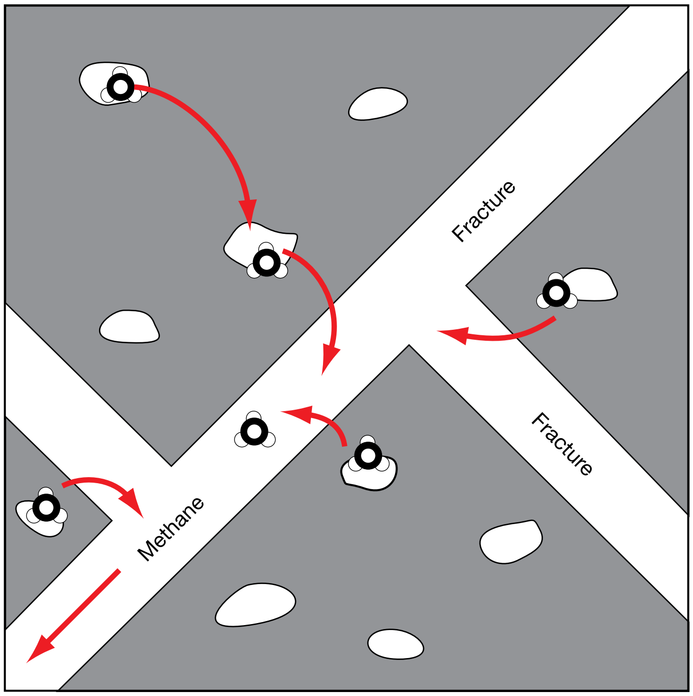

Figure 2.7 Coal seam methane can escape through the fractures in coal.

Coal may look solid, but it contains countless tiny pores that give it a huge surface area (Figure 2.7). Most of the methane forms a layer on the surface of these pores. The remainder exists as a gas in the natural fractures of the seams or is dissolved within the seam water. An established general relationship is that potential total gas content increases with the rank of the coal and depth. In contrast, the permeability of coal decreases with depth.

To recover the methane, boreholes from the surface are drilled down 300 to 500 metres into the coal seam. In one successful recovery method, the seam water is removed, thus lowering the pressure inside the coal. This helps further fracture the coal and allows the methane to escape from the pores into the fractures from which it can then be pumped to the surface. If carried out prior to the mining of an area, it allows for the commercial recovery of methane and the removal of a safety hazard.

Fracking. What happens when the gas pressure decreases as coal seam gas is removed? And what happens when there are few fractures for the gas to naturally escape? A controversial technique used to extract more coal seam gas is called **fracking** – short for hydraulic fracturing. In this process, a mixture of sand and water is pumped down the borehole into the coal seam. About 1 per cent is a variety of other chemicals to help the process work more efficiently. The high-pressure water increases the size of the fractures and the sand holds them apart (Figure 2.8). After a day or two, the water is pumped out and the gas flows from the borehole. This gas is then transported for local use or exported overseas.

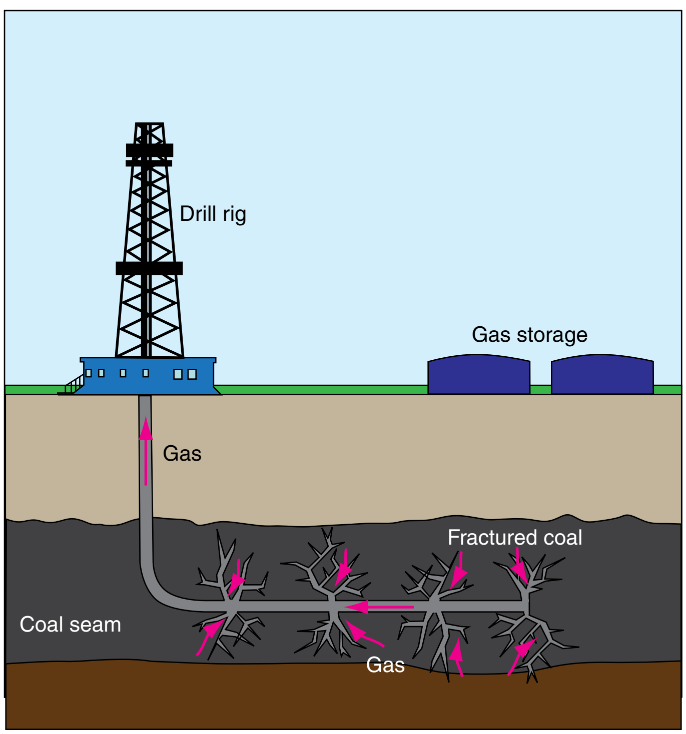

Figure 2.8 Fracking forces open the cracks in the coal to release the coal gas.

Gas from petroleum. Natural gas normally occurs in association with crude oil (although some natural gas in Australia may have come from nearby coal beds). Sometimes the amounts are relatively small compared to the amounts of crude oil. At other times, there is more natural gas. It is these supplies that are piped from the Moomba fields to Adelaide and Sydney and from Bass Strait to Melbourne (Figure 2.9). Natural gas produces about 53 MJ of energy per kilogram of natural gas burnt.

The other source of gas is the refinery process. When petroleum is refined, significant amounts of methane, ethane and propane are produced. Some of this is used to make plastics while the rest becomes part of **liquefied petroleum gas** (LPG). LPG produces about 53 MJ per kilogram burnt.

QUESTIONS

1. Define the term fossil fuel.
2. Distinguish between coal and petroleum.
3. Describe the changes in coal with increasing rank.
4. Compare the properties of heavy crude oils with light crude oils.
5. The two major gaseous fossil fuels are natural gas and coal seam gas.
   (a) Identify where each gas can be found.
   (b) Contrast the composition of each gas.
   (c) Contrast the energy yields of each gas.
6. Classify the following as renewable or non-renewable resources: water, uranium, copper, paper and coal.
7. Classify the following fossil fuels according to their properties and composition.
   (a) Solid at room temperature; hydrocarbon with 42 carbon atoms.
   (b) Gas at room temperature; hydrocarbon with two carbon atoms.
   (c) Solid at room temperature; mixture of hydrocarbons and other chemicals.
   (d) Liquid at room temperature; hydrocarbon with 18 carbon atoms.
8. Describe what happens to a coal seam during fracking.
9. Explain why fracking is used when producing coal seam gas.
10. Evaluate the case for extracting coal seam gas and using it locally and exporting it overseas

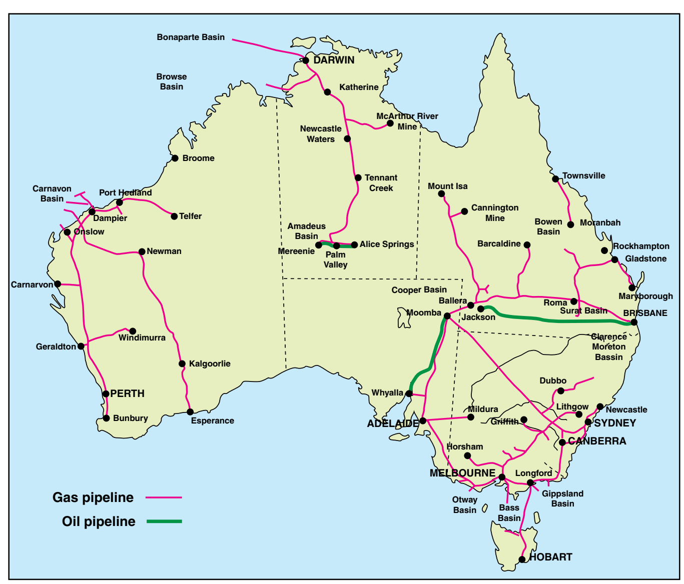

Figure 2.9 Gas and oil pipelines.

3 Formation of Fossil Fuels

Formation of coal

Most of the Permian coal deposits of Australia began forming around 300 million years ago when lush plants flourished in cool but ideal growing conditions. We know they were growing in these swamps because of the plant roots that penetrate sedimentary rocks beneath the coal. Large parts of eastern Australia were covered by a series of great freshwater lakes and swamps that accumulated enormous amounts of plant and mineral matter (Figure 3.1). The plants were not the flowering plants we are familiar with today. They were mainly ferns and the now extinct scale trees.

Figure 3.1 Swamps like these form large amounts of peat.

The swamps where coal formed were **stagnant** – very little oxygen was present to support the normal bacteria that cause decay. As a result, the plant material that fell into the swamps did not rapidly decompose. Also, the swamps were in cooler areas rather than the tropics, so decay was slowed further. The mass of plant material was partially decayed by different bacteria to form **peat** – a soft, brown and spongy fibrous material that is the first stage of coal formation. Similar swamps occur on a very small scale along the east coast of the United States and in the coastal swamps of Canada, Scandinavia and Ireland.

Gradually, this peat was buried by sediment mud, sand and other materials. Since these sediments originate from terrestrial and marine environments, it is believed the swamps existed on a massive scale along ocean margins. As the weight of accumulated plant materials and sediment caused the coastal regions to sink, the ocean invaded the area and buried it with marine sediment. This eventually silted up and enabled freshwater swamps to re-establish so that alternating layers of coal-forming plants and sediment produced a number of coal seams separated by varying thicknesses of rock.

There is evidence that at least some coal was formed in a different manner. As there are no plant roots in the sedimentary rocks beneath, and other evidence, it is believed that vegetation was washed into depressions and buried, eventually forming coal.

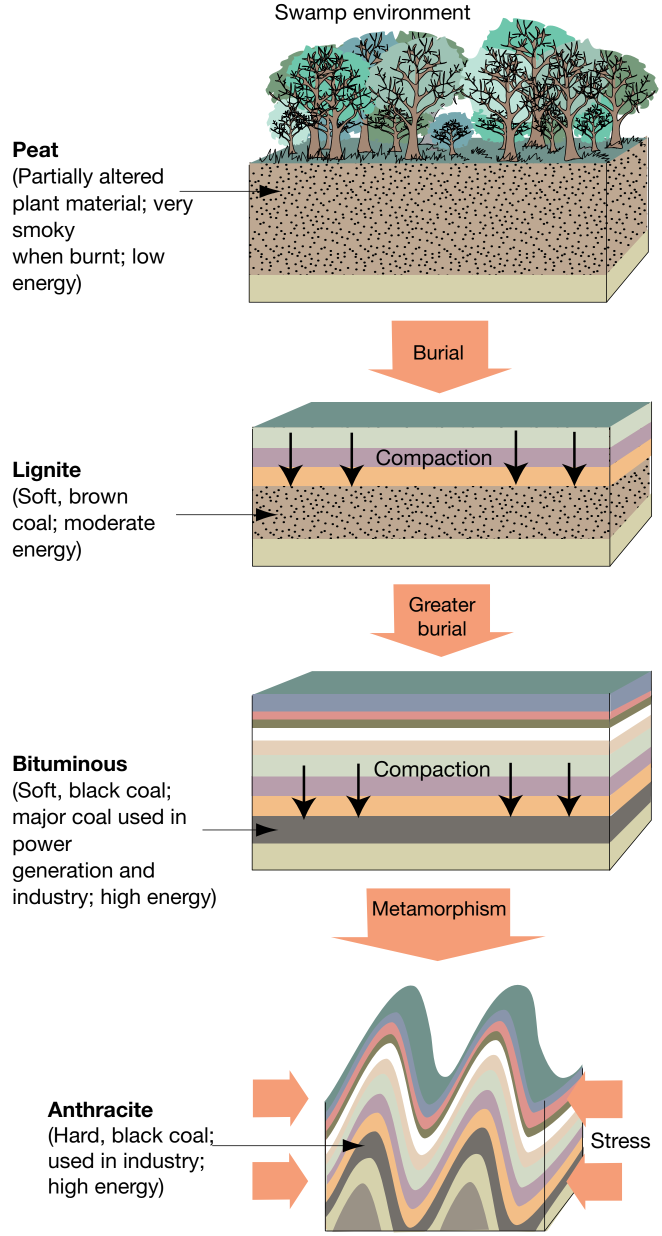

Figure 3.2 Coalification – the successive stages in coal formation.

The initial burial of the plant matter allows bacterial and fungal attack to begin. This plant material thus begins to decompose and emit mainly methane gas but also some carbon dioxide and ammonia. Gases formed biologically in this way are called **biogenic gases**.

As the coal became buried under hundreds and thousands of metres of rock cover (called **overburden**), it was subjected to heat and pressure. The liquid and gaseous contents of the coal, such as water, carbon dioxide and methane, were forced out, leaving behind a material that progressively solidified and became denser. This coal-making process is called **coalification** (Figure 3.2).

Coalification goes through the following stages of maturity (rank).

- **Peat** develops from partially decomposed plant remains. It is often possible to identify the leaves, bark and wood of the original plants. Peat can be either spongy and light brown or dense and black. It contains up to 90 per cent water, which must be reduced to 30 per cent before it can be burnt. It burns with little smoke or flame.
- **Brown coal** is formed from peat after exposure to heat and pressure over long periods of time (Figure 3.3). It is more compact than peat and dries out and crumbles when exposed to air. Brown coal has a high moisture (up to 60 per cent) and oxygen content, with a corresponding low-heating value. It is likely to undergo spontaneous combustion if allowed to dry out. This coal is used widely for power generation in Victoria, is made into briquettes as a source of solid fuel, and can be converted into liquid or gaseous fuels.
- **Black coal** is a solid rock and forms from brown coal after greater heat and pressure have been applied by longer and deeper burial (Figure 3.3). Black coals are distinguished by rank and may be sub-bituminous, bituminous or anthracite.

  Sub-bituminous coal is usually dull black and waxy in appearance. Its carbon content is higher than that of brown coal (71 to 77 per cent), though its moisture content is about 10 per cent. Sub-bituminous coal is a valuable fuel for power generation and can be converted into liquid or gaseous fuels. In Australia there are deposits in Queensland, New South Wales, Tasmania, South Australia and Western Australia.

  Bituminous coal is dense black and solid. It frequently contains bright bands with a brilliant lustre. The carbon content ranges from 78 to 91 per cent, the water content varies from 1.5 to 7 per cent and it burns with a luminous flame. There are many varieties of bituminous coal that, depending on their characteristics, can be used for gas-making, steam-raising or coke-making.

  Anthracite is a jet-black coal with a brilliant lustre. Its carbon content is over 92 per cent and its moisture content is very low. Although difficult to ignite, anthracite has a high-heating value and burns slowly with a pale blue flame. It conducts electricity and can be blended with bituminous coals to improve coking qualities.

Australia has very little true anthracite – most of the coal mined in New South Wales and Queensland is bituminous coal while brown coal is mined in Victoria.

Figure 3.3 Comparing black and brown coal.

While methane gas is formed biologically in the upper layers, the bacteria that produce *biogenic gases* are killed at greater depths. However, gas formed by **thermal cracking** becomes more important. In this process heat and pressure cause chemical bonds in large molecules to break, resulting in smaller gas molecules. Gases created in this way are called **thermogenic gases**. Those made by biogenic and thermogenic means become trapped in the minute pores and form the coal methane studied in the last chapter.

During coalification, changes in appearance and composition take place.

- Colour goes from light brown to black and usually from dull to shiny.
- Texture alters from soft and fibrous to hard and granular.
- Density increases as the coal becomes more compacted.
- Moisture content decreases from about 90 per cent in peat to 1 per cent in anthracite.
- Level of tar and gases given off when burnt lessens.
- Heat released per kilogram rises.

Formation of petroleum

Most geologists believe the major source of petroleum was floating plankton – minute marine plant and animal organisms – that grew in seas with poor circulation. When they died, their remains sank to the sea floor. One possible location where this has occurred is in the seas between island arcs and continental crust (Figure 3.4). As well, subsequent plate tectonics would help provide heat and pressure for the formation of petroleum.

The debris from huge numbers of micro-organisms is rich in organic fats and oils but also contains proteins and carbohydrates. If there was a deficiency of oxygen (anaerobic conditions) near the sea floor, animal and plant remains would be subject to decay caused by methane-producing bacteria.

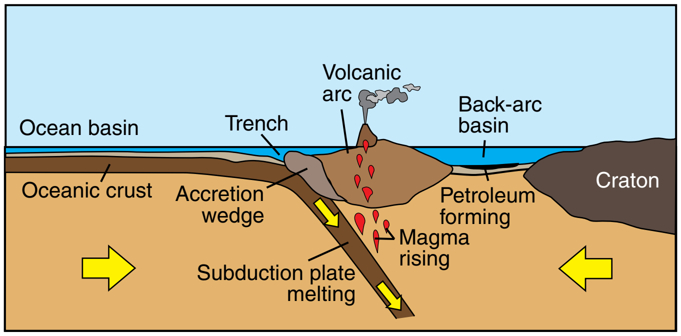

Figure 3.4 A possible location of petroleum formation is a back-arc, a sea with poor circulation located between an island arc and continental crust.

The process of oil and gas formation in marine sediments is shown in Figure 3.5. As the plankton are buried deeper in sediments, there is a general increase in temperature and pressure. In time these sediments become rocks. Temperature and pressure increase further due to the weight of rocks above and the heat from the Earth's core. This increase in temperature and pressure converts the buried organic materials into petroleum or natural gas.

Thus there are a number of factors that will determine if a deposit is mainly crude oil, natural gas or both. Natural gas is mainly produced in shallow and in deep deposits. Crude oil is produced at intermediate levels. However, liquids and gases can migrate from their point of formation. Thus a deposit may end up as a mixture of the two.

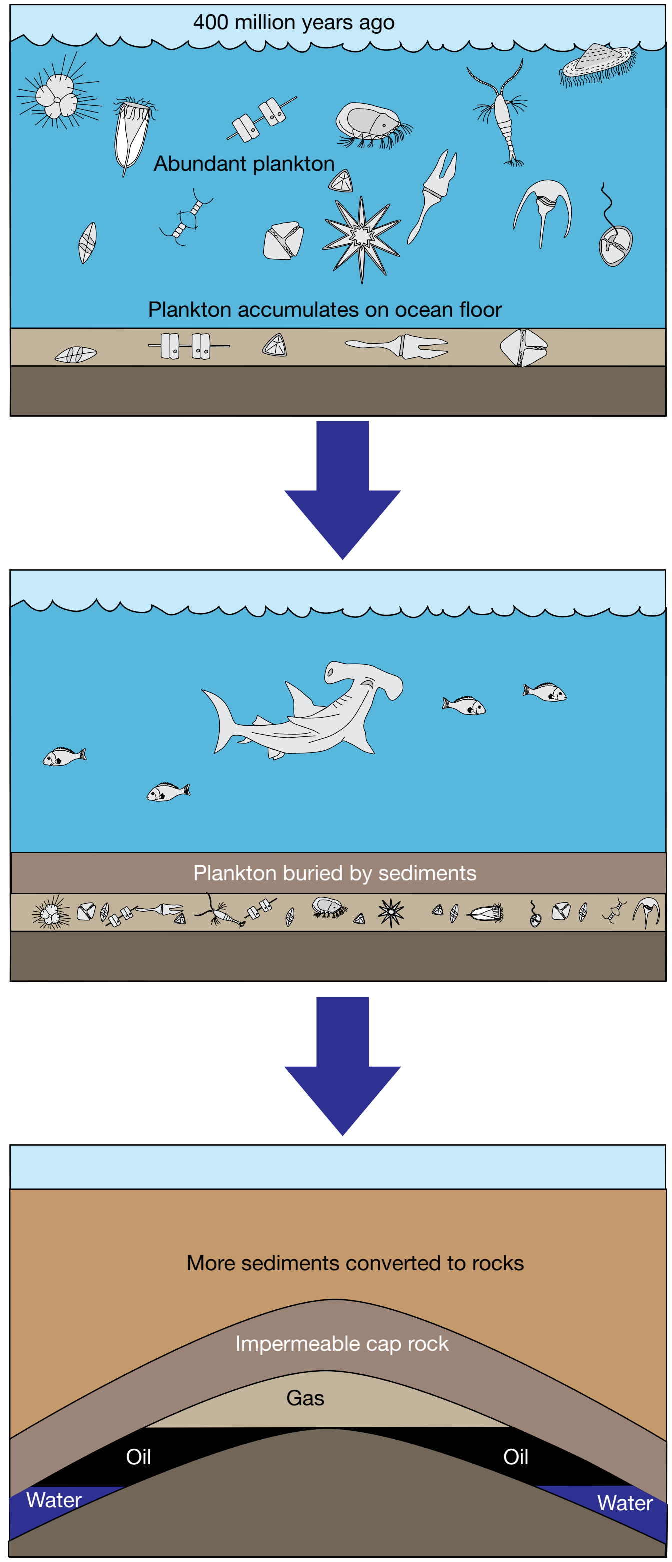

Figure 3.5 Formation of oil involves the conversion of organic matter into oil and natural gas as a function of depth of burial. The natural gas and oil often migrate from where they are formed.

QUESTIONS

1. Define the term coalification.
2. Distinguish between aerobic and anaerobic conditions.
3. Contrast how biogenic and thermogenic gases form.
4. Identify a locality where coal is forming today.
5. Describe the process of coalification.
6. Outline the characteristics of environments where coal is likely to form.
7. There are no huge coal- or petroleum-forming environments on Earth today. In the light of this finding, discuss the future of coal as a source of energy.
8. Compare the processes by which natural gas and coal methane are created.
9. Describe the characteristics of the marine petroleum-forming environment.
10. Outline why one deposit may produce mainly natural gas while another may produce mainly oil.

Answers

1 Non-renewable Resources

1. (a) Renewable resources can be replaced over a relatively short period of time; non-renewable resources are not renewed quickly if at all.
   (b) A resource is a substance humans need for some use(s) and a reserve is an amount of a resource that can be extracted at today's costs and selling prices.
   (c) High-value and low-value resources are both useful to humans in some way. However, high-value resources can be transported all over the world while low-value resources are used near to where they are obtained.
2. (a) If the price of a material rises, then the increased cost of extraction of lower-grade ores can be met and the reserve becomes a resource.
   (b) Technological innovation can lower the cost of production so that a reserve can become a resource.
3. Answers will vary: Saucepans and cutlery use metals; plates use clays; vegetables and bread come from things grown in soil; eggs come from animals that eat grain also grown in soil.
4. Sustainable use means a resource can continue to be used indefinitely by present and future generations.
5. Find more sources for the material; mine lower-grade deposits; use new technology to extract the material; reduce the amount of material we use; make more efficient use of a material; substitute the material with something else; recycle materials.
6. (a) Iron ore at 488 million tonnes.
   (b) Black coal at 50 656 million tonnes.
   (c) 258 tonnes of gold are mined.
7. Bauxite is the ore from which aluminium is obtained. Recycling of aluminium allows it to be reused so that less bauxite needs to be mined to meet demand.
8. Not all regions of Australia have been examined in detail. It may be that locations exist hidden below the surface where diamonds will one day be found.
9. 7.6 million carats = $7\,600\,000 \times 0.02 = 152\,000$ grams
   = 152 kilograms.
10. A fuel source can only be used indefinitely if it can be replaced after use. Fossil fuel resources are non-renewable resources that are not being replaced. At current rates of use petroleum reserves will be exhausted in a relatively short period but coal will last several hundred years. Thus fossil fuels will not be used indefinitely. However, there is time to adjust to use of renewable resources such as solar and geothermal energy.

2 Fossil Fuels

1. A fossil fuel is a carbon based material derived from once-living things that can be burnt to produce useful energy.
2. Coal is a solid fossil fuel derived from plants while petroleum is a liquid or gas derived mainly from marine microscopic animals and plants.
3. With increasing rank the hardness of coal increases as the percentage of water decreases and the percentage of carbon increases.
4. Heavy crude oils are higher in density and move with difficulty through the grains of a rock. Light crude is lower in density and moves more readily between the grains of a rock.
5. (a) Natural gas is found in petroleum deposits while coal seam gas occurs within coal seams.
   (b) Natural gas is more than 80 per cent methane with smaller amounts of propane and butane. Coal seam gas is more than 95 per cent methane with small amounts of other gases.
   (c) Because coal seam gas has more methane compared to natural gas (which also other gases that burn), the coal seam gas has a slightly higher energy density.
6. Renewable: water, paper.
   Non-renewable: uranium, copper, coal.
7. (a) Bitumen.
   (b) Ethane gas.
   (c) Coal.
   (d) Petroleum.
8. During fracking a mixture of water, sand and small amounts of other chemicals are pumped at high pressure into the coal seam to fracture the coal and release the gas.
9. Some coal seams have few pore spaces to allow the coal seam gas to move. By opening the fractures more coal seam gas is released.
10. Coal seam gas is a non-renewable resource. While it produces less carbon dioxide than coal or petroleum when burnt, it still produces some greenhouse gases contributing to global warming. The energy so obtained is used to power our modern society. It also generates large amounts of income for the country and provides thousands of jobs. If used in the short term to provide energy as renewable solar and geothermal sources are developed, then the environmental effects may be minimal. If used in the long term then it will contribute to increased sea levels, swings in the weather and many other effects.

3 Formation of Fossil Fuels

1. Coalification is the successive stages in the formation of coal.
2. Aerobic conditions occur when oxygen is present; anaerobic conditions occur when there is very little or no oxygen present.
3. Biogenic gases are produced by the action of bacteria on buried organic material at relatively shallow depths. Thermogenic gases are produced due to the effects of heat and pressure on the buried organic material. This causes large organic molecules to break apart forming smaller gas molecules.
4. While there are some very small areas where peat is forming in Australia, there is no coal being produced.
5. During coalification, the plant material is buried under thick layers of sediment. As the weight of sediments and later rock increases the pressure and temperature, gradual changes occur in the vegetation. The liquid and gaseous contents of the coal, such as water, carbon dioxide and methane, are forced out, leaving behind a material that progressively solidified and became denser. The final grade of coal depends on depth of burial and the amount of time the process has continued.
6. Coal forms when vegetation accumulates in stagnant water where there is little oxygen and thus little decay of the plant material before burial.
7. Coal is a non-renewable resource. Although there are large reserves of coal, it does have a limited lifetime. As well, when burnt it produces greenhouse gases such as carbon dioxide that help make global warming worse.
8. Both natural gas and coal methane are formed by the burial of organic matter which is then subjected to both heat and pressure. They differ in the source of the organic material. Coal seam gas forms from buried plant matter while natural gas forms from buried plankton.
9. Petroleum forms from the accumulation of large masses of plankton is deep ocean under anaerobic conditions. This material is eventually buried under sediments and undergoes chemical changes due to the effects of heat and pressure.
10. • When plankton was initially buried it was acted upon by bacteria that produced biogenic gases.
    • As the plankton material is further buried the effects of heat and temperature produce oil.
    • When buried further, the organic material is exposed to even higher pressure and temperature that produce thermogenic gases.
    • What is produced in a deposit will reflect the depth to which the organic material was buried.

4 Exploration and Extraction of Coal

1. Answers will vary.
2. Coal mined in Victoria is brown coal and is used locally. Coal mined in New South Wales and Queensland is bituminous black coal that is used locally and exported. Western Australia produces sub-bituminous coal at Collie most being used for use in local electricity generation. South Australia mines low-grade sub-bituminous coal at Leigh Creek north of Adelaide for local use. Coal is also mined in Tasmania mostly for local use.