Unit D Energy and the Environment

There are many kinds of farms in Alberta, and each one relies on solar energy in some way. Unlike most farms, this wind farm near Pincher Creek does not involve photosynthesis or the food chain. The turbines mounted on the tall towers are used to harvest wind—the kinetic energy of the atmosphere—and transform it into electrical energy. What role does solar energy play in this operation? Why is Pincher Creek ideally situated for this kind of development?

Radiation from the Sun causes Earth's surface to heat unevenly, resulting in surface winds. The rotation of the planet causes these winds to blow from the western parts of Canada toward the eastern parts. Although the Rocky Mountains form a barrier to the prevailing westerly winds, gaps in the mountains can create natural wind corridors. At Crowsnest Pass, the energy from the prevailing winds is funnelled toward Pincher Creek, making this area an ideal location for wind farms.

Compared to other methods of generating electrical energy, wind turbines are relatively quick and inexpensive to set up and appear to have a negligible impact on the environment. As you have learned in previous units, the same cannot be said for other methods of generating electrical energy. People around the world seem to have an increasing need for energy; and yet, evidence is mounting that the biosphere cannot sustain activities that produce energy at the expense of the environment. In this unit you will examine methods used to produce energy and consider how they can be used to balance the need for human progress with environmental stewardship.

What You Will Cover

Chapter 1: Dreams of Limitless Energy

Chapter 2: Dreams of a Sustainable Future

Chapter 1 Dreams of Limitless Energy

When was the last time you felt the urge to go out with a friend and grab a snack? For some Canadians, this means hopping in the car and heading to a fast-food restaurant. Burgers, fries, and soft drinks are among the most popular choices on the drive-through menu. One issue associated with eating fast food is that its high-calorie content may upset an individual's daily balance between energy intake and energy output.

You may be surprised to know that other things, not only the food, make going to the drive-through an energy-consuming activity. The food industry is dependent upon petroleum used to grow, process, and ship the food to the restaurant. Petroleum is also used during the production of all the food wrappers and containers that are later thrown away. And don't forget the petroleum used to run the vehicle that takes you to the drive-through window.

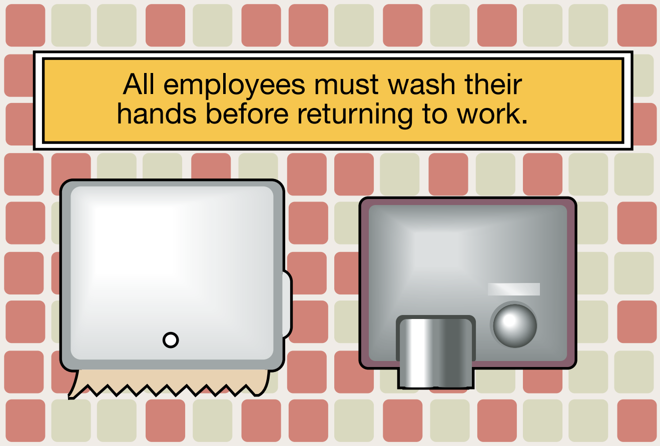
In this chapter you will analyze patterns of energy consumption in the modern world. You will explore the inner workings of some technologies that transform energy from natural sources into forms available for everyday use. You will then focus on fossil fuels as a major source of energy for generating electricity and fueling automobiles. Finally, you will consider the use of nuclear energy as a possible alternative to the combustion of fossil fuels.

Try This Activity

Electric Hand Dryer Versus Paper Towel

Science Skills
✓ Analyzing and Interpreting

Restaurants may have washrooms equipped with an electric hand dryer or paper towels for drying your hands. If you managed a restaurant and wanted to be conscious of energy use, which method of drying hands would you make available for employees and customers?



Purpose

You will identify and consider the advantages and disadvantages of two methods used for drying hands.

Procedure

Obtain the "Hand-Drying Methods" handout from the Science 30 Textbook CD. For each criteria listed in the table, determine whether the hand-drying method is an advantage or a disadvantage. You may do this individually or as a group.

Analysis

1. Identify which hand-drying method is preferred based on the table you completed in the handout.
2. Use the information in the following table to evaluate each method for drying hands based on cost. Based on this information, which method is preferred?

Description	Energy per Use (kJ)	Cost per 1000 Uses
non-recycled paper towel	743	$23
recycled paper towel	460	$23
standard electric dryer	222	$1.47
low-temperature, high-wind dryer	76	$0.50

3. Was the preferred method identified in question 1 different from the one identified in question 2? If so, consider all factors and state the preferred method for drying hands.
4. Explain why paper towels use so much more energy than electric hand dryers.
5. Use the list of perspectives on page 590 to identify the perspectives represented by each aspect listed in the Criteria column of the table in the handout.
6. In this situation, the environmental and economic perspectives are in agreement. The more environmentally friendly choice is also more economical. Give an example of an issue where the environmental and economic perspectives clash.

1.1 Energy on Demand

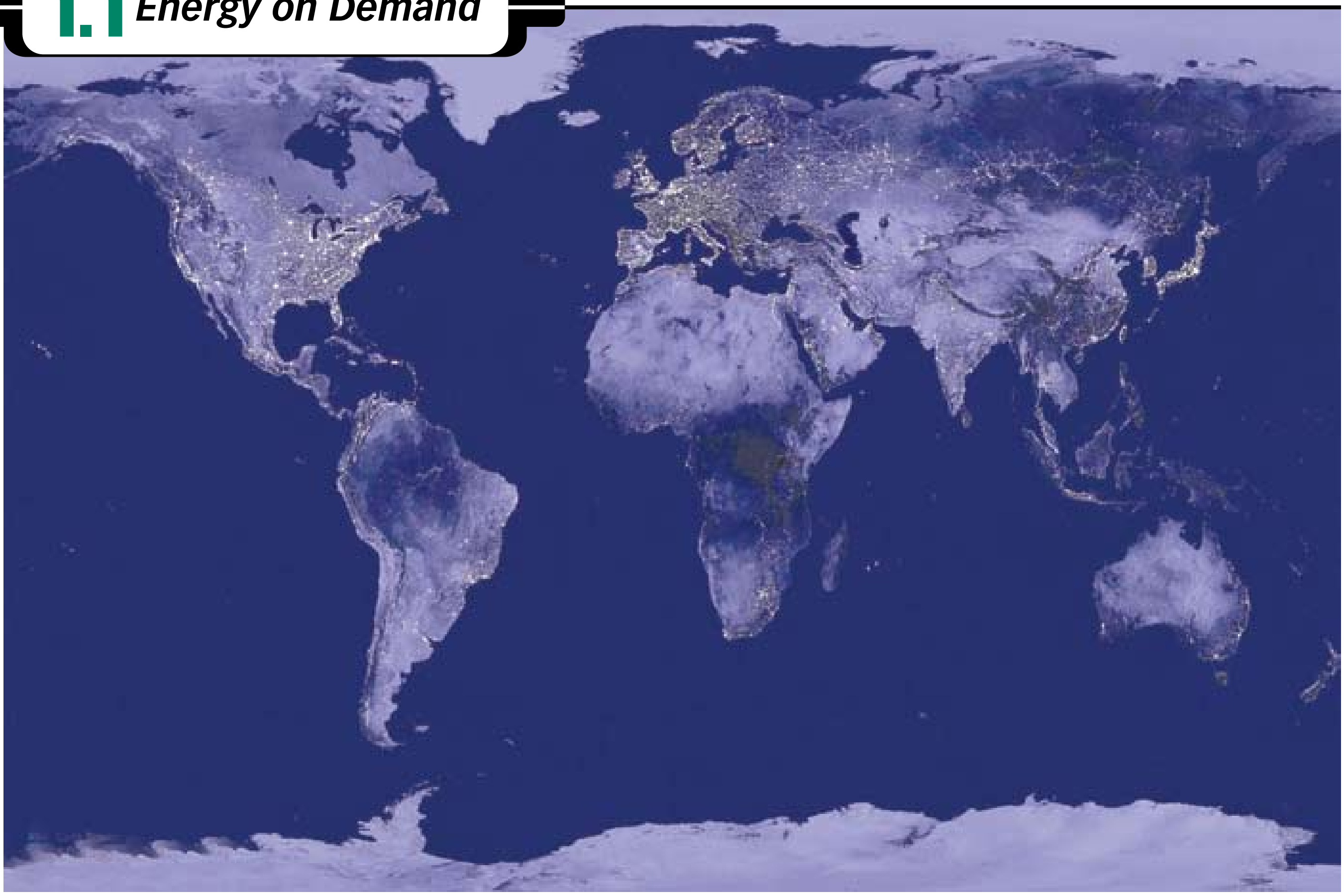


Figure D1.1: A composite of many satellite images shows light from cities across Earth that is visible from space.

Earth viewed at night from space shows a beautiful snapshot of energy use across the globe. Clusters of glowing cities dot the continents, revealing a planet transformed by human activity—activity that requires energy. Notice that some areas of the globe are not as bright as others. Is there a correlation between how bright an area appears in this photograph and energy use? How is a country's energy use affected by its level of development, economy, and climate? Imagine how this picture would change if developing countries were able to achieve the standard of living of developed countries.

Energy—The Currency of the Universe

For anything to happen around you or even in your own body, **energy** is required. When you lift a grocery bag and place it on the kitchen counter, you expend energy in your muscles to do that work. Some of the chemical potential energy stored in your muscles is transformed into an increase in the gravitational potential energy of the bag and its contents. When somebody drives a car, the engine uses energy stored in the gasoline to do work. Some of the chemical potential energy stored in the molecules of gasoline is converted into the car's kinetic energy. When you turn on the lights in your home, electrical energy is used to do work, resulting in the release of radiant energy in the form of visible light and other forms of electromagnetic radiation. Even as you read this paragraph, the cells in your brain are working. They are using the energy stored in glucose molecules to carry out the functions of comprehending and establishing memories. All of this work takes energy. Every action has its energy price. Refer to the "Some Common Expressions for Energy" table for examples of units used to express energy.

energy: the capacity to do work

DID YOU KNOW?

Food is a source of chemical potential energy. On average, 38.9 MJ are contained within 1 kg of fat compared to 17.2 MJ in 1 kg of carbohydrate and 31.5 MJ in 1 kg of gasoline.

SOME COMMON EXPRESSIONS FOR ENERGY

Unit	Symbol	Definition	Joules Equivalent	Example of Energy Involved
joule	J	energy needed to apply a force of 1 N over a distance of 1 m	1 J	Drawing a 25-cm line with a pencil on paper requires about 1 J of energy.
	TJ	terajoule	1×10^{12} J	This is equal to the energy stored in 24 tonnes of oil.
	PJ	petajoule	1×10^{15} J	This is equal to the energy stored in 24 000 tonnes of oil.
	EJ	exajoule	1×10^{18} J	This is equal to the energy stored in 24 million tonnes of oil.
calorie	cal	energy needed to raise the temperature of 1 g of water 1°C	4.19 J	A foraging hummingbird consumes about 15 cal of energy per second.
food calorie	Cal or kcal	energy needed to raise the temperature of 1 kg of water 1°C	4190 J	A human walking 33 steps consumes an average of 1 Cal.
British thermal unit	BTU	energy needed to raise the temperature of 1 pound of water by 1°F	1054 J	A typical barbecue has an energy output of 8 BTU for each second it operates.
kilowatt-hour	kW•h	equal to the work done by one kilowatt acting for one hour	3 600 000 J	This is equal to the work done during 5 h of vigorous cycling.

In the next activity you will explore the trends in world energy use, world population, and **per capita** energy use since 1850. These trends provide important background information for you to refer to throughout this unit.

per capita: for each person

Utilizing Technology

Trends in Energy Use

Science Skills
✓ Analyzing and Interpreting

Purpose

You will use a spreadsheet to perform calculations and analyze data of world energy use.

Procedure

step 1: Open the "World Energy Use" spreadsheet from the Science 30 Textbook CD.

step 2: Complete the fourth column of the spreadsheet, Per Capita Energy Use.

step 3: Graph the following:

- the world energy use from 1850 to 2000
- the world population from 1850 to 2000
- the per capita energy use from 1850 to 2000

Analysis

1. Consider the graph of world energy use from 1850 to 2000.

a. Describe the trend in world energy use.

b. Based on the trend, extrapolate your graph to the year 2050.

c. Explain why you extrapolated your graph the way you did. List the factors you considered.

d. How certain are you that your projection of energy use from the present to the year 2050 is reasonable?

2. Consider the graph of world population from 1850 to 2000.

a. Describe the trend in world population.

b. Compare and contrast the trends on the graphs of world energy use and world population.

3. Consider the graph of per capita energy use from 1850 to 2000.

a. Describe the trend shown in this graph.

b. Identify when differences to the general trend occur. Suggest a reason for differences to the general trend.

c. List some factors that influence per capita energy use.

4. Explain how the size of the world population affects on energy use.

A Canadian Way of Life

It may not surprise you that the average Canadian enjoys a lifestyle that consumes large quantities of energy. Some of this energy use is necessary to meet basic needs, such as heating homes, providing food, and travelling to and from school or work. A great deal of energy is used to support a quality of life that extends beyond basic needs.

In the early to mid 1990s, new automobile sales shifted significantly from cars to light-duty trucks (e.g., sport-utility vehicles or SUVs).

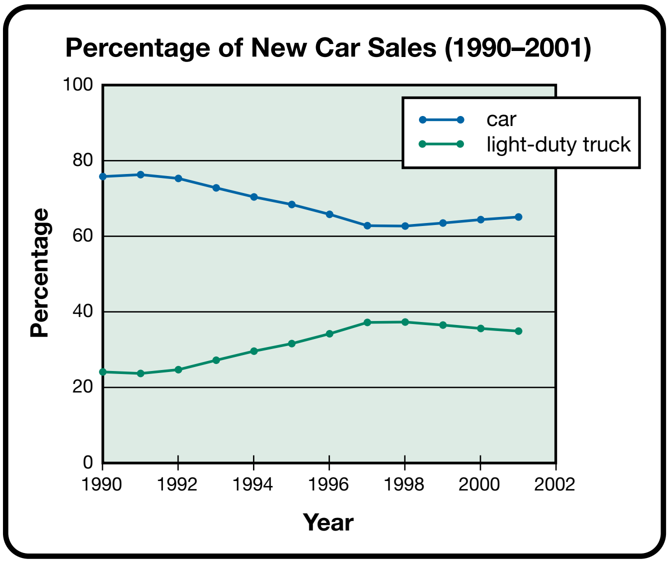


Figure D1.2

Consumers responded strongly to a general perception that driving an SUV brought with it versatility and status. However, these light-duty trucks are less fuel efficient than cars. Between 1990 and 2002, the shift in consumer preference toward SUVs resulted in an increase in energy used for passenger travel. Perception appears to strongly motivate automotive buyers. Even though smaller, more fuel-efficient vehicles are available, Canadians tend to choose heavier, more-powerful automobiles. Many people buying new vehicles are not deterred by the higher energy requirements. It is estimated that an additional $370 per year is spent on fuel for the average SUV. This value will increase as the price of fuel increases.

Practice

Use Figure D1.2 to answer questions 1 to 3.

1. Calculate the change in light-duty-truck sales from 1990 to 1997.
2. Identify reasons used to justify the purchase of light-duty trucks and other larger vehicles.
3. Suggest reasons for the trend in light-duty-truck sales shown after 1997.

Gross Domestic Product (GDP)

The reasons you provided in the answer to Practice question 2 demonstrate some of the attitudes and needs Canadians have regarding their vehicles. These attitudes and needs are, in part, reasons for Canada's large per capita energy use. How does Canada's energy use compare to other countries?

One indicator of a country's economic activity is **gross domestic product (GDP)**. Gross domestic product is measured in billions or trillions of US dollars so that comparisons can be made among countries. As an example, Canada's GDP in 2002 was US$753 billion and Kenya's was US$10 billion. Both countries have similar population sizes, but the total value of all the goods and services produced by Canada is over 75 times greater than that of Kenya. This may not be surprising given that the Kenyan economy is largely agricultural, consisting of major exports of tea and coffee. The Canadian economy, by comparison, includes a great deal of industry—exports of finished products (e.g., motor vehicles, wood products, petroleum products, and telecommunications equipment) and raw materials (e.g., metals and lumber).

Figure D1.3: Farmers' market in Kenya

Industry and the development of natural resources contribute largely to Canada's GDP; but they also use a great deal of energy. A measure of a country's GDP relative to its energy use is called **energy intensity**. Energy intensity is calculated by dividing the energy used by a country in one year by the GDP. Countries with a greater proportion of service and high-tech industries tend to have low energy intensities.

gross domestic product (GDP): the total market value of all goods and services produced by the country in one year; often considered as an indication of a country's economic output

energy intensity: the ratio of energy input (in joules) to economic output (in US$); commonly expressed in terajoules (TJ) per billions of US$ of GDP

DID YOU KNOW?

It takes the energy equivalent of two barrels of oil to produce three barrels of petroleum from oil sand.

Practice

4. Use the following table to calculate the energy intensities for Kenya, Sweden, and Canada.

Country	Energy Use (EJ)	GDP (trillions of US$)
Kenya	0.200	0.010
Sweden	2.22	0.300
Canada	13.80	0.753

5. Compare the energy intensities calculated in question 4. Do these values correspond with the tendency for countries with high-tech economies to have lower energy intensities?
6. Predict the change to Kenya's energy intensity if farmers introduced techniques that increased crop productivity.
7. Suggest reasons why Canada—a developed country—has a high energy intensity.

You will have an opportunity to explore the many factors that affect international energy use in the next activity.

DID YOU KNOW?

On average, developed countries use 7 to 8 times more energy than that of developing countries.

Utilizing Technology

Comparing Energy Use—Canada and Other Countries

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will use a spreadsheet to compare the energy used by different countries.

Background Information

A variety of factors, like climate and size of the economy, influence the quantity of energy used by a country.

Pre-Lab Questions

1. List some behaviours of people who live in colder climates. Hypothesize how these behaviours would affect a country's total energy use.
2. State aspects that determine the size of a country's economy.
3. Explain why gross domestic product (GDP) is used to measure the size of a country's economy.

Part A: Energy Use by Country

Procedure

step 1: Open the "Comparing Energy Use" spreadsheet on the Science 30 Textbook CD. Click on the tab labelled "Part A." You should see the "Part A: Energy Use by Country (2002)" table.

step 2: Construct a bar graph showing the total energy use by each country in 2002.

step 3: Construct a bar graph showing the per capita energy use in each country in 2002.

Analysis

4. Consider the graph showing the total energy use by each country in 2002.
   - **a.** Of the countries on your graph, which had the greatest total energy use in 2002?
   - **b.** Which country had the lowest total energy use in 2002?
   - **c.** In 2002, the United States used 2.3 times more energy than China, despite the fact that China's population was 5.5 times larger than the United States's. Provide a reason for this difference.
5. Consider the graph showing the per capita energy use for each country in 2002.
   - **a.** Of the countries on your graph, which had the greatest per capita energy use in 2002?
   - **b.** State possible reasons for Canada having a higher per capita energy use than the United States.
   - **c.** State one advantage of having data describing per capita energy use in addition to total energy use when comparing energy use by countries.

Part B: Effect of Climate on Energy Use

Procedure

step 1: In the "Comparing Energy Use" spreadsheet, select the tab labelled "Part B." You should see the "Part B: Effect of Climate on Energy Use (2002)" table.

step 2: Construct a graph showing the per capita energy use on the vertical axis and average annual temperature of each country's capital city on the horizontal axis.

step 3: Add a linear line of best fit to your graph by selecting "Add Trend line" in the Chart menu. **Note:** This menu only appears when you click on the graph.

Analysis

6. Describe the general relationship between per capita energy use and average annual temperature of a country's capital city.
7. State a generalization about the level of economic development of the countries positioned above and below the line of best fit.
8. Berlin has the same average annual temperature as Ottawa, yet Germany's per capita energy use is less than half that of Canada's. Suggest reasons for the difference in per capita energy use between these two countries.
9. Identify two limitations of any conclusions made from studying this data.

Part C: Effect of Size of Economy on Energy Use

Procedure

step 1: In the "Comparing Energy Use" spreadsheet, select the tab labelled "Part C." You should see the "Part C: Effect of Size of Economy on Energy Use (2002)" table.

step 2: Construct a graph showing each country's GDP (in trillions of US$) on the horizontal axis and the total energy use on the vertical axis.

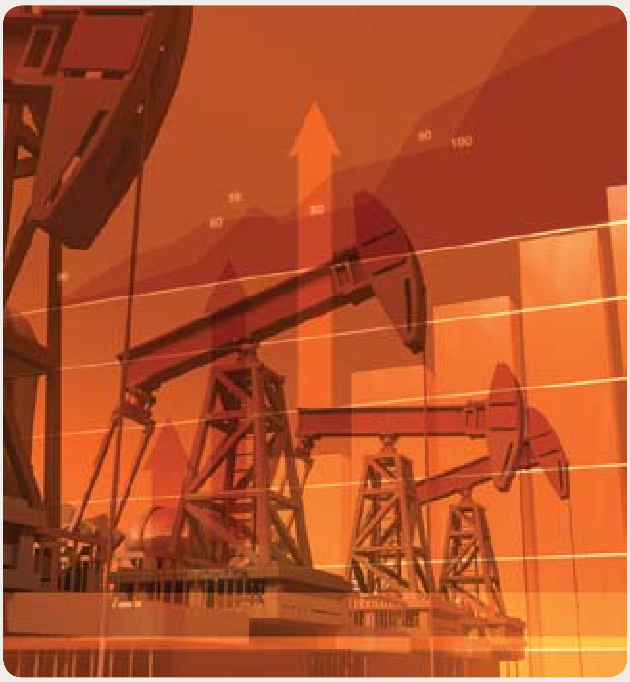
step 3: Draw a linear line of best fit on your graph.

step 4: Calculate each country's energy intensity (in EJ/trillion of US$), filling in the appropriate column in the table.

step 5: Construct a bar graph showing each country's energy intensity (in EJ/trillion of US$).

Analysis

10. Describe the general relationship between total energy use and GDP.
11. State a generalization about the level of economic development of the countries positioned above and below the line of best fit on your graph.
12. Identify which country has the highest energy intensity. Provide a possible explanation as to why this country's value is the highest.
13. Compare the energy intensity of Canada to those of the United States and Japan. Suggest reasons for the differences in energy intensity between these three countries.



Factors Affecting Energy Use

Climate

As you found in the last activity, there is a relationship between climate and energy use. People who live in cooler climates, like Canada and Russia, use energy to heat their homes. However, people who live in warmer countries, like Australia, use energy to cool their homes. In fact, the most important aspect of climate that influences energy use is extremes in temperature. For example, in Canada in 2002, a cooler than usual winter and warmer than usual summer caused a 47.9-PJ increase in the amount of energy used to heat and cool homes. For comparison purposes, one petajoule (PJ) is approximately the quantity of energy needed to meet the needs of a town of 3800 people for one year.

Figure D1.4: Factors including colder weather and reduced daylight during winter influence energy use in Canada.

Activity

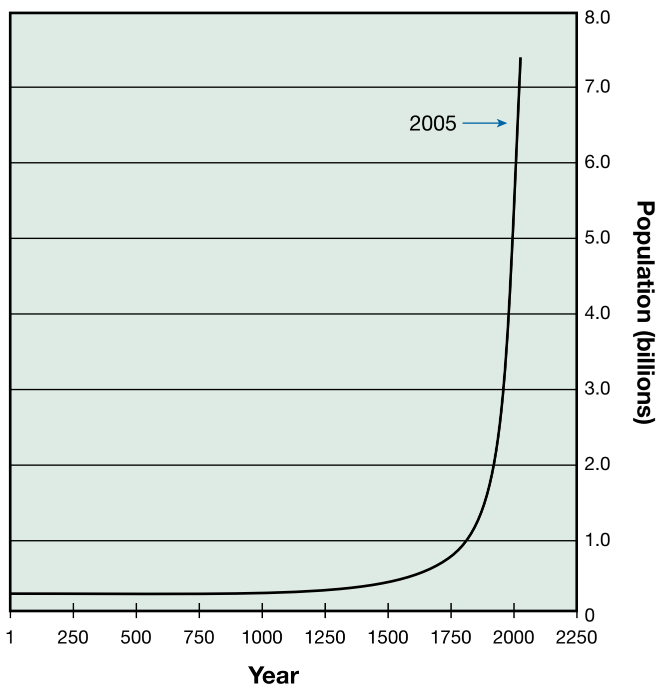
The term *activity* refers to how much work is being done. For many industries, activity can be measured in terms of tonnes of steel manufactured or number of cars produced. In other parts of Canada, activity has to be measured using other criteria. The financial industry is an important part of Canada's economy, and its activity is measured by dollars made from investments. Activity in the transportation sector is measured by how many kilometres are travelled. Regardless of how you measure activity within an economy, energy is required to maintain it.

Earlier, you learned that the total economic value of a country's industrial activity is measured as gross domestic product (GDP). Countries that enjoy a high standard of living tend to have thriving economies and large GDPs. In Part C of the "Comparing Energy Use—Canada and Other Countries" activity, you saw that the United States has the world's largest GDP. It should not surprise you to recall that the United States, which has the highest economic activity, also has the largest total energy use. Since Canada has a much smaller economy than the US, it has a smaller GDP in addition to a lower total energy use.

Population

Regardless of other measures of a country's economy, per capita energy use is a valuable measure of a country's level of prosperity. The goal of many developing countries is to industrialize and improve the standard of living for its citizens. As you have seen, in order to meet these goals, developing countries will also become larger users of energy and of natural resources (e.g., coal, oil, and natural gas) that can be combusted to supply energy. Recall that increasing the standard of living often requires an increase in the energy use per capita. Many developing countries have large populations, drastically increasing the energy required to meet these goals. Improvement to the standard of living may not only cause total energy use to rise drastically; it may also adversely affect the environment if the consequences are not considered.

World Population



DID YOU KNOW?

Service-sector industries that are less energy intensive include communications, banking, insurance, real estate, education, and health care. Also included are the manufacturing of computers, electronics, and machinery.

Science Links

In Unit B, it was determined that acid deposition and particulate pollution are some of the consequences from the use of technology that involves the combustion of fossil fuels for energy production. Later in this unit you will study alternative energy sources and technologies that may help to meet global energy demands while preserving the environment.

Energy Intensity

Figure D1.5: Large equipment and extensive pipelines (shown left) are costly parts of the process to produce petroleum from oil sand. Manufacturing silicone wafers for computer chips (shown right) is a much lower energy-intensive process.

Industry involved with the extraction, refining, or development of natural resources are often highly energy intensive—they require more energy for every dollar of economic output. Whether it is forestry, coal mining, or oil sand development, large equipment and high costs for transporting the materials increase the value for energy intensity compared to other industries. In the "Comparing Energy Use—Canada and Other Countries" activity, you saw that development of Canada's plentiful natural resources resulted in a higher energy intensity compared to other industrialized countries, like the United States, Germany, and Japan. However, since 1990, the percentage of Canada's economy composed of energy-intensive industries has been decreasing, shifting toward a less energy-intensive economy.

DID YOU KNOW?

Tires for the trucks used to haul oil sand cost about $50 000 each.

Practice

8. The energy intensities of Canada and Germany in 2002 were 18 and 6 (in EJ/trillion US$ of GDP), respectively. Use the Internet to identify and compare Canada's and Germany's major exports. Explain how the differences among exports support the different energy intensities of these two countries.

Energy Efficiency

Figure D1.6: The Energy Star symbol identifies the most energy-efficient appliances available.

Every time energy is used, some of it is transformed. The proportion transformed into a desired form is called **useful output energy**. Do you recall a demonstration in Unit C where the energies of different forms of electromagnetic radiation emitted by a light bulb were measured? In this demonstration, electrical energy was the **input energy** to the light bulb and visible light was considered the useful output energy of this energy conversion. In the demonstration a large amount of non-visible radiation was detected, including infrared (often called thermal energy). The **energy efficiency** of a light bulb is determined by the proportion of input energy that is converted into visible light and not into other forms of energy. For all devices that convert energy, some energy is always lost as thermal energy. Energy efficiency is often represented as a percentage of input energy that has been transformed into useful output energy.

$$\text{energy efficiency} = \frac{\text{useful output energy}}{\text{input energy}} \times 100\%$$

The types of input and output energies vary with the device. Refer to the “Input and Output Energy for Some Energy-Converting Devices” table.

- **useful output energy:** the desired energy form resulting from a process involving a transformation of energy
- **input energy:** the form of energy entering into a process involving a transformation of energy
- **energy efficiency:** the percentage of input energy that has been transformed into useful output energy

INPUT AND OUTPUT ENERGY FOR SOME ENERGY-CONVERTING DEVICES

Device	Input Energy	Useful Output Energy	Waste Energy
light bulb	electrical	visible light	non-visible EMR, such as infrared (heat)
car engine	chemical potential (gasoline)	kinetic	thermal
oven	electrical	thermal energy transferred to food	thermal energy not transferred to food
television	electrical	visible light	non-visible EMR, thermal

Practice

9. Calculate the energy efficiency of a water heater that uses 200 J of energy to increase the thermal energy of water 55 J.
10. If an automobile engine is 20% efficient, calculate the useful output energy from 1 kg of gasoline containing 44.5 MJ of chemical potential energy.

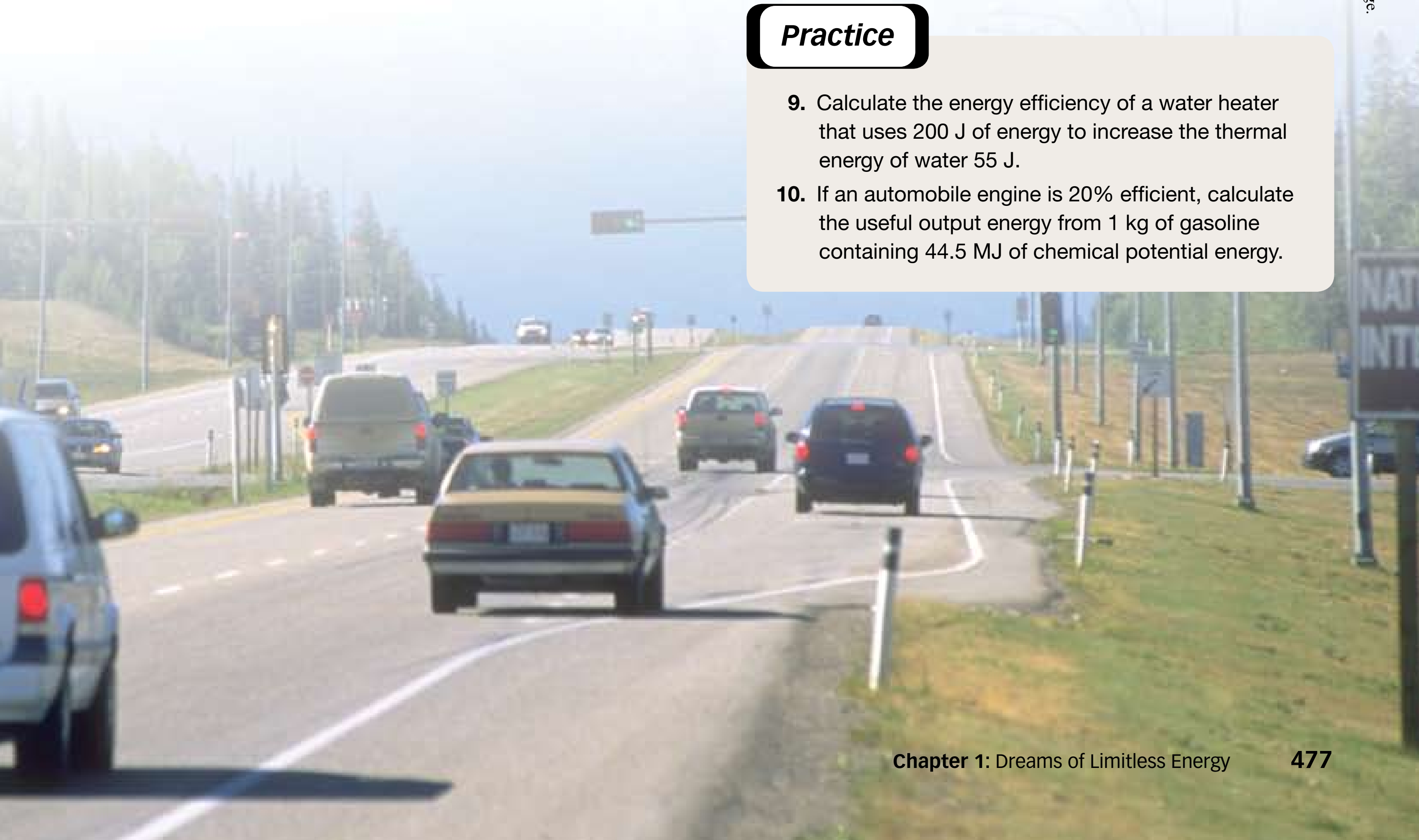


Figure D1.7: The 60-W incandescent light bulb (left) and the 17-W compact fluorescent light bulb (right) produce the same quantity of useful output energy but with greatly different efficiencies. Legislation in Canada will ban the sale of incandescent light bulbs by 2012.

When selecting a replacement bulb for the lamp beside your desk, you may have considered the power rating of the bulbs you had to choose from. Although a 60-W light bulb is not as bright as a 100-W light bulb—the bulb with the higher energy requirement—both devices have similar efficiencies. If you had the chance to consider using a compact fluorescent bulb, you may have noticed that it has a considerably lower power rating (17 W); and it provides the equivalent amount of light as a 60-W incandescent bulb. The drastic reduction in input energy to produce the same quantity of useful output energy is the result of increased efficiency of compact fluorescent lights compared with incandescent bulbs.

Practice

11. Using power ratings, determine the percentage of the total power required by a compact fluorescent bulb versus the total power required by an incandescent light bulb that provides similar output energy.

12. Improvements to energy efficiency from 1990–2003 were estimated to be 883 PJ. If the estimated energy requirement of a small town is 47.9 PJ, calculate the energy saved in terms of the number of additional towns that could have their energy needs met due to improvements in efficiency.

Science Links

Compact fluorescent lights contain trace amounts of mercury. If improperly disposed of, mercury may collect in landfills. Despite this risk, the increased efficiency of compact fluorescent lights could result in an overall reduction in mercury released into the environment from the combustion of coal. Unit B provides further information regarding the effects of mercury and other heavy metals within ecosystems and the effects of other by-products from the combustion of coal.

The use of more efficient electrical devices and other technologies, including the replacement of incandescent lights with compact fluorescent lights, is an important way to offset the increasing need for energy. For example, since 1990, the use of computers in Canadian workplaces has increased 73%, but the energy used by these devices as a whole only increased by 50%. The energy savings of 23% was the result of improvements in the energy efficiency of computers during this time. Improvements in efficiency can also occur in large industry. In fact, between 1990 and 2002, energy use in Canada's mining industry decreased by 12%. This was mostly due to improvements that made processes more energy efficient.

Figure D1.8: A worker operates a remote-control scoop tram at the Rabbit Lake mine in northern Saskatchewan.

DID YOU KNOW?

The Athabasca Basin in northern Saskatchewan is home to the world's richest, high-grade uranium mines. Although there are some open-pit facilities, the most productive operations use deep shafts to provide access to the uranium ore found hundreds of metres below the surface. The person shown in Figure D1.8 is working approximately 400 m underground.

Alberta's Energy-Based Economy

Within Canada, Alberta is known for its development of non-renewable energy resources of coal, petroleum, and natural gas. Alberta, however, also produces energy through renewable resources, like wind and hydro. The role of the energy industry is vital to Alberta's economy. Fossil fuels make up over half of the province's exports. In addition, **royalties** paid to the Alberta government by energy companies that extract and process natural resources account for about one-third of the province's total revenue. Also, nearly one in six workers in Alberta is employed, either directly or indirectly, by the energy sector.

royalty: money paid to the government that is a share of the profits made from the development of a natural resource

Figure D1.9: Many refineries are located near Edmonton and Fort Saskatchewan and are involved in processing petroleum or its components.

Although Alberta has an abundance of energy resources, the processes used to extract and process coal, natural gas, and petroleum are very energy intensive. Figure D1.10 shows the 2003 per capita energy use in Canada. Notice that Alberta's per capita energy use is two-and-a-half times greater than the national average.

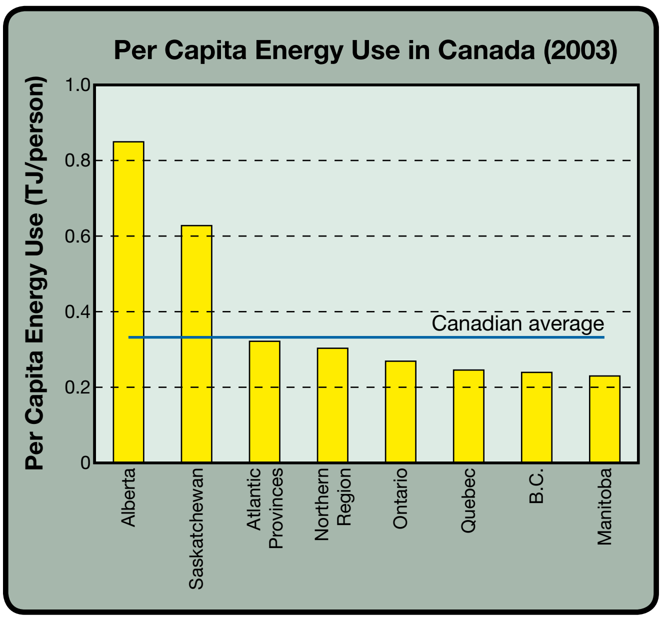


Figure D1.10

1.1 Summary

Energy use is on the rise globally due to exponential population growth and increasing development. Canada is a major contributor to global energy production and energy use, and it is one of the developed world's largest per capita energy users. Factors that affect energy use by countries include climate, size of economy, economic diversity, level of technology, and efficiency in the conversion of energy.

1.1 Questions

Knowledge

1. Identify considerations, apart from energy use, that influence decisions about the purchase of products.
2. Describe the trend of the world's energy use from 1850 to the present.
3. Define *per capita* and *gross domestic product* (*GDP*).
4. State an example of how a change in consumer preference led to an increase in the quantity of energy used by Canadians for transporting both people and products.
5. List five factors that affect energy use. Provide definitions for each factor.
6. Describe the relationship between the size of a country's economy (as measured by GDP) and its total energy use.

Applying Concepts

7. The United States is Canada's largest trading partner and shares many similarities in terms of lifestyle and culture.
   a. Compare the total energy consumption of Canada to that of the United States.
   b. Compare the per capita energy use of Canada to that of the United States.
   c. Provide reasons for the differences between the per capita energy use of these two countries.

Use the following information to answer questions 8 and 9.

This table summarizes the average Canadian's energy use for various activities as a percentage of total daily energy use.

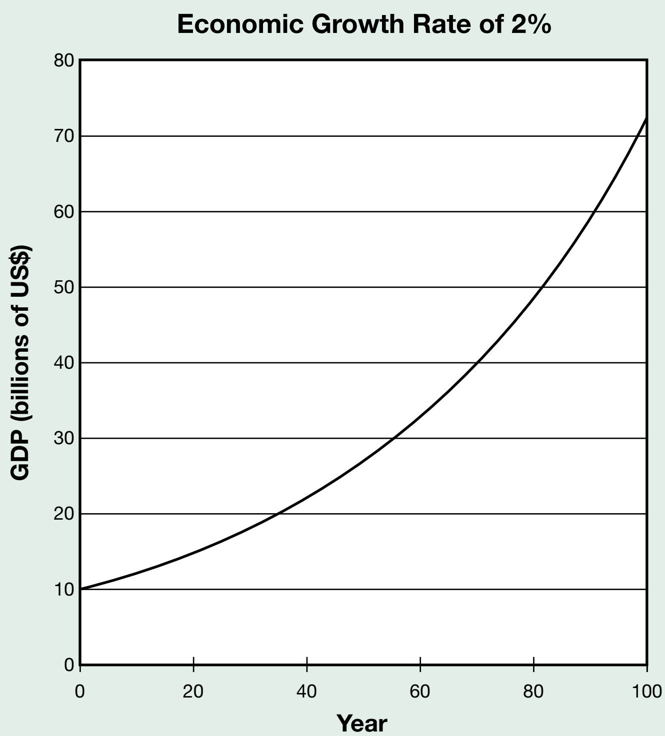
Household Item	End-Use of Energy (% of total daily energy use)
furnace/air conditioner	45
water heater	11
washer and dryer	10
lighting	7
refrigerator	6
TV, VCR, DVD	2
computer	2
dishwasher	2
other	15

8. For each household item listed in the table, suggest one action that would reduce personal energy use.

9. Describe how you would develop an experiment or a study to determine the effect of making the changes suggested in question 8. State any data or information you would need to complete this experiment or study.

Use the following information to answer questions 10 to 12.

A yearly increase of 2% in GDP is considered to be an indicator of a healthy economy. The graph given shows an economy growing at a constant rate of 2% per year for 100 years.



10. Describe the pattern of change in GDP over the time shown on the graph.

11. Discuss the implications that this type of economic growth would have in terms of total energy use.

12. Identify an important strategy for reducing energy use that would counteract an increasing energy demand.

1.2 Solar Fuel from the Past

It is a hot, dry summer afternoon deep in a northern forest. It has been weeks without rain when, finally, a thunderstorm rolls in. Lightning strikes the dry grass, igniting a wildfire that eventually engulfs several hundred hectares of forest. The flames are evidence of a violent release of energy.

In previous science courses you learned that **chemical potential energy** is stored in plant material. The original source for almost all energy, including the energy stored in plant material, is the Sun. Nuclear reactions occurring within the Sun's core produce energy that is emitted into space as electromagnetic radiation. A tiny fraction of the **radiant energy** from the Sun strikes Earth, allowing some of it to be absorbed by the complex molecule called chlorophyl, which drives a glucose-making process called photosynthesis. Once the glucose is made, much of it is used to power the plant's growth and reproduction. The remaining glucose within the plant is transformed into other compounds, most notably cellulose—the main component of wood.

All over the world, humans have long harnessed the chemical potential energy of wood for cooking and warmth. The light and heat from wood fires enabled First Peoples to inhabit colder regions of the planet, like the forests of northern Alberta. Heat from fires brings about changes in food as it is cooked, helping make some foods possible to eat and thereby increasing the supply of available food. The vital importance of wood and the ability to release its energy is evident in many stories from Canada's First Nations that describe how fire came to be controlled and used over the past 10 000 years.

Figure D1.11: This diorama—created from stories passed down by elders—at the Royal Alberta Museum shows how First Nations people traditionally dried and smoked fish in the boreal forest of northern Alberta hundreds of years ago.

- **chemical potential energy:** the energy present within the chemical bonds of a substance
- **radiant energy:** the energy of electromagnetic waves

In developing countries, like Kenya, wood is still the least expensive and most accessible form of energy. Wood is the standard fuel for cooking. Most of the wood fuel consists of dead trees and fallen branches collected from fields or from roadsides. Collecting the fuel wood is exhausting work that can consume hours of every day. Since the wood is often burned in an open pit or in a poor-quality stove, incomplete combustion occurs, releasing CO(g), polycyclic aromatic hydrocarbons (PAHs), particulate matter, and other pollutants into the cooking area.

Figure D1.12: A woman in Kenya stands outside her hut beside a pile of firewood.

It has been suggested that health and quality of life could improve in developing countries if charcoal were used for cooking instead of firewood. Charcoal is a fuel produced from wood that used to be commonly used in North American barbecues before gas-fueled models became popular. Although charcoal is a more energy-rich fuel than wood, the process to make charcoal produces many harmful emissions.

DID YOU KNOW?

Charcoal is made during the combustion of wood when extra care is taken to reduce oxygen. In many early societies, charcoal was an important fuel and was made by skilled workers.

Science Links

Substances contained within smoke from combustion can cause asthma, respiratory problems, and even cancer. More information about the health effects of substances within smoke appears in Units A and B.

Practice

13. Studies indicate that approximately 1.6 million people worldwide die prematurely from respiratory diseases caused by the pollution from inefficient wood-burning fires. Refer to your work in previous units to describe the health concerns related to the release of CO(g), polycyclic aromatic hydrocarbons (PAHs), and particulate matter into the environment.

From Wood to Coal

Although wood has been used as a fuel by humans since the beginning of recorded history, it has drawbacks. Wood is bulky, for example, which makes it hard to store and transport. Since charcoal is a more compact, cleaner fuel, it represents an improvement. As populations grow and countries industrialize, new fuels may have to be found in order to meet energy demands.

Figure D1.13: A worker stokes the furnace of a steam locomotive with coal.

Coal, a carbon-rich mineral found in Earth's crust, had been used by ancient societies—in particular the Greeks, Romans, and Chinese—but only for minor applications. In the mid-1800s, coal became the preferred fuel in England. Because of its abundant supply and energy richness, coal provided a dependable energy source for industrial processes and transportation, fuelling the Industrial Revolution.

DID YOU KNOW?

Small pieces of coal can be found along the banks of many rivers in Alberta.

Figure D1.14 shows that coal quickly replaced wood as the dominant energy source after the start of the Industrial Revolution. It is this plentiful and powerful fuel that first inspired humans to dream of a world with limitless energy—a dream where coal-powered machines, such as the steam engine, would lead to lives of leisure and prosperity. Today, coal continues to be an important source of energy across the world. Albertans rely on coal to provide many of their basic needs and wants, since coal is used to generate about 70% of Alberta's electricity.

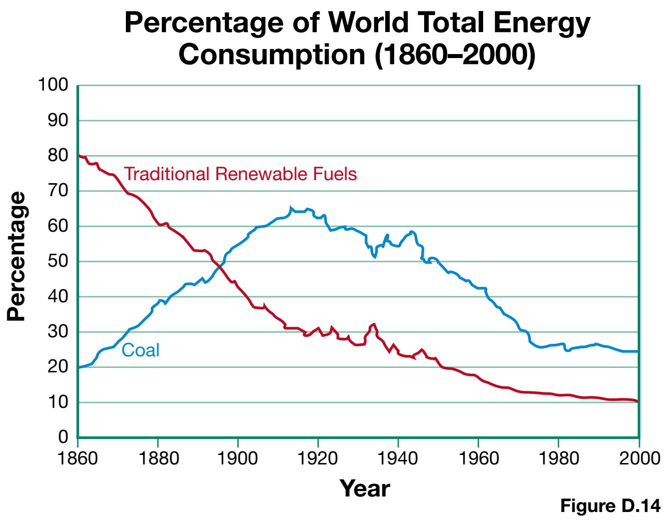


Figure D.14

Practice

Use Figure D1.14 to answer questions 14 and 15.

14. The two fuels shown are coal and traditional renewable fuels. Identify materials that could be classified as traditional renewable fuels.

15. Determine the total percentage of energy consumption provided from coal and traditional renewable fuels in 1950. Account for the value calculated. What other energy sources could be accounting for the difference?

Making Coal

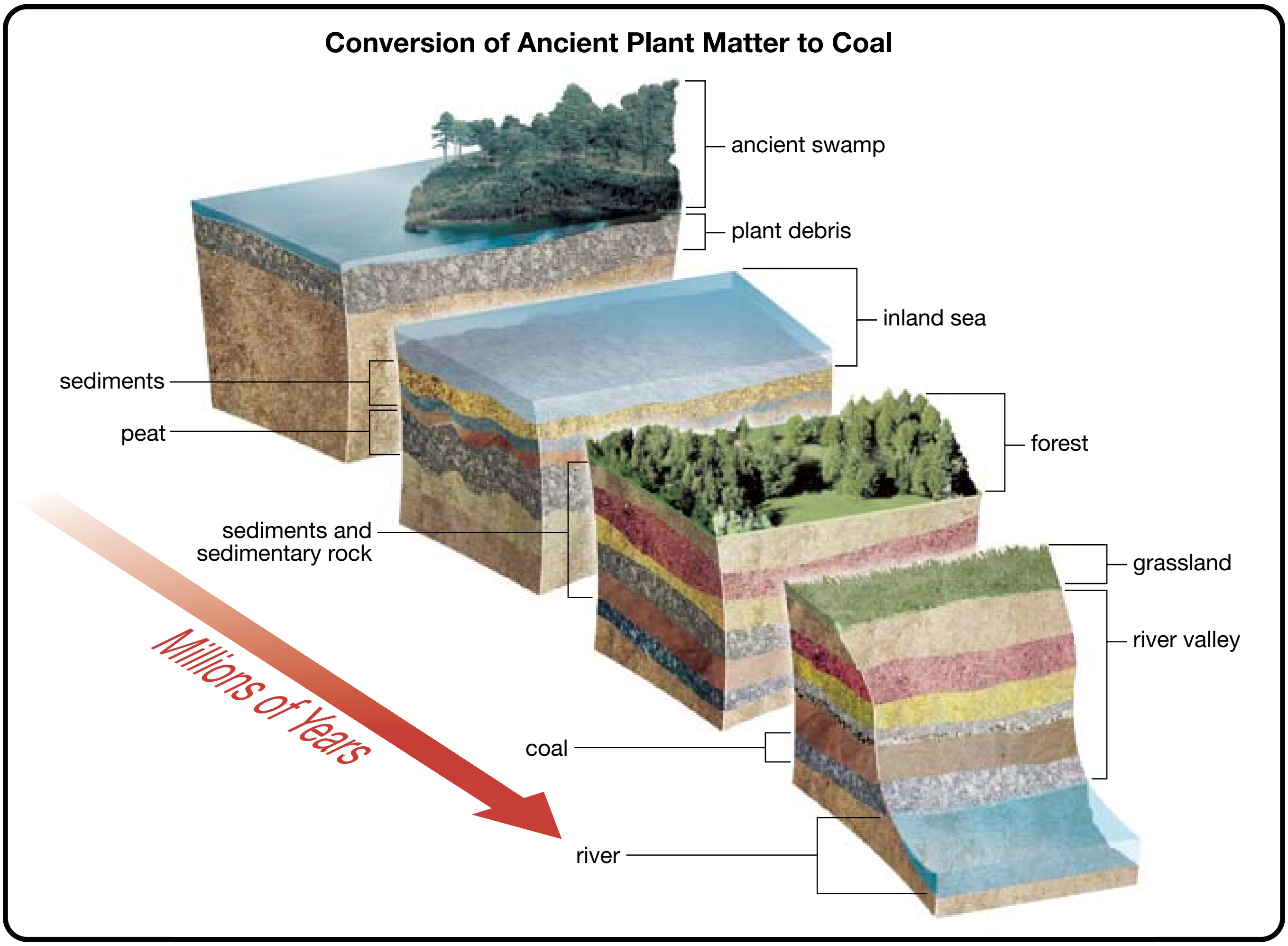


Figure D1.15: It takes millions of years and very specific conditions to make coal. Only a tiny fraction of one percent of the solar energy striking the ecosystem is eventually stored in the chemical bonds of coal.

Specific conditions are required to make coal. In tropical, swampy areas—where moisture and sunlight are abundant—thick layers of plant debris collect in the swamp over time. This layer, called peat, begins to decompose while submerged under water (in conditions without much oxygen). As more layers of plant debris and other sediments accumulate, the peat is compressed, beginning the process of its transformation into coal. The transformation of peat into coal requires millions of years and the pressure of many more layers of sediment. Since coal is derived from the remains of prehistoric life, coal is referred to as a **fossil fuel**.

fossil fuel: a hydrocarbon deposit (e.g., petroleum, coal, and natural gas) derived from plants and animals that lived millions of years ago that is used for fuel

Figure D1.16: Structures of plant parts are often visible on the surface of coal. Parts of a plant's stem are visible as vertical lines in this photograph.

More recent geological events—such as the retreat of the glacial ice sheets that once covered Alberta—removed some of the top layers of sediment that helped compress the coal. The massive runoff from the continental glaciers carved deep river valleys in the Alberta landscape. Events like this exposed coal seams close to the surface, making them accessible for mining.

Lots of Coal

Figure D1.17: A tipple, like this one seen at an abandoned coal mine near Drumheller, Alberta, is used to clean, screen, size, and load coal into rail cars.

Figure D1.18: Many of the coal mines currently in operation in Alberta are open-pit mines, where the topsoil is removed to allow the coal to be loaded into large trucks.

Coal has been mined in Alberta since the early 1900s. Towns like Drumheller, Bellevue, Hillcrest, and Frank have museums where you can view the original buildings and equipment used. Today, coal mining is still a vibrant industry in Alberta and around the world.

In Alberta, surface mining is primarily used to extract coal. Surface mining involves the removal of layers of earth above the coal deposit. The coal seam lying beneath appears like a black carpet and is removed using large mechanical shovels and trucks. Although the cost of machinery to conduct surface mining is high, coal is a relatively inexpensive fuel to obtain using surface-mining techniques. Coal reserves in Alberta that are accessible using surface-mining techniques are estimated to be 620 billion tonnes.

DID YOU KNOW?

When exposed to oxygen, coal begins to decompose, releasing heat. Coal stored outside power plants must be covered with dirt to prevent spontaneous combustion.

In Alberta, areas where coal and other natural resources have been extracted must undergo **reclamation**. Provincial regulations require mining companies to restore land to a condition similar to what existed prior to mining. Areas that have undergone surface mining in Alberta have been restored to make farmland or to blend with the neighbouring natural habitat.

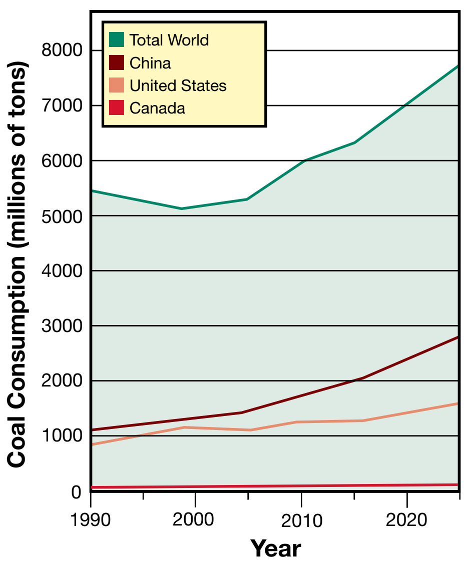
reclamation: restoring an area to its original form or some other usable form

Figure D1.19: Reclamation of the Egg Lake Mine, near Legal, has restored the local ecosystem.

Coal Use on the Rise Around the World

Coal use has increased worldwide and is projected to increase dramatically in the near future. For emerging countries with extensive coal reserves, like China, the availability of coal and the ease by which it can be turned into energy are contributing to the increased use of this energy source. Even in more developed countries, the relatively low cost of coal mining makes it an economical energy source.

Projected Coal Use



DID YOU KNOW?

Coal is the largest commodity carried by Canadian railways.

Practice

16. Peat forms at an average rate of 5.0×10^{-4} m/a (metres per year). It takes 10 m of peat to make 1 m of coal.

a. Calculate the time it took to produce the peat required to make a 5-m thick layer of coal. (**Hint:** Think of this question as a speed problem, $v = \frac{d}{t}$.)

b. Does your answer to question 16.a. account for the total time it would take to make the 5-m thick coal layer? Explain.

c. According to the evidence and the answers to the previous questions, should coal be classified as a renewable or non-renewable resource?

17. Energy density—the energy available per kilogram of combusted fuel—is often used to compare fuels. The following table compares the energy density of bituminous coal (the type found in Alberta), wood, and charcoal.

ENERGY DENSITIES OF SOME FUELS

Fuel	Energy Density (MJ/kg)
coal (bituminous)	23.9
wood	13.5
charcoal	29.0

a. Identify the fuel with the highest energy density.

b. State reasons why the use of charcoal as a fuel is restricted.

c. Explain the benefit of comparing fuels based on energy density.

d. Is it possible to determine the energy density of liquid fuels?

Petroleum—Today's Dominant Fuel

In the 1950s, due mostly to the impact of the automobile on society, **petroleum** became the world's primary fuel. In the 10 years following World War I (1918 to 1928), the number of automobiles in the United States and Canada increased by a factor of 4. By the beginning of World War II, most families in Canada and the United States owned a car or truck. Today, petroleum is by far the world's top energy source. Petroleum is a mixture of hydrocarbons—each a rich energy source but suited for different purposes. One of the early uses for petroleum was to make kerosene for lamps.

petroleum: liquid hydrocarbons formed over millions of years from the remains of ancient microscopic marine organisms

DID YOU KNOW?

Gasoline, the mixture of hydrocarbons consisting of seven to ten carbon-atom chains, is one of the by-products of making kerosene. In the mid-1800s there was no use for gasoline, so it was discarded.

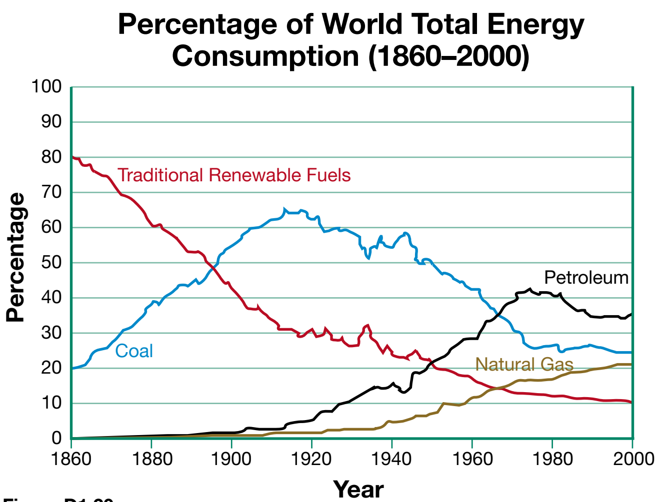


Figure D1.20

Practice

18. Use Figure D1.20 to answer questions 18.a. to 18.d.

a. In the year 2000, identify the two fuels, other than coal, used the most.

b. Describe the trend in the use of coal from 1860 to 1920.

c. Identify the fuels that began to replace coal as an energy source from 1920 to 1950. Suggest reasons why coal was replaced.

d. Describe the trend in energy supplied by coal from 1975 to 2000. Suggest a reason for this trend.

Figure D1.21: In the 1950s, parked cars lined Edmonton's Jasper Avenue, signifying society's reliance on the automobile and the importance of petroleum.

Making Petroleum

Petroleum, like coal, requires special conditions and a great deal of time to form. The shallow tropical seas that existed 360 million years ago over what we now call Alberta contained coral reefs that covered many hundreds of square kilometres. Photosynthetic plants within the reef ecosystem trapped and stored solar energy. Over millions of years, the pressure from hundreds of metres of sediments that covered these reefs, and just the right amount of heat, converted the molecules containing carbon from these organisms into petroleum.

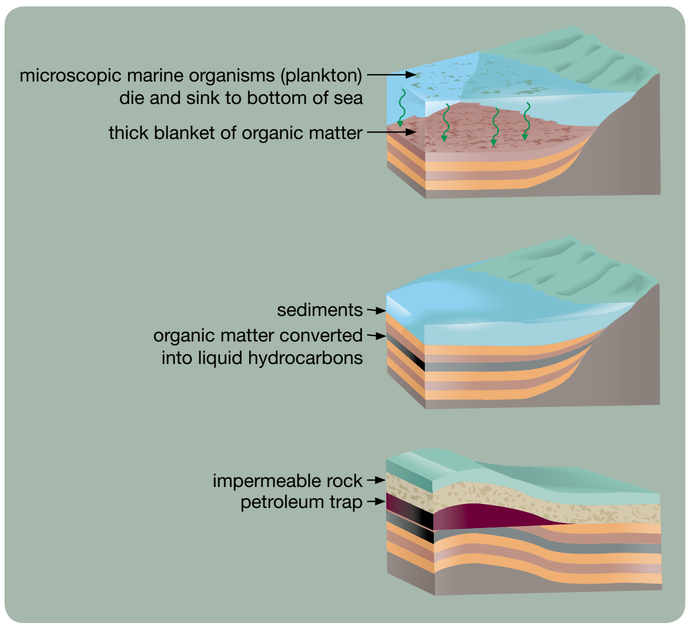


Figure D1.22: Many geologists believe petroleum formed from plankton over millions of years.

The buckling of rock layers, caused by movement of Earth's tectonic plates, allows petroleum to seep from within the rocks and then to form larger pools. The movement of water through rock layers forces the less dense petroleum upward, where it becomes trapped in dome-shaped formations that contain today's petroleum reservoirs. Since the discovery of petroleum near Leduc in 1947, Alberta has enjoyed a lucrative industry to extract and process petroleum.

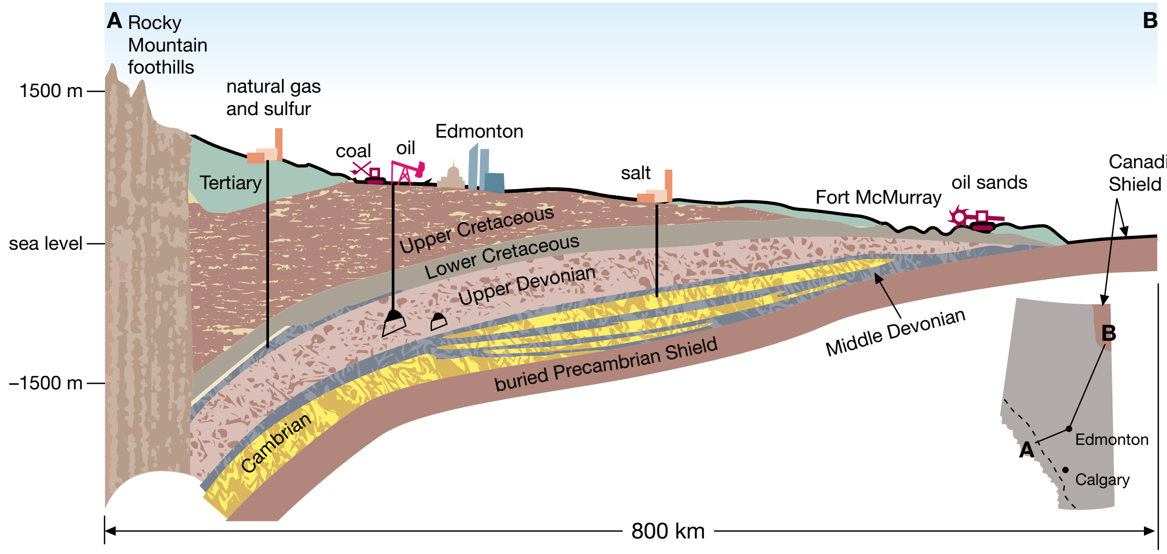
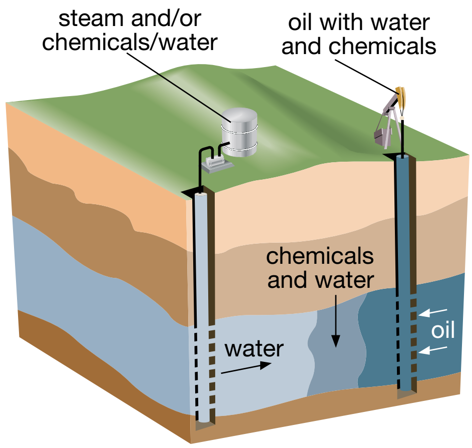


Figure D1.23: A cross section of Alberta shows major rock layers and some of the mineral resources they contain.

Enhanced Oil-Recovery Process

Over half of the petroleum within a deposit is difficult to remove. Enhanced oil-recovery techniques involve the pumping of water, chemicals, or gases into the rock layers that surround a petroleum reservoir to force petroleum into the well for extraction.



Practice

19. A great deal of concern exists over the use of water from lakes and rivers for enhanced oil recovery. Use the Internet to prepare a list of some of the concerns expressed over the use of water for enhanced oil recovery.

The Athabasca Oil Sands

Alberta's Athabasca oil sands may be one of the world's largest petroleum reserves; however, the petroleum is relatively difficult to extract. Rather than being deposited in a trap, as with conventional petroleum reservoirs, the petroleum in oil sand is stuck to individual grains of sand.

The production of petroleum from oil sand is an expensive endeavor. Oil sand can be removed using surface mining techniques similar to those used in open-pit coal mines. Approximately two tonnes of earth is removed to produce one barrel of petroleum. After extraction, the oil sand is washed with water and solvents. Two main products from washing include bitumen (a black tar) and tailings (a wet, sandy mixture). Thermal energy is required to break the hydrocarbon molecules in bitumen into smaller molecules suitable for use in products like diesel fuel. Additional production costs include reclamation of the land, cleaning of the tailings from the mine, and the treatment of water use in the oil sand extraction process.

Figure D1.24: The Athabasca oil sands span 77 000 km^2 of land and contain up to 18% petroleum.

DID YOU KNOW?

In 2006, the average cost to produce petroleum from oil sand was just over $27 per barrel.

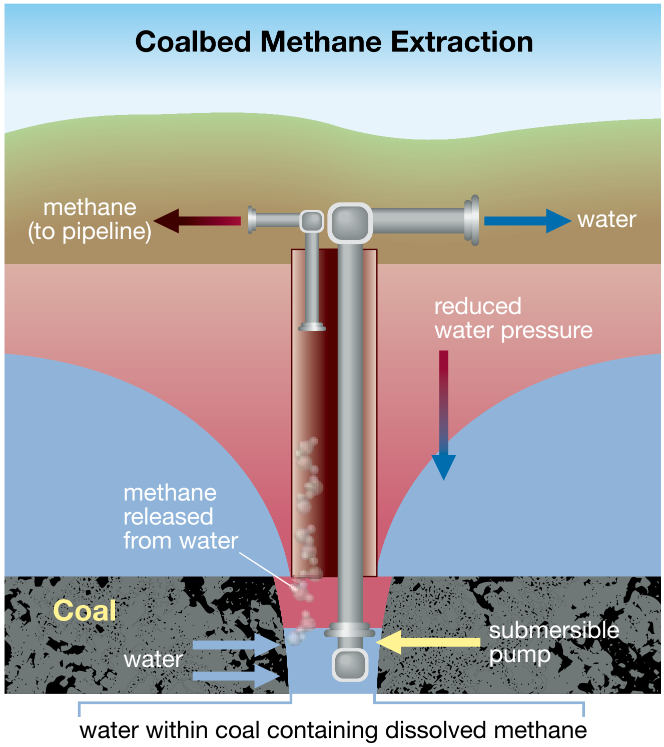
Natural Gas (Methane)

Natural gas is a mixture of hydrocarbons primarily composed of methane and, to a lesser extent, ethane, propane, and butane. Natural gas forms in much the same way as crude petroleum. The key factor that determines whether the ancient organic material will become natural gas instead of petroleum is temperature—natural gas requires more heat as it forms. Natural gas is often extracted by drilling deep underground. It is then transported by networks of pipes to individual buildings, like homes and schools. It is natural gas that most likely fuels a home's furnace and water heater and, possibly, kitchen stove; it likely fuels any Bunsen burner that may be in a school's science laboratory. Natural gas is the primary fuel used for heating in industrial processes, like processing bitumen from oil sands. It is also used as an essential ingredient for thousands of industrial and consumer products.

Coalbed Methane and Methane Hydrate

Concern about the limited supply of conventional hydrocarbon resources has created interest in new sources of hydrocarbons, namely methane. As you learned earlier, methane, $CH_4(g)$, is the major component of natural gas. Although methane is the smallest hydrocarbon molecule, it has a very high energy density—over three times that of wood. Given its energy richness and the ease by which it can be used, reserves of methane are highly sought after.

Recently, attention has been focused on a new source of methane—coalbed methane. Coal, being a porous material, often contains water. During the processes that make coal, methane is also produced and becomes trapped within the layers of coal, dissolving into the water within the coal bed. Dissolved methane can be removed from the coal bed by pumping the water within the coal formation to the surface. As the water nears the surface, the reduction in pressure causes the methane to vapourize and separate from the water. Unlike enhanced oil recovery, water is not needed to collect coalbed methane; but the water collected by this process tends to contain high concentrations of dissolved minerals, making it unsuitable for irrigation or other uses.



The development of coalbed methane projects in Alberta is connected to water issues. There are concerns that if you draw water from coalbeds, there will be an impact on water wells used by farmers. Also, the fate of water drawn from a coal bed is not certain. Simple solutions like pumping it back underground where it could contaminate other water sources may not be suitable.

Methane can also be found within ice as methane hydrate. In deeper, high pressure regions of Earth's oceans, where water temperatures are near freezing, methane leaks from geological sediments and becomes trapped within ice.

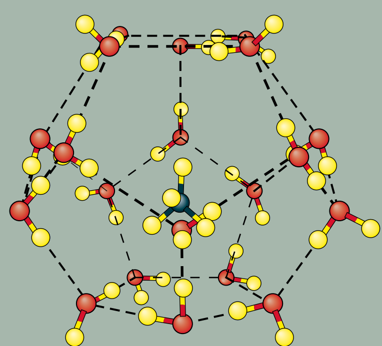


Figure D1.25: Methane hydrate (right) is methane frozen within water. The methane molecule (above) is surrounded by water molecules to form methane hydrate.

Fossil Fuels—Non-Renewable Resources

Coal, petroleum, and natural gas are all fossil fuels. As the name implies, they are extremely old and take a very long time to form. Fossil fuels are **non-renewable**. This means that once the world's supplies of coal, petroleum, and natural gas are consumed, they cannot be replaced. Fossil fuels are often called **hydrocarbons** because they contain mostly hydrogen and carbon.

Many scientists believe that over half of the world's petroleum supplies have already been used up; but, as shown in Figure D1.26, the world's petroleum production is increasing. Estimates of how long coal, petroleum, and natural gas reserves will last vary significantly. Differences between estimates are often due to the research methods selected to collect data or the interpretation of the data.

Whenever you hear information or conclusions from a study, you must consider the source of the information and any possible **bias**. Research—since it is an activity conducted by humans—needs to be evaluated for any potential bias. For example, a team of researchers sponsored by a large multinational oil company could have a different set of biases than a team sponsored by an environmental organization.

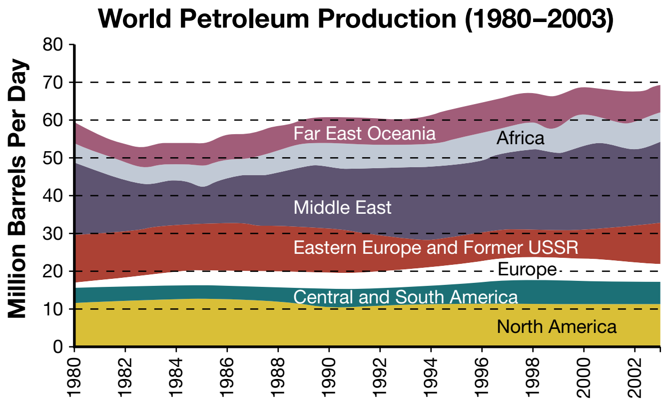


Figure D1.26

- **non-renewable:** can only be used once within the scope of human timescales
- **hydrocarbon:** an organic compound containing only carbon and hydrogen atoms
- **bias:** a preference for one particular point of view that interferes with neutral or objective decision making

Utilizing Technology

How Long Will Fossil Fuels Last?

Background Information

Information or opinions must be considered for any possible bias. In this activity you will consider the bias of sources as you collect estimates regarding the length of time that the world's supplies of fossil fuels will last.

Purpose

You will find three estimates of how long each type of fossil fuel will last, and you will evaluate the resources from which the information is obtained.

Procedure

step 1: Obtain the document "Researching the Future of Fossil Fuels" from the Science 30 Textbook CD.

step 2: Use the Internet to complete the "Estimates of How Long Conventional Fossil Fuels Will Last" table on page 1 of the handout.

step 3: Use the Internet to complete the "Newly Developed Sources of Fossil Fuel Energy" table on page 2 of the handout.

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Analysis

1. In step 2, you likely found that predictions concerning the availability of fossil fuels in the years to come varied. This indicates that there is some uncertainty surrounding this issue. Should this uncertainty prevent industry, governments, and consumers from investing time and money in research into alternatives to fossil fuels?
2. Identify at least one action you think should be taken by each of the following groups to address the likelihood of the world's petroleum and natural gas supplies running out in the next several decades.
   - citizens
   - government
   - industry
3. Suppose new sources of hydrocarbon fuels, such as coalbed methane and methane hydrate, could meet the world's energy demand for several centuries. Suggest reasons why efforts should still be made to find alternative fuels.

1.2 Summary

Fossil fuels—such as coal, petroleum, and natural gas—are important energy sources. All fossil fuels are finite and non-renewable. Given the present rates of consumption, estimates suggest that supplies of petroleum and natural gas will likely be depleted within decades. Estimates for coal suggest it will be depleted within centuries. In the lessons that follow, you will examine alternative energy sources to fossil fuels and the contributions these alternative energy sources can make toward meeting projected energy demands.

1.2 Questions

Knowledge

1. List the three main fossil fuels used today. Of these fuels, identify which is consumed globally at the highest rate.
2. Identify the energy source used to generate most of Alberta's electricity.
3. Describe how burning fossil fuels results in the release of solar energy.
4. Define the following terms.
   a. fossil fuel
   b. solar energy
   c. hydrocarbon
   d. non-renewable
   e. chemical potential energy
5. Identify the world's main energy source prior to the widespread use of coal in the 1800s.

Applying Concepts

6. Determine whether the energy stored in fossil fuels is best classified as kinetic energy or chemical potential energy. Explain your reasoning.
7. Imagine that fossil fuels are no longer available and there is no replacement available. List the activities in your life that would no longer be possible or would have to change.

Use the following information to answer questions 8 to 10.

Many countries, like Japan and the United States, rely heavily on petroleum imports, which can be threatened by political instability. This was the case in 1973 when the members of OPEC (Organization of the Petroleum Exporting Countries) would not export petroleum to the United States. This embargo on the shipment of petroleum had many effects on the United States's economy. At the height of the crisis, gasoline prices quadrupled. This massive petroleum shortage motivated the automobile industry to develop more fuel-efficient engines.

8. As petroleum and natural gas become more difficult to extract in the coming decades, describe the likely effect on the price of gasoline.
9. Identify the main areas of the economy that would be affected by a shortage of petroleum and natural gas.
10. Explain why a shortage of petroleum might lead to new developments in automotive technology.

1.3 Harvesting Chemical Energy

Which device—the snowmobile or the camera phone—is powered by fossil fuels? The snowmobile's internal combustion engine runs on gasoline, a petroleum product. As you learned in the previous lesson, petroleum is a valuable fossil fuel. But what is the energy source for a camera phone? These phones run on rechargeable batteries that must be periodically plugged into a wall outlet for recharging. The number of devices like camera phones that run on rechargeable batteries demonstrates the importance of electricity in society. In Alberta, coal—a fossil fuel—is used to generate over 75% of the electricity. So, like almost every other device that runs on rechargeable batteries in Alberta, the camera phone is also powered by a fossil fuel.

Are you surprised that both of these devices are fossil-fueled? Most people in Alberta don't make the connection between electricity and fossil fuels. As you covered in Lesson 1.2, fossil fuels are non-renewable. Even though supplies of fossil fuels are being depleted, you have learned that the rate at which they are being used as an energy source is actually increasing. In this lesson you will investigate what makes fossil fuels so energy-rich, how the energy content of fuels is determined, and how the energy from fossil fuels is released and converted into other forms of energy.

DID YOU KNOW?

In 2006, over 2000 tonnes of rechargeable batteries were discarded in Canada. Rechargeable batteries can contain metals like nickel, cadmium, aluminium, and cobalt, all of which can be toxic to organisms within the environment. Many areas have programs to promote the proper disposal of rechargeable and non-rechargeable batteries to help prevent metals from leaching into water and soil.

Energy Released in Combustion Reactions

Releasing the stored energy in gasoline or coal involves **combustion**. Recall that combustion is a type of chemical reaction that requires oxygen and, in the case of hydrocarbons, yields carbon dioxide and water vapour. During a combustion reaction, the chemical bonds within the fuel are broken and new chemical bonds are formed. The process of breaking and forming chemical bonds results in a change of chemical potential energy. Hydrocarbons are considered to be energy-rich molecules. The chemical potential energy of a hydrocarbon is the sum of the potential energy stored in all of the bonds in the molecule.

combustion: a chemical reaction that occurs in the presence of oxygen and results in the release of energy

Combustion of Octane

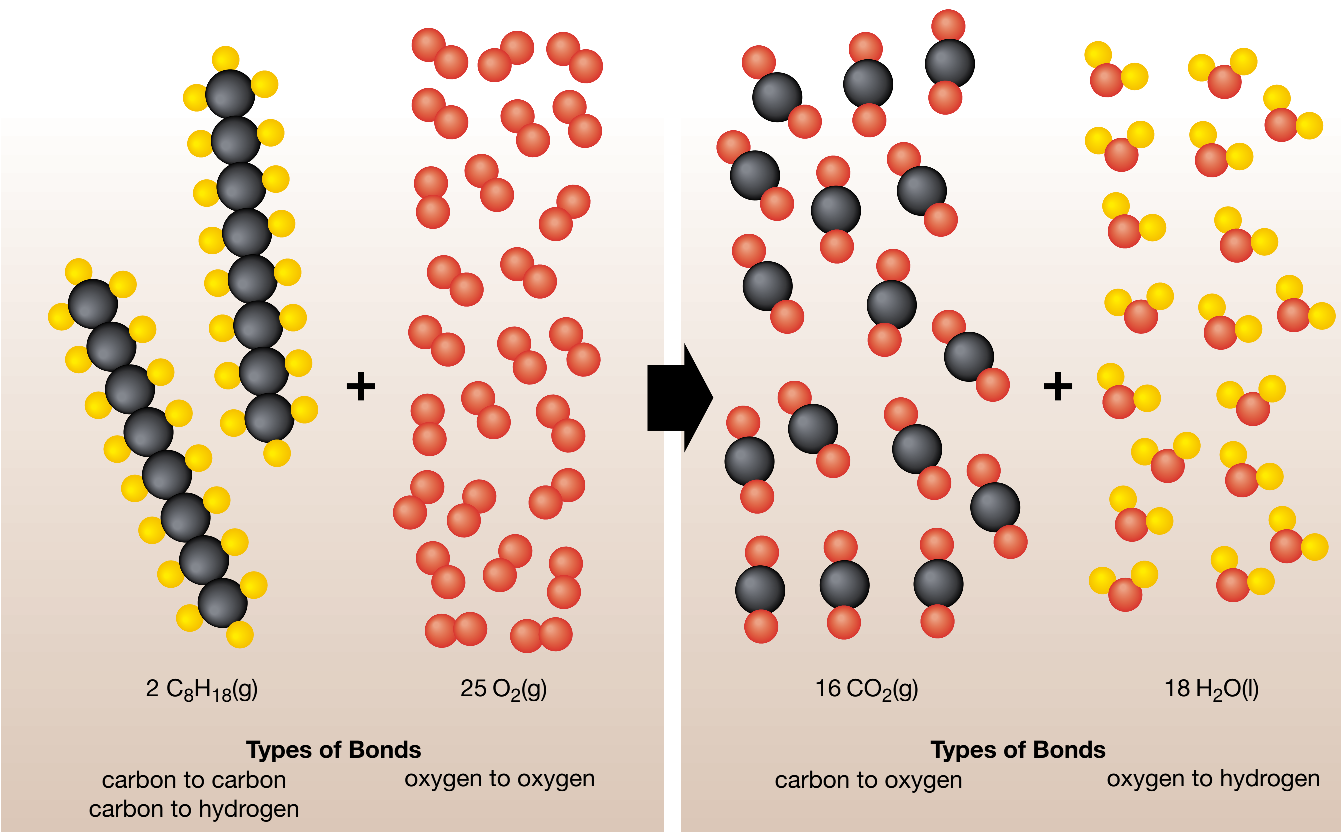


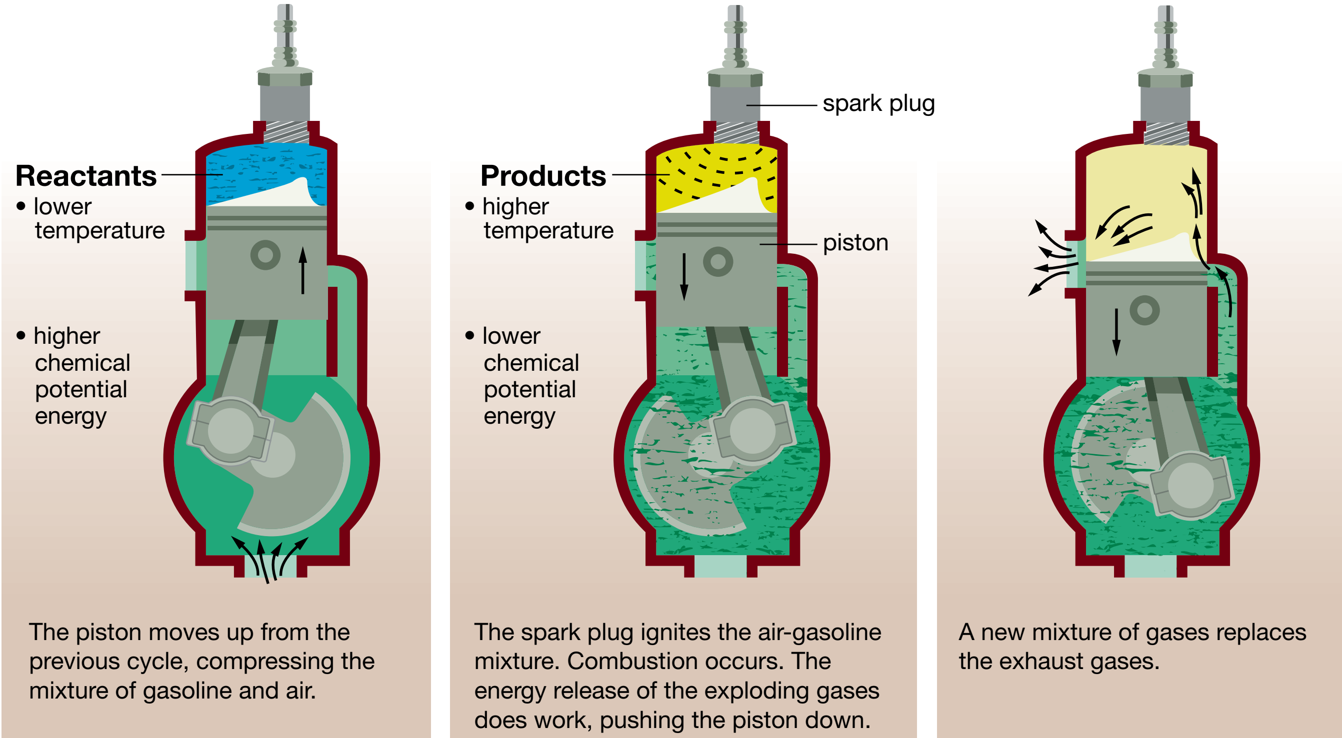
Figure D1.27: The combustion of octane, a component of gasoline, involves breaking chemical bonds and forming new chemical bonds between atoms.

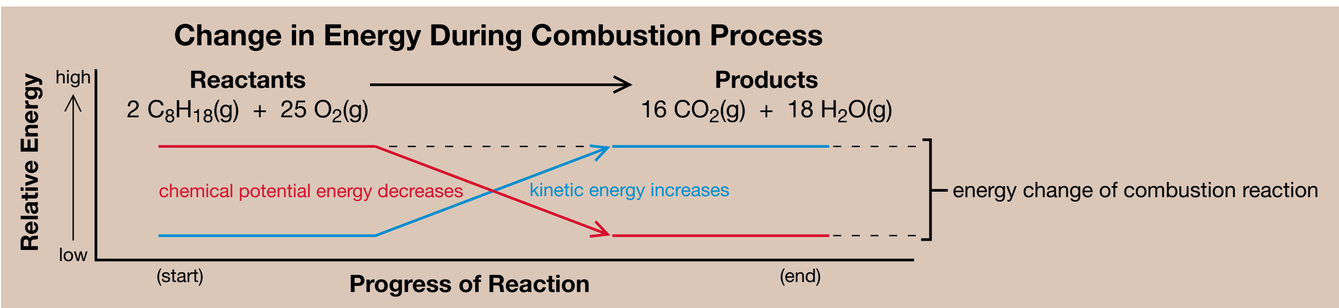
temperature: a measure of the average kinetic energy of the atoms or molecules of a substance

heat: the transfer of energy from molecules or atoms at a higher temperature to those at a lower temperature

The release of energy that occurs as a result of a combustion reaction can take many forms. Radiant energy in the form of infrared and visible light photons is emitted from the flame produced by the reaction. During a combustion reaction, the kinetic energy of the molecules involved also changes. The products of a combustion reaction are at a higher **temperature** than the reactant molecules. Recall that the collision between molecules with different kinetic energies results in a transfer of energy from warmer to cooler objects—this is often called a transfer of **heat**. The following illustration shows the energy changes that occur during the operation of a snowmobile engine:

Combustion in a Typical Snowmobile Engine





It is important to remember that not all of the energy released by the combustion of a fossil fuel does useful work on the moving parts of the engine. The radiant energy from the spark does not contribute to the useful work of pushing the piston down, nor does the energy that transfers to the non-moving parts of the engine. Earlier, you learned that energy efficiency is defined as the proportion of input energy that is converted into useful output energy.

Practice

20. Identify the forms of the input energy and output energy associated with the operation of a snowmobile engine.

21. Rewrite the formula for energy efficiency to reflect the forms of energy involved in operating a combustion engine like one found in a snowmobile.

Heat of Combustion

The rearrangement of atoms that occurs during a chemical reaction results in a change of potential energy. When the chemical reaction involves combustion, the product molecules store less chemical potential energy in their bonds relative to the bonds between the atoms of the reactant molecules. The difference in the potential energies of the reactants and products corresponds to the energy released during the combustion reaction. Figure D1.28, an energy diagram, summarizes the energy change that occurs during a combustion reaction.

The symbol $\Delta_c H°$, the **heat of combustion**, is used to represent the quantity of energy released during the combustion reaction. As shown in Figure D1.28, the molecules in the products have a lower potential energy than the molecules in the reactants. This means a release of energy in this combustion reaction occurred. Chemical changes that involve a release of energy are called **exothermic changes**. As you will see later, an exothermic energy change can be represented using a negative sign to signify that energy is released by the process to the surroundings.

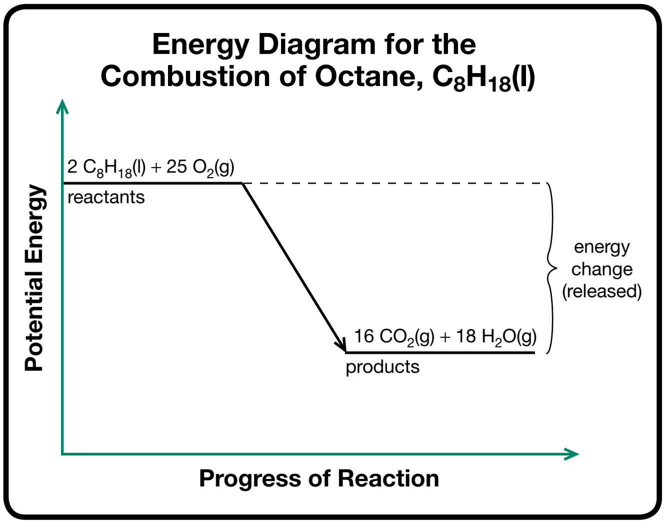


Figure D1.28

heat of combustion ($\Delta_c H°$): the amount of heat released when a substance undergoes combustion

exothermic change: a chemical change that involves a release of energy, usually in the form of heat, to the surroundings

In Lesson 1.2 you compared the energy densities of wood, charcoal, and coal. The energy densities you compared express the heat of combustion for each of these fuels per gram of fuel combusted. In the next investigation you will have an opportunity to perform an experiment to determine the heats of combustion and energy densities of some fuels.

Investigation

Determining Heat of Combustion

Science Skills
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Purpose

You will determine and compare the amount of heat released by the combustion of three different fuels.

Experimental Design

During the experiment you will measure the mass of each fuel required to raise the temperature of 20.0 mL of water 20.0°C. The data you collect will be used to calculate an experimental value for the heat of combustion of each fuel tested.

CAUTION!

Because you will be working with open flames in this investigation, ensure that you and your partners take the following precautions:

- Wear safety goggles.
- Avoid wearing loose clothing.
- Tie back long hair.
- Keep your workspace clear of combustible materials.
- Be aware of the procedures for safely dealing with fire in the laboratory.

Materials

- graduated cylinder
- electronic balance
- test tube clamp
- matches
- test tube rack
- thermometer
- candle holder
- ethanol burner
- 3, 25 mm by 200 mm test tubes
- 60 mL of distilled water at room temperature
- thermometer clamp
- 100% paraffin wax candle
- eyedropper
- laboratory stand
- butane lighter
- "Determining Heat of Combustion" handout from the Science 30 Textbook CD

Procedure

step 1: Use a graduated cylinder to fill each of the three test tubes with 20.0 mL of distilled water. Once you have filled the test tubes, place them in a test tube rack for later.

step 2: Use the electronic balance to measure the initial masses of each of the following: ethanol burner with ethanol inside, butane lighter, and candle plus candle holder. Record these values in the data table given in the handout.

step 3: Assemble the apparatus as shown in the handout. The bulb of the thermometer should not be touching the bottom or walls of the test tube. Measure the initial temperature of the water in the first test tube, and record it in the data table.

step 4: Determine the desired final temperature by adding 20.0°C to the initial temperature, and record it in the data table.

step 5: Ignite the ethanol burner, and quickly place it under the test tube so that the upper tip of the flame just touches the bottom of the test tube. Carefully monitor the rising temperature of the water. Once it reaches the final desired temperature, quickly remove the ethanol burner and extinguish the flame.

step 6: Replace the first test tube with another test tube from the test tube rack, and repeat steps 4 and 5 with the butane lighter.

step 7: Replace the test tube with the last test tube in the rack, and repeat steps 4 and 5 to test the paraffin (candle) wax.

step 8: Use the electronic balance to measure the final masses of each of the following: the alcohol burner containing the ethanol, the lighter containing the butane, and the candle. Record these values in the data table given in the handout.

step 9: Disassemble and clean the apparatus, and return all materials to their appropriate places. Make sure your work area is also clean.

Analysis

1. Complete the table in the Analysis part of the "Determining the Heat of Combustion" handout.
2. Identify the manipulated and responding variables in this experiment.
3. List three variables that were controlled during this experiment. Describe the actions you took to maintain consistency between trials.
4. Since the energy change for each trial was identical, use the mass of fuel combusted to rank the three fuels from most energetic to least energetic.
5. Use the calculated values for heat of combustion from your table to rank the fuels from highest heat of combustion per mole to the lowest.
6. Describe the relationship between the molar mass of the molecule tested and the heat of combustion per mole of each fuel tested.
7. Compare the rankings listed in your answers to questions 4 and 5. Account for any differences between the two answers.
8. Identify one major flaw in the design of this experiment. Hypothesize how this flaw may have affected your results.
9. Suggest improvements to the apparatus that might minimize the flaw indicated in question 8. If possible, include a diagram of your improvements to the apparatus used in the experiment.

Calorimetry—Measuring Energy Changes

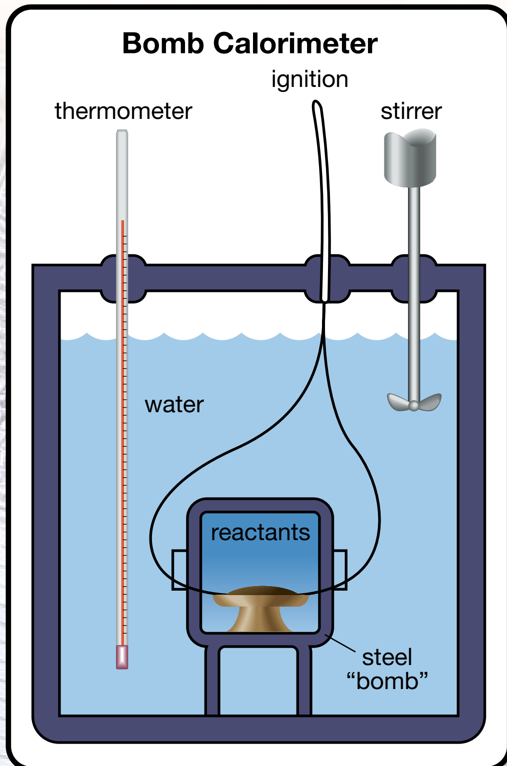
A **calorimeter**, like the one you constructed and used in the "Determining Heat of Combustion" investigation, is a device that measures the energy transferred to the water due to the combustion of a substance. Using a calorimeter yields an experimental value for the heat of combustion. Energy from the combustion reaction is transferred to the contents of the calorimeter and is observed as a temperature change to the water within the calorimeter.

calorimeter: a device that measures energy changes

In the "Determining Heat of Combustion" investigation, you were probably able to indicate more than one flaw, most likely involving the probable loss of energy. Energy radiating away from the water cannot be measured using a calorimeter. Energy losses that occur with crude calorimeters decrease the accuracy of experimental values. Scientists performing experiments use more advanced calorimeters that are better able to ensure that the energy released by the reaction is mostly, if not completely, transferred to the water. This ensures that more accurate changes in temperature are measured. In a bomb calorimeter, the combustion reaction occurs within a sealed chamber (bomb) submerged in the water. The water is contained in an outer double-walled container—similar to that of a Thermos bottle—designed to reduce the transfer of energy to the surroundings. These modifications to the basic design of a calorimeter minimize energy loss to the surroundings and improve the accuracy throughout the experiment.

DID YOU KNOW?

At one time, the values for energy in food were determined using a calorimeter. Now, values for energy are calculated using the mass of fat, carbohydrates, and protein within the food and the heat of combustion values for each gram of fat, carbohydrates, and protein.



Theoretical Heat of Combustion—Hess's Law

When determining heat of combustion, another approach is to consider the energy involved in the formation of the products and the reactants within a chemical system. Although it is impossible to exactly know the potential energy of any substance, the energy associated with a substance's formation—its **standard heats of formation**—can be used to estimate its chemical potential energy. As you have seen, the difference between the chemical potential energies of the products and the chemical potential energies of the reactants is equal to the energy change for the reaction.

The standard heat of formation for an element, when not part of a compound, is defined as zero. Each compound is given a standard heat of formation that is equal to the energy change that occurs during the chemical reaction in which the compound is formed. Giving elements an arbitrary value of zero allows for comparisons to be made among compounds and for an estimation of the potential energy of a compound (higher or lower than its respective elements). Using the standard heats of formation for all the substances involved in a reaction allows for a comparison of the potential energy of the products relative to the reactants. This is summarized in the formula for energy change of reaction, $\Delta_r H°$.

standard heat of formation ($\Delta_f H°$): the energy change for a chemical reaction that involves the formation of a compound from its elements determined at standard conditions

$$\Delta_r H° = \sum n\Delta_f H° \text{ products} - \sum n\Delta_f H° \text{ reactants}$$

where $\Delta_r H°$ = energy change of reaction (kJ)

$\sum$ = the sum of

n = amount (number of moles) represented by coefficient from balanced chemical equation

$\Delta_f H°$ = standard heat of formation

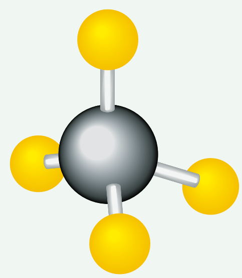
If the reaction is a combustion reaction, $\Delta_r H° = \Delta_c H°$. This means that the heat of combustion, $\Delta_c H°$, is equal to the difference between the sum of the heats of formation of the products and the sum of the heats of formation of the reactants for that equation. Example Problem 1.1 shows how this formula can be applied to predicting the energy change for a chemical reaction.

Example Problem 1.1

The balanced chemical equation for the combustion of methane is as follows.

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

Use standard heats of formation to calculate the energy change for the combustion for methane, the main component of natural gas.



Solution

$$\Delta_c H° = \sum n\Delta_f H° \text{ products} - \sum n\Delta_f H° \text{ reactants}$$

Organize the information in a table.

	Products		Reactants	
Substance	$CO_2(g)$	$H_2O(g)$	$CH_4(g)$	$O_2(g)$
Coefficient	1 mol	2 mol	1 mol	2 mol
$\Delta_f H°$	−393.5 kJ/mol	−241.8 kJ/mol	−74.6 kJ/mol	0

$$\begin{aligned}\Delta_c H° &= \sum n\Delta_f H° \text{ products} - \sum n\Delta_f H° \text{ reactants}\\ &= \left[\left(1\ \cancel{\text{mol}}\right)\left(-393.5\ \text{kJ}/\cancel{\text{mol}}\right)+\left(2\ \cancel{\text{mol}}\right)\left(-241.8\ \text{kJ}/\cancel{\text{mol}}\right)\right]-\left[\left(1\ \cancel{\text{mol}}\right)\left(-74.6\ \text{kJ}/\cancel{\text{mol}}\right)+\left(2\ \text{mol}\right)\left(0\right)\right]\\ &= \left(-393.5\ \text{kJ} - 483.6\ \text{kJ}\right) - \left(-74.6\ \text{kJ} + 0\right)\\ &= -802.5\ \text{kJ}\end{aligned}$$

The energy change is −802.5 kJ.

Practice

22. The following balanced chemical equations are for the combustion reactions for each of the fuels tested in the "Determining Heat of Combustion" investigation. Calculate the heats of combustion for each reaction.

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

b. $2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g)$

c. $2\ C_{36}H_{74}(s) + 109\ O_2(g) \rightarrow 72\ CO_2(g) + 74\ H_2O(g)$

Note: Assume the heat of formation for paraffin wax, $C_{36}H_{74}(s)$, is -1862.6 kJ/mol.

23. Express the heats of combustion in question 22 as energy changes per mole of fuel combusted. State a reason why energy changes are often expressed per mole of reactant.

DID YOU KNOW?

The formula $\Delta_r H° = \sum n\Delta_f H°$ products $- \sum n\Delta_f H°$ reactants can also be used to predict the energy change for any chemical reaction, as long as standard heats of formation for the products and reactants are provided. This formula is one way to state Hess's Law, named after Germain Henri Hess—a Swiss chemist who, in 1840, published his work with energy changes in chemical reactions. Hess's Law states that the energy change for a process is the same whether it occurs in one step or many steps. Energy diagrams are another way to summarize Hess's contribution to a greater understanding of energy changes in chemical reactions.

Machines—Always Leaking Energy

Think back to the first time you ever checked a machine's oil level. Checking fluid levels has become a standard part of most driver-training classes. At some point in the instructions of how to locate and read the oil level on the dipstick, instructors will also warn you that the engine will still be hot, even though it is not running. As with any engine that runs by burning fuel, the combustion of the fuel results in energy being transferred to the engine parts.

It's important to remember that all the energy transferred to the engine is an important component of the total energy output of the engine. The total output energy of the engine is always equal to the total input energy of the engine. In other words, energy can neither be created or destroyed. In previous courses you may have referred to this as the law of conservation of energy. It is also called the **first law of thermodynamics**.

The flow of heat to parts of the engine is classified as non-useful output energy because it does not contribute to the useful work done by the engine. The engine is designed to exert a force on the moving parts that give the vehicle kinetic energy. Whenever energy does work, some of it is wasted. Some of it is lost to the surroundings in the form of heat. In the "Determining Heat of Combustion" investigation, you probably realized that not all of the thermal energy released by the combustion reaction is transferred to the water. Some thermal energy escaped to the room at large. Even if you tried to capture 100% of that escaping energy, as is attempted with bomb calorimeters, you will never fully succeed. A tiny fraction of the energy always escapes. So, inevitably, when people harness energy to do work, some energy passes to the environment as waste heat. The **second law of thermodynamics** states that 100% efficiency is impossible. All people can do when designing machines is to try and minimize waste heat.

first law of thermodynamics: a law stating that energy cannot be created or destroyed

Energy is always conserved.

second law of thermodynamics: a law stating that when energy is transferred or changed from one form into another, some of the energy is always transferred to the surroundings (usually as waste heat)

Example Problem 1.2

During a trip, a car uses 2.35×10^7 kJ of chemical potential energy supplied by combustion of gasoline. The car's engine is able to transform 4.73×10^6 kJ of that chemical potential energy into useful work.

a. Calculate the efficiency of the car.

b. Use the first law of thermodynamics to determine the percentage of the car's input energy that is transformed into non-useful forms of output energy.

c. List some of the non-useful forms of energy produced by the car's engine.

d. Explain why the non-useful forms of output energy can never be completely eliminated.

Solution

a. useful output energy $= 4.73 \times 10^6$ kJ

input energy $= 2.35 \times 10^7$ kJ

energy efficiency = ?

$$\text{energy efficiency} = \frac{\text{useful output energy}}{\text{input energy}} \times 100\%$$

$$= \frac{4.73 \times 10^6 \text{ kJ}}{2.35 \times 10^7 \text{ kJ}} \times 100\%$$

$$= 20.1\%$$

The energy efficiency of the car is 20.1%.

b. According to the first law of thermodynamics, energy is conserved; therefore, the total energy output equals the total energy input. Since 20.1% of the output energy does useful work, that means 100% – 20.1% = 79.9% of the input energy is transformed into non-useful forms of energy.

c. The non-useful forms of energy include the thermal energy that passes as waste heat to the environment, the radiant energy produced during combustion, and the sound energy produced by the car's engine.

d. According to the second law of thermodynamics, it is impossible for a machine designed to do useful work to be 100% efficient because some energy is always lost in the transfer.

DID YOU KNOW?

Energy loss is at its greatest when objects are hot because the greater the temperature difference, the greater the rate of heat loss to the cooler surroundings.

Investigation

Calculating the Efficiency of a Calorimeter

Science Skills

✓ Analyzing and Interpreting

Purpose

In this investigation you will use the results from the "Determining Heat of Combustion" investigation and the heats of combustion calculated in Practice question 23 to calculate the energy efficiency of the calorimeter.

Pre-Lab Question

1. For a calorimeter, define *useful output energy* and *input energy*. Describe how useful output energy is measured.

Procedure

step 1: Record the following table into your notebook.

Fuel	ethanol	butane	paraffin wax
Useful Output Energy (kJ/mol)			
Input Energy (kJ/mol)			
Energy Efficiency of Calorimeter (%)			

step 2: Insert your results from the "Determining Heat of Combustion" investigation into the first row of the table.

step 3: Insert your answers to Practice question 23 into the second row of the table.

Analysis

2. Calculate the energy efficiencies of the calorimeter. Record these values in the third row of the table.
3. Calculate an average efficiency of the calorimeter.
4. List possible reasons why the energy efficiency of the calorimeter was less than 100%.
5. State the precision (number of decimal places) of the balance used in the "Determining Heat of Combustion" investigation. Describe the effect the precision of the masses measured has on the values calculated for the efficiency of your calorimeter.

Coal-Fired Generating Stations

Coal is used to produce more than 70% of Alberta's electricity. Because of the increased price for petroleum, coal's popularity has increased as a source of energy to meet ever-increasing energy needs. A coal-fired generating station operates by burning coal, converting its chemical potential energy into electricity.

The process of transforming the energy within coal requires that it first be crushed into a fine dust and blown into a combustion chamber, where it ignites. The energy released by the combusting coal is then absorbed by water contained within a network of tubes surrounding the combustion chamber. The combustion chamber and water lines form the boiler, allowing the water in the lines to be converted into high-pressure steam. The force generated by the expansion of the high-pressure steam causes the turbine to spin. The axle of the turbine is connected to a generator, which is composed of a conductive wire spinning within a magnetic field. As you saw in Unit C, a generator induces an electrical current in the conducting wire—thus producing electricity. The following flowchart summarizes how the energy is transformed during the conversion of coal into electricity by the generating station.

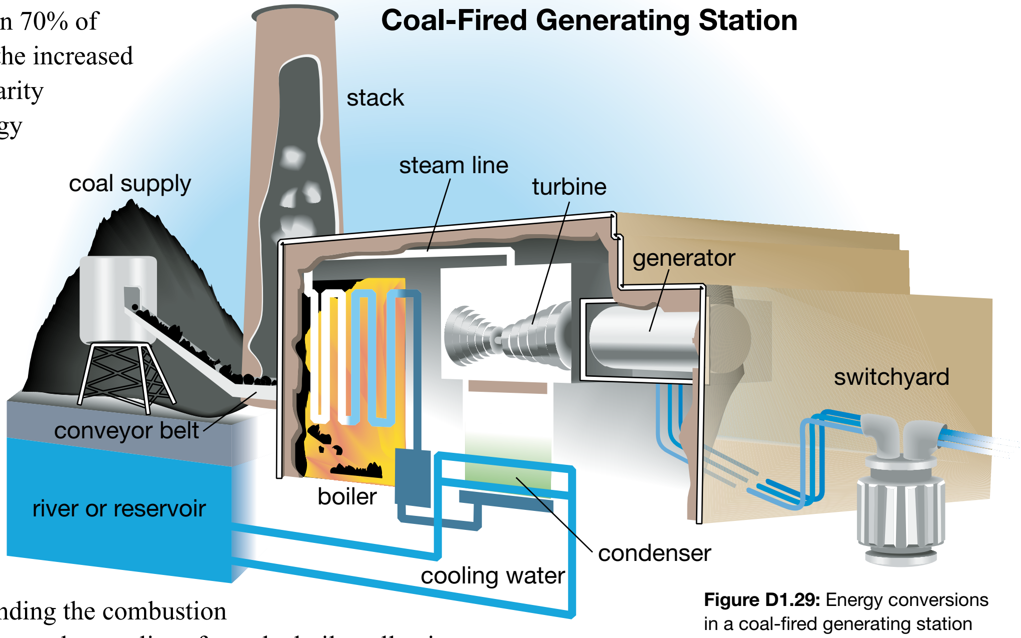
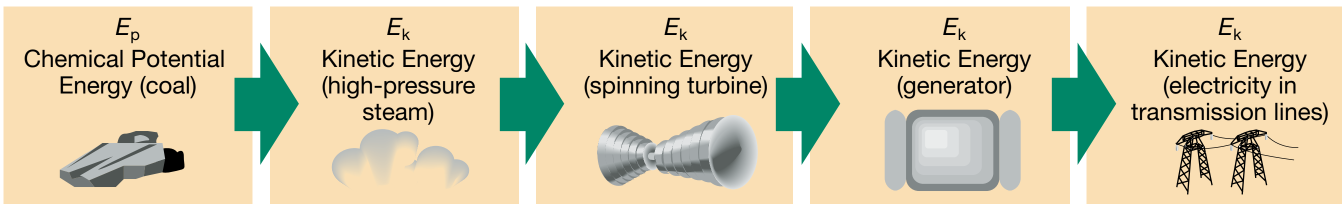


Figure D1.29: Energy conversions in a coal-fired generating station



Practice

24. Electricity can be produced using natural gas—a fossil fuel—in place of coal. Use the Internet to research natural gas-fired electricity generation. Identify similarities and differences between coal-fired electricity generation and natural gas-fired generation in terms of processes used to produce electricity and the energy transformations involved.

25. Modifications to the processes in a coal-fired power plant are listed in the following table. Explain how each modification could improve the energy efficiency of the plant.

Modification	Description
I	evaporating water normally found within coal prior to combustion
II	allowing the steam to pass more than once across turbine blades

Science Links

Older coal-fired generating stations are only about 33% efficient. Experimental, low-emission generating stations may improve energy efficiency to 45% or higher. More information about the processes involved in low-emission coal-fired power plants appears in Units B and C.

1.3 Summary

Fossil fuel combustion reactions provide the energy for many of the technological devices you use daily, like vehicles, electrical appliances, and electronic devices. The energy released by a combustion reaction can be measured experimentally or by using standard heats of formation. All energy conversions are less than 100% efficient. This is due to some of the energy being transferred to the environment as heat.

1.3 Questions

Knowledge

1. Identify the energy source used to generate the majority of Alberta's electricity.
2. Name the type of energy present within fossil fuels.
3. Identify the type of chemical reaction used to release the energy stored in fossil fuels.
4. Write the formula used to calculate energy change for a combustion reaction using standard heats of formation. Identify each variable in the formula.
5. Define *heat of combustion* and *standard heat of formation*.

Applying Concepts

6. Explain how the combustion of a hydrocarbon causes a change in potential energy.
7. Describe the result of a change in potential energy during a chemical reaction.
8. Draw an energy diagram for an exothermic process indicating the position of the reactants, products, and net energy change.
9. A natural gas-fired generating station uses 2.5 MJ of heat from the combustion of methane.
   - **a.** Calculate the station's energy efficiency if 1.3 MJ of electrical energy is generated.
   - **b.** Compare this to the typical efficiency of a coal-fired generating station.
10. For thousands of years, the Inuit traditionally relied upon animal power for transportation. In the 1970s, gasoline-powered snowmobiles replaced dogsleds as the primary mode of transportation for Inuit in the Arctic during the winter months.

   - **a.** Write the balanced combustion reaction for octane, $C_8H_{18}(l)$, the main component of gasoline.
   - **b.** Use standard heats of formation to calculate the heat of combustion for octane.
11. For millennia, Inuit people have burned seal and whale blubber as sources of heat and light. Design an experiment that could compare the heat of combustion of seal blubber with that of whale blubber. Your design should include a problem statement; manipulated, responding, and controlled variables; a diagram of the apparatus you will use; and a data table showing the information you wish to measure and record.

1.4 Harvesting Nuclear Energy

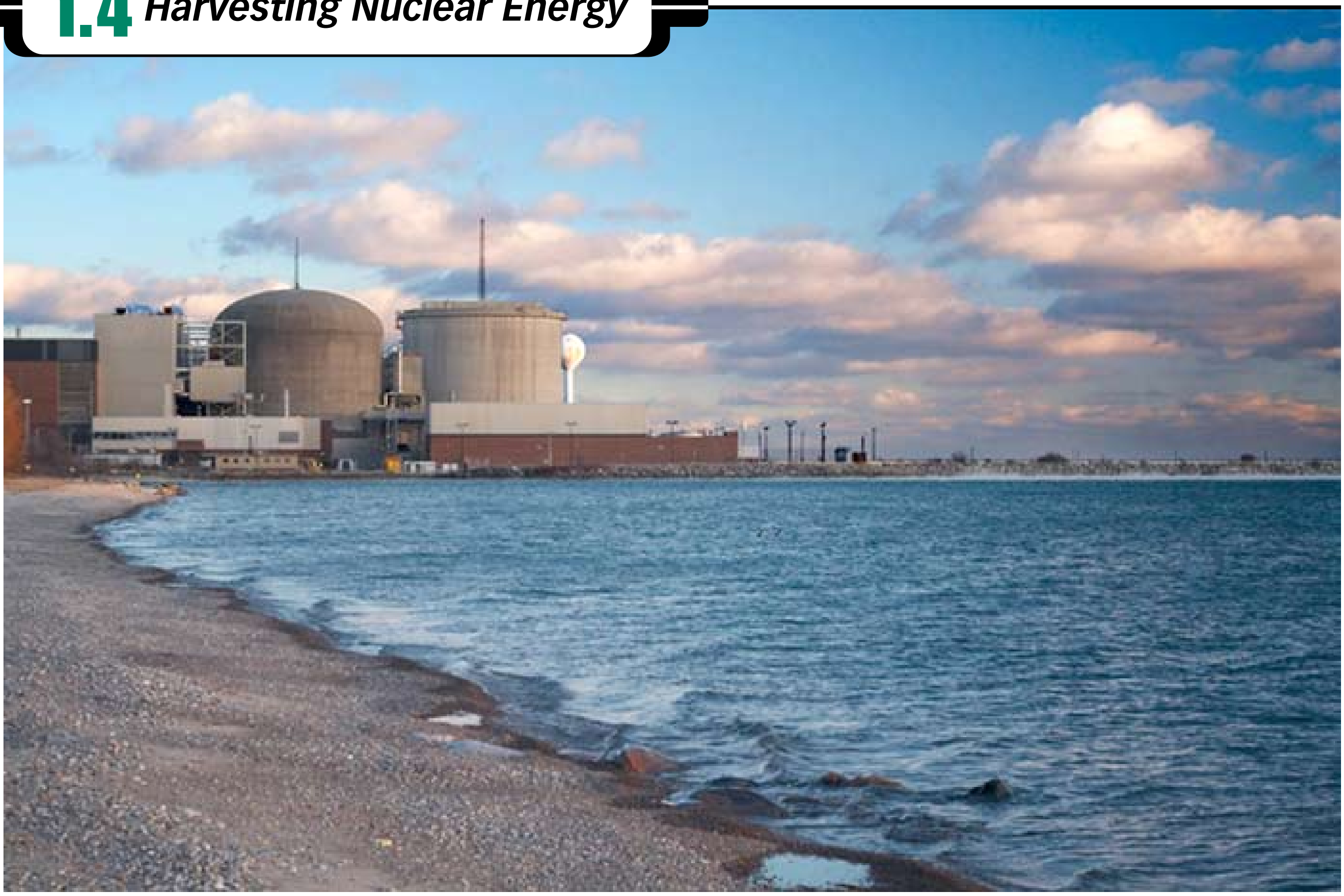


Figure D1.30: Pickering, Ontario, is home to one of the world's largest nuclear power facilities.

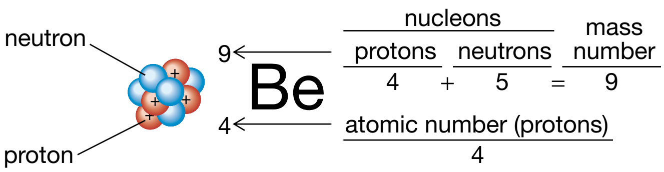
On the shore of Lake Ontario, just east of Toronto, Pickering Nuclear Power Stations A and B produce enough electricity to power a city of about 2 million people. Each domed building, of which there are eight, contains a **CANDU** nuclear reactor. Each building has thick concrete walls to contain the gamma radiation emitted during the nuclear reaction that provides the energy to generate electricity. The cylindrical building with the flat roof in Figure D1.30 is part of the plant's safety system. It contains low-pressure air that can capture any radioactive gases that might escape from the reactors.

How, exactly, does the energy produced by nuclear reactions generate electrical energy? Is the nuclear reaction that takes place within the reactor buildings the same as the nuclear reactions that occur within the Sun's core? In addition to gamma radiation, are any other types of radiation produced? How does the process of generating electricity from nuclear reactions compare to the processes that occur in a coal-fired power plant? In this lesson you will have an opportunity to answer these questions as you incorporate what you have already learned about energy transformations and electricity production with information about nuclear reactions.

CANDU: Canadian Deuterium Uranium Reactor; a nuclear reactor technology developed in Canada and now operating in Canada and six other countries

Describing the Nucleus

Every atom has a nucleus composed of **protons** and **neutrons**. The number of protons determines an element's identity. The number of protons is called the **atomic number**. For example, all beryllium atoms have 4 protons. Although all atoms of the same element must have the same number of protons, they can vary in mass due to differences in the number of neutrons they possess. For example, the most common type of beryllium is called beryllium-9. Since the nucleus of beryllium-9 has 4 protons and 5 neutrons, it has a **mass number** of 9. Since protons and neutron make up the nucleus, they are often referred to as **nucleons**; therefore, the beryllium-9 nucleus has a total of 9 nucleons. The nucleus of beryllium-9 can be concisely described using **nuclear notation** as follows.



Other forms of the beryllium atom, like beryllium-10, have a different number of nucleons (mass number) but the same atomic number. Beryllium-9 and beryllium-10 are **isotopes**. As you learn more about nuclear reactions, it will be important to differentiate between the isotopes of various elements.

DID YOU KNOW?

Beryllium-10 is formed in the upper atmosphere when cosmic rays collide with oxygen or nitrogen atoms.

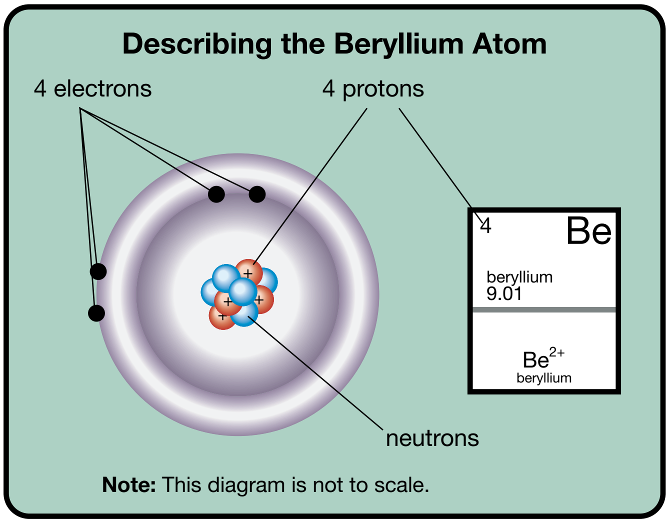


Figure D1.31: A beryllium atom is made up of protons, neutrons, and electrons. Here is one such representation.

- **proton:** a component of an atomic nucleus with a mass of 1 atomic mass unit and a charge of 1+
- **neutron:** a component of an atomic nucleus with a mass of 1 atomic mass unit and no net charge
- **atomic number:** the number of protons in the nucleus of an atom; determines the identity of an element
- **mass number:** the total number of protons and neutrons in an atom; frequently written after the name of an element to identify a specific isotope
- **nucleon:** the name applied to protons and neutrons (the parts of an atom's nucleus)
- **nuclear notation:** representation of an atom, ${}^{A}_{Z}X$, that lists the chemical symbol for the element (*X*), its atomic number (*Z*), and its mass number (*A*)
- **isotope:** a particular variety of an element as defined by its atomic mass

Practice

26. Complete the following table.

Isotope	Atomic Number	Mass Number	Number of . . .		
			Protons	Neutrons	Nucleons
hydrogen-2 (deuterium)					
carbon-13					

27. The masses of a proton, neutron, and an electron are as follows:

- proton: $1.007\ 28 \times 10^{-3}$ kg/mol
- neutron: $1.008\ 66 \times 10^{-3}$ kg/mol
- electron: 5.49×10^{-7} kg/mol

a. How many times larger are protons than electrons?

b. It is customary to delete the mass of electrons when calculating the atomic mass. Use your answers to question 27.a. to justify this practice.

28. Using nuclear notation, express the following isotopes.

a. uranium-235 **b.** uranium-238 **c.** polonium-210 **d.** polonium-218

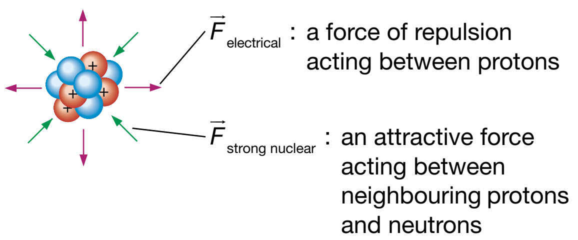
Science Links

In Units B and C you learned that Earth's atmosphere and magnetic field provide a significant degree of shielding to protect organisms from the harmful effects of ionizing radiation from space. Some of this radiation is in the form of electromagnetic radiation: X-rays and gamma rays. Other forms of radiation consist of streams of fast-moving particles: electrons, protons, and helium nuclei.

Alpha Radiation

If a nucleus is comprised of protons and neutrons, a good question to ask is what keeps it together? After all, shouldn't the positive charge of such tightly packed protons repel one another? Recall from Unit C that the force between two charges increases exponentially in response to a reduction in their distance. Therefore, to keep a nucleus together, the forces at work within it must be greater than the force of repulsion between protons.

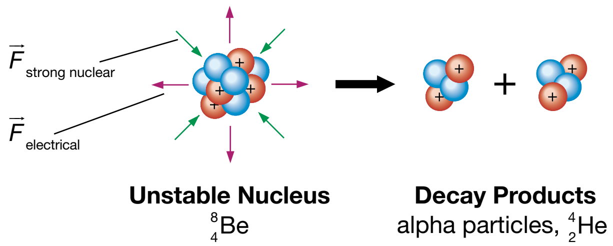
A Stable Nucleus—Balanced Forces in $^{9}_{4}Be$



A **strong nuclear force** is a force that attracts protons to neutrons, neutrons to neutrons, and even protons to protons. Although this force attracts all these particles to one another, it only acts between particles that are close enough to touch each other. The electrical force generated by repelling particles acts over any distance. Larger nuclei—those containing more protons—require neutrons to "dilute" the repulsive forces within the nucleus. In addition to spreading out the repulsive electrical force, neutrons increase the strong nuclear force by acting like glue to hold nucleons together. The **radioactive decay** demonstrated by unstable isotopes demonstrates the role of neutrons in balancing the forces within the nucleus.

Beryllium-8 is an unstable isotope when compared to beryllium-9. The difference of one neutron reduces the strong nuclear force relative to the force caused by the repulsion between protons. The instability caused by the imbalance between forces within the nucleus causes the beryllium-8 atom to break apart into two **alpha particles**. Alpha particles are nuclei composed of two protons and two neutrons, having a net charge of 2+. The alpha particles have the same composition as the nucleus of a helium atom and are often written as $^{4}_{2}He$. The release of alpha particles during nuclear decay is called **alpha radiation**. For beryllium-8, its radioactive decay is unusual in that both products happen to be alpha particles. In most situations, only one product of the decay is an alpha particle.

An Unstable Nucleus—Unbalanced Forces in $^{8}_{4}Be$



- **strong nuclear force:** an attractive force between nuclear particles that acts over short distances
- **radioactive decay:** a spontaneous change in which an unstable nucleus emits radiation
- **alpha particle:** a positively charged particle consisting of two neutrons and two protons, which is a helium nucleus
- **alpha radiation:** a stream of alpha particles emitted from unstable nuclei; one of the three principal types of nuclear radiation

The process of radioactive decay can be represented using a nuclear equation. When balancing a nuclear equation, the number of nucleons is conserved. Example Problem 1.3 shows how to balance a nuclear equation.

Example Problem 1.3

Many smoke detectors contain the isotope americium-241. Alpha particles emitted during the decay of americium-241 ionize molecules in the air, allowing an electric current to flow between two plates in the smoke detector. During a fire, smoke particles that come between these two plates interfere with the current, setting off the detector's alarm.

a. State the name of the process that produces an alpha particle.

b. Write a balanced nuclear equation describing the decay of americium-241 that results in an alpha particle and another product.

Solution

a. The process that releases an alpha particle is called alpha radiation.

b. Write the nuclear equation. Let ${}^{A}_{Z}X$ represent the unknown product.

Reactant **Products**

$$\underset{\text{ }}{{}^{241}_{95}\text{Am}} \rightarrow \underset{\substack{\text{alpha}\\\text{particle}}}{{}^{4}_{2}\text{He}} + \underset{\substack{\text{unknown}\\\text{product}}}{{}^{A}_{Z}X}$$

step 1: In a table, list the mass numbers (total nucleons) and the atomic numbers of the reactant side and the products side of the nuclear equation.

	Reactant	Products
Mass Number	241	$4 + A$
Atomic Number	95	$2 + Z$

step 2: Determine the mass number and the atomic number of the unknown product. **Note:** The reactant side and the products side must have the same total.

$$241 = 4 + A \qquad 95 = 2 + Z$$
$$A = 237 \qquad Z = 93$$

The mass number and atomic number of the other product are 237 and 93, respectively.

step 3: Identify the other product, and write its nuclear notation.

atomic number 93 = neptunium, Np

Therefore, ${}^{A}_{Z}X = {}^{237}_{93}\text{Np}$.

step 4: Write the balanced nuclear equation.

$${}^{241}_{95}\text{Am} \rightarrow {}^{4}_{2}\text{He} + {}^{237}_{93}\text{Np}$$

Practice

29. Write the balanced nuclear equation showing the alpha decay for each isotope given.

- **a.** beryllium-8
- **b.** uranium-232
- **c.** polonium-210

30. Each of the following atoms is a product of an alpha-decay reaction. Write a balanced nuclear equation for each.

- **a.** uranium-235
- **b.** plutonium-236

31. Radium-226 is an unstable isotope that decays to radon-222.

- **a.** Write the balanced nuclear equation for this process.
- **b.** Identify the type of radiation produced by the decay of radium-226.

Beta Radiation

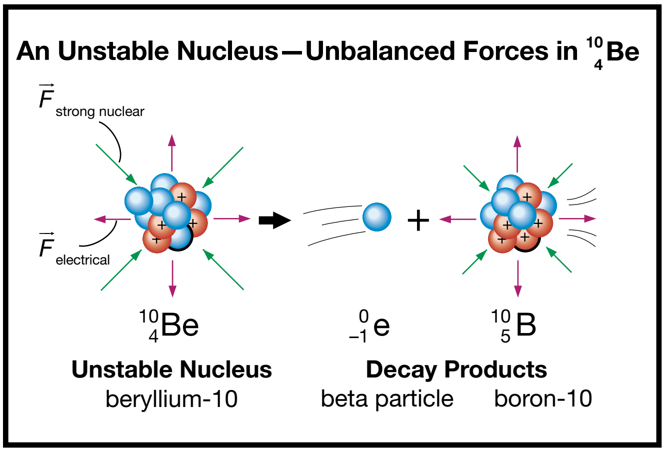


Figure D1.32

You have seen that an imbalance between the strong nuclear force and the electrical force within a nucleus results in an unstable nucleus. The instability within the nucleus of beryllium-10 leads to the emission of a **beta particle**—an electron. A beta particle is represented by the symbol $^{0}_{-1}e$.

A stream of negatively charged beta particles is called **beta radiation**. Even though a beta particle is an electron, the term *beta particle* is used to indicate that each particle originates from the nucleus and not from the orbiting electrons that participate in chemical bonding.

beta particle: a high-speed electron emitted from an unstable nucleus; the result of the change of a neutron to a proton during a nuclear reaction

beta radiation: a stream of beta particles emitted from unstable nuclei; one of three principle types of nuclear radiation

Reactant **Products**

$$\underset{\text{neutron}}{^{1}_{0}n} \rightarrow \underset{\text{beta particle}}{^{0}_{-1}e} + \underset{\text{proton}}{^{1}_{1}p}$$

	Reactant	Products
Mass Number	1	0 + 1
Atomic Number	0	−1 + 1
Note: The reactant and products sides of the equation balance.		

Beta particles are ejected from the nucleus when a neutron is converted into a proton. During **beta decay**, the number of nucleons comprising a nucleus does not change, but the atomic number does. The 1– charge of a beta particle is balanced by the conversion of a neutron into a proton, as demonstrated in the nuclear equation for the decay of beryllium-10 (Figure D1.32).

beta decay: a spontaneous change in which an unstable nucleus emits beta radiation

Beryllium-10 Decay

$$^{10}_{4}Be \rightarrow {}^{0}_{-1}e + {}^{10}_{5}B$$

	Reactant	Products
Mass Number	10	0 + 10
Atomic Number	4	−1 + 5
Note: The reactant and products sides of the equation balance.		

Since beta decay causes the conversion of one neutron into a proton, beryllium-10 nuclei are converted into boron-10 nuclei. The boron nucleus has one more proton (5) than the beryllium nucleus (4).

Example Problem 1.4

Carbon-14 is a radioactive isotope that emits beta radiation. Carbon-14 is found in the atmosphere and eventually finds its way into living systems. Once a plant or animal dies, the amount of carbon-14 remaining in the tissue can be used to estimate the number of years that have passed since the organism's time of death. This is done by using the half-life of carbon-14. To get a clearer picture of human history, archaeologists use carbon-14 dating to estimate the age of ancient remains, like teeth or bone fragments.

Use this information to write a balanced nuclear equation for the beta decay of carbon-14.

Solution

step 1: List the reactant and the products.

reactant: ${}^{14}_{6}\mathrm{C}$

products: ${}^{0}_{-1}\mathrm{e}$ and ${}^{A}_{Z}X$

step 2: In a table, list the mass numbers (total nucleons) and the atomic numbers of the reactant and the products.

	Reactant	Products
Mass Number	14	$0 + A$
Atomic Number	6	$-1 + Z$

step 3: Determine the mass number and the atomic number of the other product.

$14 = 0 + a \qquad 6 = -1 + Z$

$A = 14 \qquad z = 7$

The mass number and atomic number of the unknown product are 14 and 7, respectively.

step 4: Identify the unknown product, and write its nuclear notation.

atomic number 7 = nitrogen, N

Therefore, ${}^{A}_{Z}X = {}^{14}_{7}\mathrm{N}$.

step 5: Write the balanced nuclear equation.

$${}^{14}_{6}\mathrm{C} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{14}_{7}\mathrm{N}$$

Practice

32. Each isotope listed undergoes beta decay. Write a balanced nuclear equation showing the change that occurs.

a. krypton-87

b. silicon-32

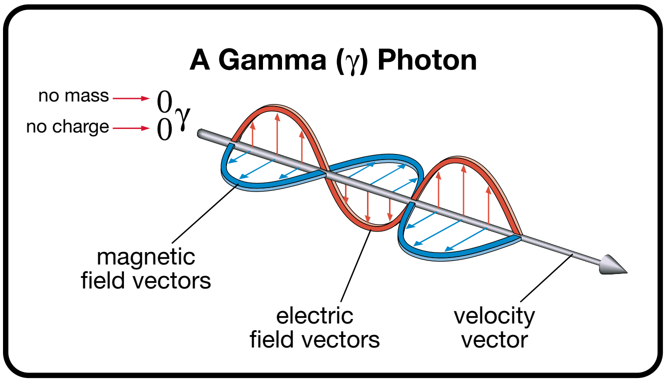
33. Each isotope listed is a product of beta decay. Use a balanced nuclear equation to determine the identity of the isotope that underwent nuclear change.

a. gallium-71

b. nickel-60

Gamma Radiation

Unlike alpha and beta radiation, gamma radiation is not comprised of a stream of charged particles. As you learned in Unit C, gamma radiation consists of a stream of gamma photons—the most energetic form of electromagnetic radiation.



Because a photon is a bundle of electromagnetic energy—consisting of electric and magnetic fields—photons have no mass or charge. The symbol for a gamma photon, $^{0}_{0}\gamma$, concisely communicates this information.

Gamma radiation is usually emitted as an additional product of alpha or beta decay, but it can be emitted on its own. In Unit C, when you were comparing forms of electromagnetic radiation, you discovered that gamma rays have even more energy than X-rays. As a result, gamma rays are very damaging when they are absorbed by biological molecules. This is why gamma radiation is frequently used in cancer therapy to kill cancerous cells.

Example Problem 1.5

Cobalt-60 is a source of gamma radiation that is frequently used to treat patients with cancer. Machines used in modern cancer therapy, like the one in the photograph, can focus narrow beams of gamma radiation from over 200 cobalt-60 sources to destroy cancer cells deep within the patient.

Write a balanced nuclear equation to describe the emission of beta and gamma radiation from a cobalt-60 source.

Solution

$^{60}_{27}\text{Co} \rightarrow {}^{0}_{0}\gamma + {}^{0}_{-1}\text{e} + {}^{A}_{Z}X$

	Reactant	Products
Mass Number	60	0 + 0 + a
Atomic Number	27	0 + −1 + *z*

Determine the mass number and the atomic number of the unknown product.

$$60 = 0 + 0 + A \qquad 27 = 0 + -1 + Z$$
$$A = 60 \qquad Z = 28$$

The product with an atomic number of 28 is nickel. Therefore, $^{A}_{Z}X = {}^{60}_{28}\text{Ni}$.

Thus, the balanced nuclear equation is

$^{60}_{27}\text{Co} \rightarrow {}^{0}_{0}\gamma + {}^{0}_{-1}\text{e} + {}^{60}_{28}\text{Ni}$.

Shielding Nuclear Radiation

Radioactive materials are used in a number of specialized medical procedures. These materials are transported and stored in shielded containers that absorb the emitted particles or photons and ensure that radiation does not pass into the environment. Would the shielding requirements be different if the radioactive isotope in the vial were a source of alpha radiation or beta radiation? Why is shielding so important when working with these materials?

In Units B and C you discovered that high-energy radiation is capable of ionizing the material through which it passes, leading to the formation of free radicals. Ionizing radiation is harmful to living tissue—particularly to DNA, which is especially vulnerable to the damage caused by free radicals. This is why it is important to ensure that exposure to ionizing radiation is kept ALARA (as low as reasonably achievable).

Figure D1.33: Radioactive materials are stored and transported in specially shielded containers.

Alpha, beta, and gamma radiation are all classified as ionizing radiation because they are each capable of ionizing the material they penetrate. As you have seen in this lesson, each of these types of nuclear radiation has remarkably different properties. As a result, the type of material that is an effective shield for one type of radiation may not necessarily be effective for another. So, different types of shielding materials can be used for transporting isotopes or in the design of a nuclear reactor.

The effectiveness of a shielding material can be determined by placing it between a source of a particular radiation and a device that can detect the radiation, like a **Geiger counter**. The output of a Geiger counter displays the number of charged particles and/or photons that have entered the device. In the next activity you will have an opportunity to use an animated version of this kind of set-up.

Geiger counter: a device that detects and measures the intensity of ionizing radiation

Figure D1.34: A Geiger counter

Practice

34. Antimony-126, a beta particle, and a gamma photon are the three products of a nuclear reaction. Identify the isotope that undergoes a nuclear reaction to form these products.

35. Polonium-218 emits an alpha particle and a gamma photon. Identify the other product of the decay of polonium-218.

DID YOU KNOW?

Damage to DNA can come from hydroxyl radicals formed when water absorbs ionizing radiation. Hydroxyl radicals can react with the deoxyribose sugar within the DNA strand, causing mutation or significant damage to cause the death of the cell.

Utilizing Technology

Shielding Radiation

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will use the applet "The Alpha, Beta, and Gamma of Radiation" from the Science 30 Textbook CD to determine which types of materials are capable of shielding alpha, beta, and gamma radiation.

Background

Before starting, familiarize yourself with the features of the applet. Select an isotope, select different barriers (shielding materials), and adjust the position of the Geiger counter. In the first part of the procedure, you will measure the radiation emitted by natural sources, often referred to as background radiation. You will then complete measurements of the radiation emitted from different isotopes as it travels through air and through other barriers.

Procedure

Obtain the "Shielding Radiation" handout from the Science 30 Textbook CD.

step 1: Set the Geiger counter 10 mm to the right of the shielding material.

step 2: Measure the background radiation. To do this, select "No isotope" for the isotope and "Air" for the barrier; then click on "Start Count." **Note:** The applet is set to collect data over five seconds.

step 3: Record the total radiation count from the Geiger counter in the appropriate place on the handout. Repeat this step two more times.

step 4: Repeat steps 2 and 3 with uranium-238, strontium-90, and cobalt-60 as the isotope. Record your results in the appropriate places.

step 5: Repeat steps 1 to 3 using paper, aluminium, and lead as the barrier. Record your results in the appropriate place.

1. Complete the data tables in the handout.

Analysis

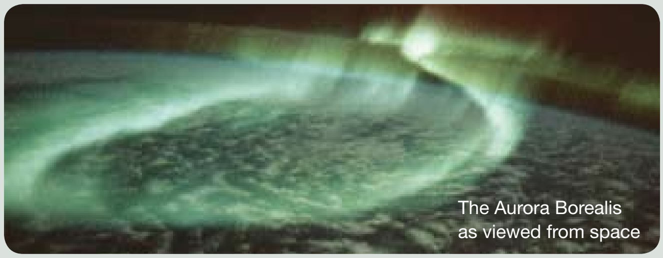
2. Rank the barriers tested from greatest to least shielding ability for each type of radiation.
3. Use the applet to collect data that allows you to write a balanced nuclear equation describing the decay reaction for each isotope. Explain how you used the data from the applet to write these equations.

Shielding with Solid Materials

The results from the “Shielding Radiation” activity demonstrate that the type of radiation emitted by a source must be considered before you can select an appropriate shielding material. Shielding involves using a material that absorbs the radiation emitted by an isotope. The size of the alpha particle makes it one of the easiest forms of radiation to absorb by sheilding, whereas the considerably smaller beta particle has the ability to penetrate denser substances, like those that were tested. Gamma sources are the most difficult to shield. They require thick walls of lead or, in the case of CANDU nuclear reactors, several metres of concrete. As you can see, shielding is an important technique in the safe use of radiation for many technologies.

Science Links

Shielding protects life on Earth from the harmful effects of ionizing radiation from space. You discovered in Unit C that Earth’s protective shield consists of two parts: Earth’s magnetic field and the molecules, like ozone, that make up Earth’s atmosphere.

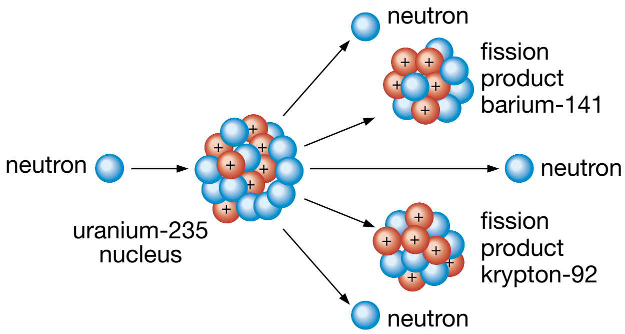


The Aurora Borealis as viewed from space

Nuclear Fission

Earlier you learned that radioactive decay involves atoms spontaneously changing from one element into another, and that a nuclear change is accompanied by a release of energy in the form of radiation. Radiation emitted during alpha and beta decay can possess sufficient energy to harm living tissue, but not enough energy to be used for large-scale energy production. Currently, the only application for the energy released by these processes is providing electricity and heat for deep-space probes. Using nuclear energy for the large-scale generation of electricity requires a different process.

Nuclear Fission of Uranium-235



$$^{235}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba}$$

	Reactants	Products
Mass Number	235 + 1 = 236	3 + 92 + 141 = 236
Atomic Number	92 + 0 = 92	0 + 36 + 56 = 92

Figure D1.35

The nuclear reaction used to release energy in CANDU reactors, like those at Pickering Nuclear Power Stations A and B, is **nuclear fission**. Nuclear fission involves splitting atoms. It was used in the first atomic bombs and is still used today to generate electricity for millions of homes, businesses, and industries in Canada and throughout the world. A fission reaction occurs when a large nucleus, such as uranium-235, is struck by a neutron and breaks into two smaller nuclei, called fission products. As shown in Figure D1.35, the fission of uranium-235 also yields three neutrons and high-energy gamma radiation which is not shown. View the “Nuclear Fission” applet, from the Science 30 Textbook CD, to see an animation of a fission reaction.

nuclear fission: a nuclear reaction in which a large nucleus splits into smaller nuclei or particles with the simultaneous release of energy

The kinetic energies of the neutrons and fission products add up to a lot of energy—much more than is released by a chemical reaction. In a nuclear reactor, this energy is transferred as heat to water surrounding the nuclear fuel.

Practice

36. The fission of uranium-235 can produce many different products. The following equations show one product of the fission of uranium-235. Use a balanced nuclear reaction to determine the unknown product, ${}^{A}_{Z}X$, in each reaction.

a. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{A}_{Z}X + {}^{137}_{53}I$

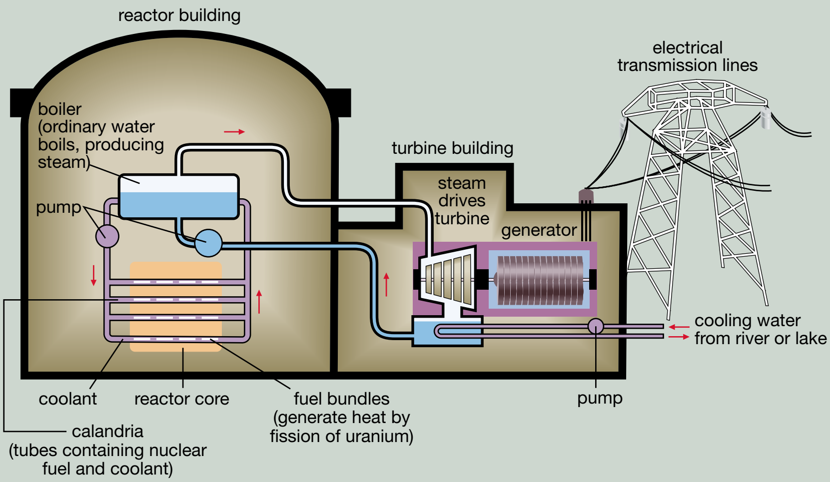
b. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{A}_{Z}X + {}^{90}_{35}Br$

DID YOU KNOW?

A small mass of uranium yields a lot of energy. For example, the fuel used for an entire year of operations at Pickering could fit into a double-car garage. In comparison, Alberta's newest coal-fired power plant, Genesee 3, produces about one-ninth of the energy using 1.9 million tonnes of coal per year. This is roughly equivalent to a pile of coal that covers a football field and has a height of a 45-storey building.

Electricity from Nuclear Fission—CANDU

Products of a fission reaction have large quantities of kinetic energy. If this energy can cause water to boil and become high-pressure steam, it can spin turbines, which can spin generators, which can generate electricity. Sound familiar? It should. This is very similar to the design of a conventional coal-fired power plant. A nuclear power plant enables the release of **intranuclear potential energy**, allowing it to be transformed into useful electricity. Nuclear power plants are similar to fossil fuel power plants in that they are both thermal sources of electricity. The best way to get an overview of how all this works is to take a quick tour of a generating station powered by a CANDU reactor.



intranuclear potential energy: energy stored within the nucleus of atoms

Figure D1.36: Cross section of a CANDU power plant

Utilizing Technology

Reactor Operation

Science Skills
✓ Performing and Recording

Reactor Operation

Watch the video "Reactor Operation" from the Science 30 Textbook CD. Use the information from the video to answer the Analysis questions.

Analysis

1. Prepare a table with three columns, and use the following headings: Similar Components, Similar Processes, and Unique Processes. In the first column, list the similar components found in coal-fired and nuclear power plants. In the second column, list the similar processes used in coal-fired and nuclear power plants. In the third column, list the processes that are unique to nuclear power plants.
2. Identify two functions of heavy water in a CANDU nuclear reactor.
3. Explain "Defence in Depth."
4. Justify the practices used to train nuclear-plant operators, including a careful selection of experienced individuals and participation in intensive training programs.

Practice

37. Refer to the cross section of a CANDU nuclear power plant (Figure D1.36) and to the cross section of a coal-fired power plant (Figure D1.29 on page 500). Compare these two methods of producing electricity by considering the following:

- energy source
- form of energy in energy source
- reaction used to release energy from the energy source
- list of energy transformations for water during the process
- method of converting kinetic energy into electrical energy

Controlling the Fission Reaction

Controlling the release of energy from the energy source is an important aspect of plant operation and design. In a coal-fired generating station, the release of energy can be controlled by adjusting the amount of pulverized coal that is fed into the furnace.

The energy released by a CANDU reactor is determined by the mass of uranium-235 that undergoes fission. As shown in Figure D1.35 on page 510, the fission of uranium-235 requires a supply of neutrons. Uranium-235 used in the CANDU process is in the form of uranium dioxide pellets assembled into cylindrical fuel bundles. Within the reactor, sections of the fuel bundles are exposed, allowing them to undergo fission. How does exposing a section of a fuel rod allow for the control of a fission reaction? Recall that the key to a fission reaction is neutrons. Controlling the neutrons that strike the U-235 regulates the mass of isotope that reacts and, therefore, the quantity of energy released by the reactor.

One means of controlling neutrons within the reactor involves the use of **heavy water**. The higher density of heavy water acts to slow neutrons to a speed that is ideal for colliding with U-235 nuclei, initiating its fission. Heavy water is often referred to as a **moderator** when used to control the speed of neutrons in a nuclear reactor.

Figure D1.37: Fuel bundles are used to generate electricity in CANDU reactors.

heavy water: water composed of two atoms of the heavier isotopes of hydrogen and one atom of oxygen

moderator: a substance of low molecular mass capable of reducing the speed of neutrons during the operation of a nuclear reactor

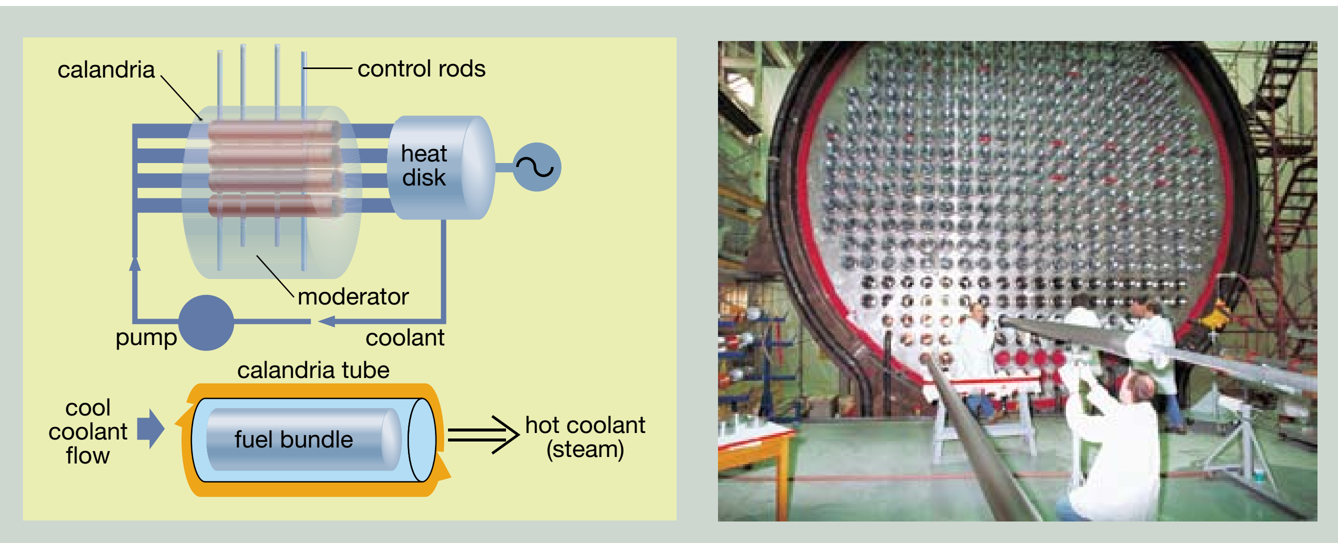


Figure D1.38: The core of a nuclear reactor is a calandria, composed of many long tubes in which the fuel rods are placed. The tubes containing the fuel rods are each surrounded by larger tubes containing coolant (heavy water). Thermal energy from the fission reaction in the fuel is transferred to the heavy water, converting the water into steam.

A second method of controlling neutrons and the energy output of the reactor is the use of control rods. Lowering the control rods further into the core of the reactor allows for greater absorption of neutrons, thereby decreasing the number of fission reactions that occur and reducing the energy output of the reactor.

The emergency-shutdown systems of a CANDU reactor are also based on controlling the neutrons that initiate fission reactions. The first emergency-shutdown system involves quickly inserting neutron-absorbing control rods into the reactor to immediately stop the reaction. The second involves the injection of neutron-absorbing liquid into the moderator.

You may have noticed that all of the safety and control mechanisms mentioned for a CANDU reactor involve mechanisms to control neutrons. Previously, you discovered that the fission reaction of uranium-235 is initiated by a collision with a neutron. This collision then releases three neutrons as products. The proper control of neutrons produced by each fission reaction prevents an uncontrolled **chain reaction,** whereby an exponential increase in the number of fission reactions that occur results in an exponential release in energy.

A rapid energy release could occur due to poor control of fission reactions in the reactor or to poor control of the transfer of energy from the reactor. This could result in extensive damage, often called **nuclear meltdown**.

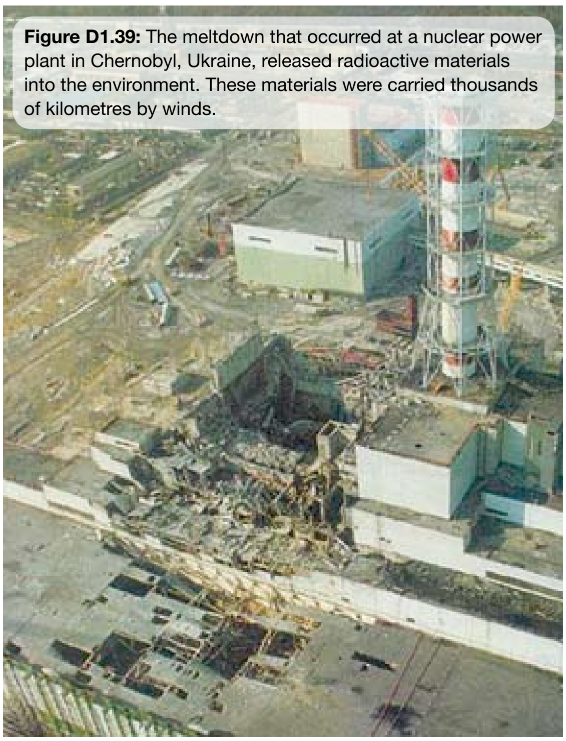
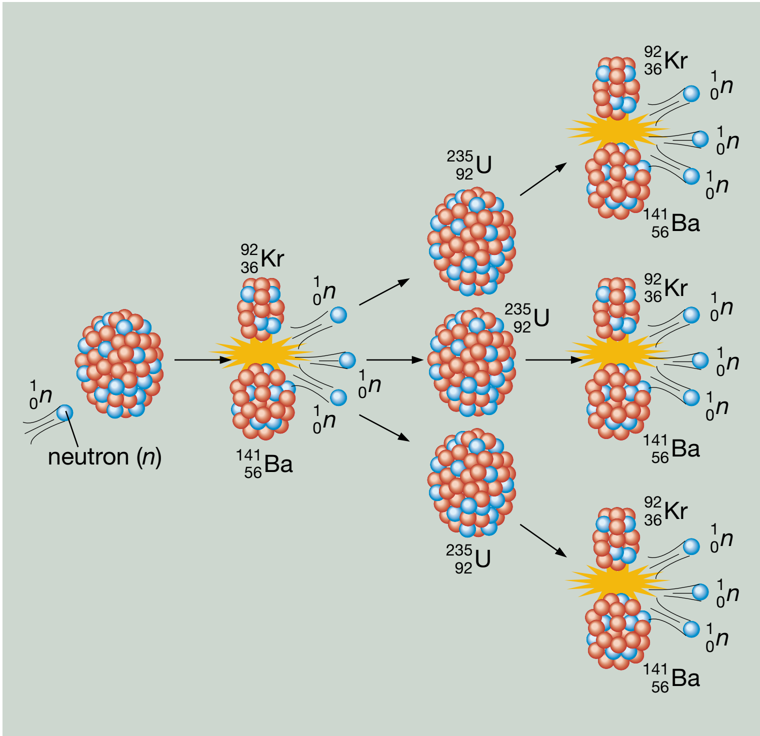


Figure D1.39: The meltdown that occurred at a nuclear power plant in Chernobyl, Ukraine, released radioactive materials into the environment. These materials were carried thousands of kilometres by winds.

DID YOU KNOW?

Cobalt-60 is an isotope created when cobalt-59 is used within adjuster rods of some CANDU reactors. Cobalt-60 undergoes beta decay and releases gamma radiation, making it useful for cancer radiotherapy and for sterilizing medical instruments.



chain reaction: a nuclear reaction that perpetuates itself; the release of neutrons during nuclear fission that initiates the fission of other atoms

nuclear meltdown: the result of improper control of a nuclear reaction within a reactor; the increase in the temperature of the core of a nuclear reactor, resulting in damage and increasing the risk of releasing radioactive substances into the environment

Reactor meltdowns, like the one that occurred on April 25, 1986, in Chernobyl, Ukraine, can result in the release of radioactive materials into the environment. Although the CANDU reactor is designed in such a way that a meltdown is extremely unlikely, the Chernobyl incident was such a frightening event that many people are still nervous about embracing nuclear power.

DID YOU KNOW?

Since 1991, children from the Ukraine and Belarus who were born with low-functioning immune systems—believed to be the result of the incident in Chernobyl—have been coming to Canada for a break from the exposure of radiation in their environment. These visits have allowed the children to strengthen their immune systems and, thus, increase their ability to fight simple infections like colds.

Mass-Energy Equivalence—$E = mc^2$

A pellet of uranium used in nuclear power plants has a mass of about 7 g; but it can release the same quantity of energy as 3.5 barrels (556.5 L) of oil, 480 000 L of natural gas, or 807 kg of coal. How can such a small pellet of uranium be an enormous source of energy?

The answer can be traced back to the work of Albert Einstein, who in the early 1900s published articles describing a theory of general relativity (pertaining to gravity) and a special theory of relativity (describing the motion of particles approaching the speed of light). One of the predictions of the special theory was that mass could be converted into energy and energy could be converted into mass. In other words, mass and energy are interchangeable. Previously you have always balanced reactions with respect to the law of conservation of mass, focusing on either the number of nucleons or the number of moles of each type of atom involved. Einstein's theory redefined people's understanding of the nature of matter and energy.

In Einstein's theory, mass is not just the sum of its constituent parts; it is also the sum of the kinetic, potential, and mass energy. Energy is now considered to be the only commodity in the universe that cannot be created or destroyed. Any difference between the masses of the products and the reactants of a process must be the result of mass having been converted into energy. Einstein was able to describe the relationship between the change in mass and its conversion to energy by using his famous equation, $E = mc^2$.

It is more descriptive to express Einstein's equation as $\Delta E = \Delta mc^2$, where

ΔE = change in energy

Δm = change in mass
= mass of products − mass of reactants

c = speed of light $\left(3.00 \times 10^8 \text{ m/s}\right)$

Because the square of the speed of light is an enormous number, a small change in mass corresponds to a very large energy change. You can see how this equation is used in Example Problem 1.6.

Example Problem 1.6

In the fission of 1 mol of beryllium-8, the mass of the products is determined to be 2.29×10^{-5} kg less than the mass of the reactants. Calculate the change in energy that corresponds with this change in mass. Identify whether this reaction is exothermic or endothermic.

Solution

$\Delta m = 2.29 \times 10^{-5}$ kg

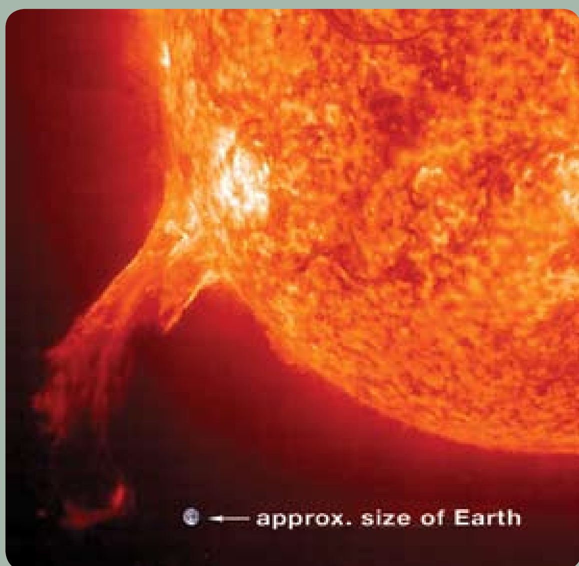
$c = 3.00 \times 10^{8}$ m/s

$\Delta E = ?$

$$\begin{aligned}\Delta E &= \Delta mc^2\\ &= \left(2.29 \times 10^{-5} \text{ kg}\right)\left(3.00 \times 10^{8} \text{ m/s}\right)^2\\ &= 2.06 \times 10^{12} \text{ kg}\bullet\text{m}^2/\text{s}^2\\ &= 2.06 \times 10^{12} \text{ J}\end{aligned}$$

The energy change for 1 mol of beryllium-8 is 2.06×10^{12} J. Since the mass of the products is **less** than the mass of the reactants, the missing mass must have converted into energy. Therefore, the reaction is exothermic.

Science Links: Fuel for the Sun



The radiation that the Sun pours into space originates from nuclear reactions deep within its core. Every second, approximately 3.8×10^{26} J of energy is emitted from the Sun's surface. Using the equation $E = mc^2$, this means that the Sun must be converting about 4.2×10^{9} kg of mass into energy every second. Although this seems like a very large value, this loss of mass is actually quite small compared to the total mass of the Sun, which is about 2×10^{30} kg.

The electromagnetic radiation emitted from stars can be analyzed by astronomers to provide valuable information about the composition and temperature of these distant suns. This work is described in Unit C.

Example Problem 1.7

Earlier, you learned that beta decay involves the conversion of a neutron into a proton and a beta particle: ${}^{1}_{0}n \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{1}_{1}p$. Use the "Masses of Subatomic Particles and Radiation" table from the Science Data Booklet to calculate the change in mass between the products and the reactants. Identify whether this reaction is exothermic or endothermic.

Solution

$${}^{1}_{0}n \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{1}_{1}p$$

Determine the mass of the reactant and the mass of the products.

$$m_{\text{reactant}} = 1.008\ 66 \times 10^{-3}\ \text{kg}$$

$$\begin{aligned} m_{\text{products}} &= m_{\text{beta}} + m_{\text{proton}} \\ &= \left(1\ \cancel{\text{mol}}\right)\left(0.000\ 549 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(1.007\ 28 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 1.007\ 829 \times 10^{-3}\ \text{kg} \end{aligned}$$

Determine the change in mass.

$$\begin{aligned} \Delta m &= m_{\text{reactant}} - m_{\text{products}} \\ &= 1.008\ 66 \times 10^{-3}\ \text{kg} - 1.007\ 829 \times 10^{-3}\ \text{kg} \\ &= 0.000\ 831 \times 10^{-3}\ \text{kg} \\ &= 8.31 \times 10^{-7}\ \text{kg} \end{aligned}$$

The change in mass is 8.31×10^{-7} kg when 1 mol of neutrons is converted. Since the mass of the products is less than the mass of the reactant, this reaction is exothermic.

Example Problem 1.8

The fission of uranium-235 that occurs in a CANDU reactor involves the following reaction.

$${}^{235}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow 3\ {}^{1}_{0}n + {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr}$$

Calculate the change in mass between the reactants and the products for this reaction and the corresponding energy change.

Solution

$${}^{235}_{92}\mathrm{U} + {}^{1}_{0}n \rightarrow 3\ {}^{1}_{0}n + {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba}$$

Determine the mass of the reactants.

$$\begin{aligned} m_{\text{reactants}} &= m_{\text{U}} + m_{n} \\ &= \left(1\ \cancel{\text{mol}}\right)\left(235.043\ 92 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(1.008\ 66 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 236.052\ 58 \times 10^{-3}\ \text{kg} \end{aligned}$$

Determine the mass of the products. Recall that three neutrons are produced during each fission reaction.

$$\begin{aligned} m_{\text{products}} &= 3m_{n} + m_{\text{Ba}} + m_{\text{Kr}} \\ &= \left(3\ \cancel{\text{mol}}\right)\left(1.008\ 66 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(91.926\ 11 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &\quad + \left(1\ \cancel{\text{mol}}\right)\left(140.914\ 41 \times 10^{-3}\ \text{kg}/\cancel{\text{mol}}\right) \\ &= 235.866\ 50 \times 10^{-3}\ \text{kg} \end{aligned}$$

Determine the change in mass.

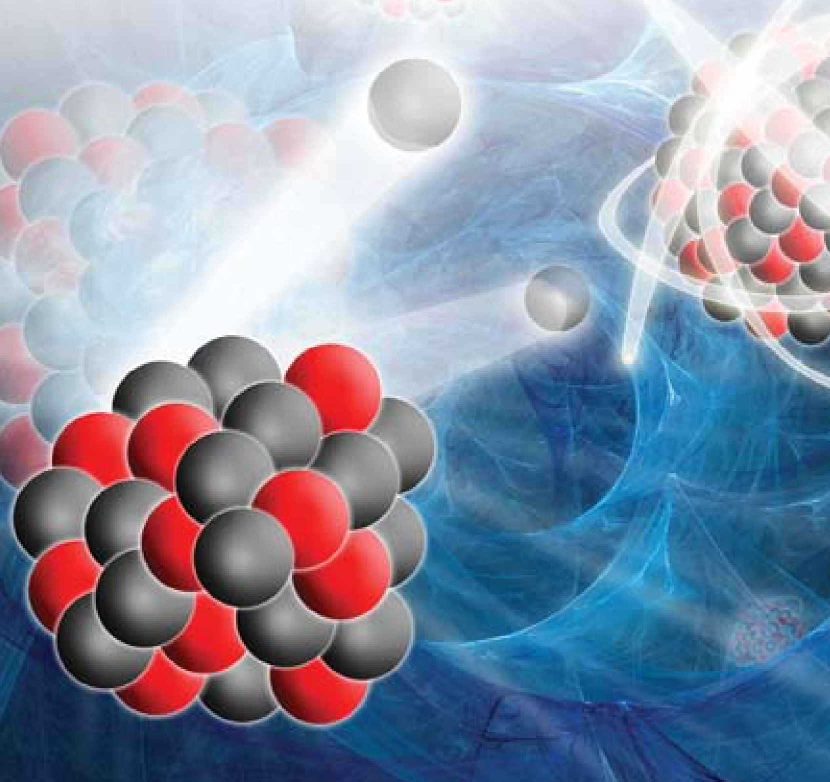
$$\begin{aligned} \Delta m &= m_{\text{reactants}} - m_{\text{products}} \\ &= 236.052\ 58 \times 10^{-3}\ \text{kg} - 235.866\ 50 \times 10^{-3}\ \text{kg} \\ &= 0.186\ 08 \times 10^{-3}\ \text{kg} \\ &= 1.8608 \times 10^{-4}\ \text{kg} \end{aligned}$$

The change in mass is 1.8608×10^{-4} kg.

Now, determine the energy change.

$$\begin{aligned} \Delta E &= \Delta m c^{2} \\ &= \left(1.8608 \times 10^{-4}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)^{2} \\ &= 1.67 \times 10^{13}\ \text{kg}\bullet\text{m}^{2}/\text{s}^{2} \\ &= 1.67 \times 10^{13}\ \text{J} \end{aligned}$$

The energy change for 1 mol of uranium-235 is 1.67×10^{13} J.



Vast Amounts of Energy from a Tiny Fraction of Total Mass

When completing Example Problems 1.7 and 1.8, you calculated the change in mass of a nuclear process using more accurate masses for subatomic particles and nuclides. The mass difference for nuclear reactions is often very small—often a fraction of a gram. Recall that only the unaccounted mass (Δm) is converted into energy. Einstein's theory states that when mass "disappears," it must be converted into some form of energy. In the operation of a nuclear reactor, the energy released during the fission of uranium is converted into heat and, eventually, into electricity.

Practice

38. Calculate the change in mass and corresponding energy change per mole of uranium-235 in the nuclear reactions given. Use masses given in the Science Data Booklet and those provided in the following table.

Nuclide	Mass (10^{-3} kg/mol)
bromine-91, $^{91}_{35}Br$	90.916 27
lanthanum-142, $^{142}_{57}La$	141.899 71
strontium-94, $^{94}_{38}Sr$	93.915 29
xenon-140, $^{140}_{54}Xe$	139.918 43

a. $^{1}_{0}n + ^{235}_{92}U \rightarrow 2\,^{1}_{0}n + ^{94}_{38}Sr + ^{140}_{54}Xe$

b. $^{1}_{0}n + ^{235}_{92}U \rightarrow 3\,^{1}_{0}n + ^{91}_{35}Br + ^{142}_{57}La$

39. Calculate the change in mass that would correspond to a release of 2.0×10^{14} J of energy.

Concerns About Nuclear Waste

You learned in this lesson that the small change in mass that occurs to the uranium-235 within a CANDU reactor can be used to meet the energy demands of huge numbers of people. In 2003, the 17 operating nuclear power plants in Canada produced almost 62 000 spent fuel bundles. For comparison, the space these bundles would occupy is less than the size of two classrooms within a school. You also learned that the spent fuel contains the products of fission reactions, which may emit ionizing radiation for many years. How is spent nuclear fuel dealt with? What concerns do people have about nuclear waste?

In Canada, spent fuel from reactors still contains a small amount of unreacted uranium-235 and is first stored under water in the nuclear power plant. The water in the deep pools absorbs thermal energy released by the fission of the remaining isotope and acts as a shield, preventing the release of radiation. After a few years in the pools, spent fuel bundles are moved into concrete canisters and stored above ground. Currently, there is no long-term storage facility for spent nuclear fuel in Canada. Such a facility, when developed, would have to ensure that the containers of waste remain intact and isolated. Current plans suggest that a long-term storage facility could be developed deep within the granite rock formation of the Canadian Shield. A major concern about the development of a long-term storage facility for nuclear waste is the possibility of accidentally releasing radioactive substances during transport.

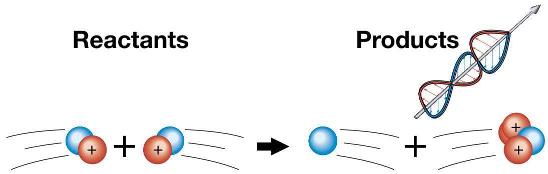
DID YOU KNOW?

Some military submarines operate using uranium fission reactions as a power source. Because of the large quantity of energy contained within nuclear fuels, like uranium, a nuclear submarine can operate for ten years without refuelling. Some icebreaker ships and aircraft carriers are also nuclear powered. The main disadvantage of nuclear-powered vessels is the risk of reactor damage or meltdown. Unless contained, the reactor damage or meltdown could expose the crew and the environment to ionizing radiation and radioactive isotopes. Once decommissioned, nuclear vessels must also be properly dismantled. This involves the removal and long-term storage of radioactive components. The estimated cost of a submarine is $30 million.

Nuclear Fusion

Thus far, you have studied alpha, beta, and gamma decay and nuclear fission. The final type of nuclear reaction to consider is **nuclear fusion**. In one sense, nuclear fusion is the opposite of nuclear fission: *fusion* means "to bring together," whereas *fission* means "to break apart."

A Fusion Reaction



Nuclear Equation

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \longrightarrow ^{0}_{0}\gamma + ^{1}_{0}n + ^{3}_{2}\mathrm{He}$$

nuclear fusion: a process in which two smaller nuclei join to form a larger nucleus, with the simultaneous release of energy

deuterium: a heavy isotope of hydrogen with one proton and one neutron in the nucleus

Figure D1.40: Nuclear fusion is the source of the Sun's energy.

In a fusion reaction, a heavy isotope of hydrogen called **deuterium**, nuclides collide at high speed to form a product, helium-3, that has a larger nucleus than either of the reactants. Recall from Unit C that hydrogen fusion reactions occur deep within the Sun, where extremely high temperatures and pressures exist. Also recall that the fusion of hydrogen within the Sun emits radiation that is the primary energy source for photosynthesis—the process that provides food either directly or indirectly for all organisms on Earth.

DID YOU KNOW?

All elements are born in stars. Fusion reactions within stars produce larger elements from hydrogen. The largest atom made by fusion within the Sun is iron, which has 26 protons. Larger elements—like gold, platinum, and uranium—are formed in supernovas (exploding stars). Supernovas leave behind gas and dust that serve as raw materials for making new planets.

Practice

40. For each fusion reaction given, complete the equation and identify the unknown product, $^{A}_{Z}X$.

a. $^{2}_{1}\mathrm{H} + ^{3}_{1}\mathrm{H} \rightarrow ^{1}_{0}n + ^{A}_{Z}X$ **b.** $^{14}_{7}\mathrm{N} + ^{1}_{1}\mathrm{H} \rightarrow ^{0}_{0}\gamma + ^{A}_{Z}X$

41. Calculate the energy change for each reaction in question 40. Determine whether the fusion reaction results in a release of energy. Support your answer.

Solar Fusion Reactions

hydrogen to deuterium: $^{1}_{1}\mathrm{H} + ^{1}_{1}\mathrm{H} \rightarrow ^{0}_{+1}\mathrm{e} + ^{2}_{1}\mathrm{H}$

Note: The symbol, $^{0}_{+1}\mathrm{e}$, represents a positron—an elementary particle with the same mass as an electron, but with a positive charge.

deuterium to helium-3: $^{2}_{1}\mathrm{H} + ^{1}_{1}\mathrm{H} \rightarrow ^{0}_{0}\gamma + ^{3}_{2}\mathrm{He}$

helium-3 to helium-4: $^{3}_{2}\mathrm{He} + ^{3}_{2}\mathrm{He} \rightarrow 2\,^{1}_{1}\mathrm{H} + ^{4}_{2}\mathrm{He}$

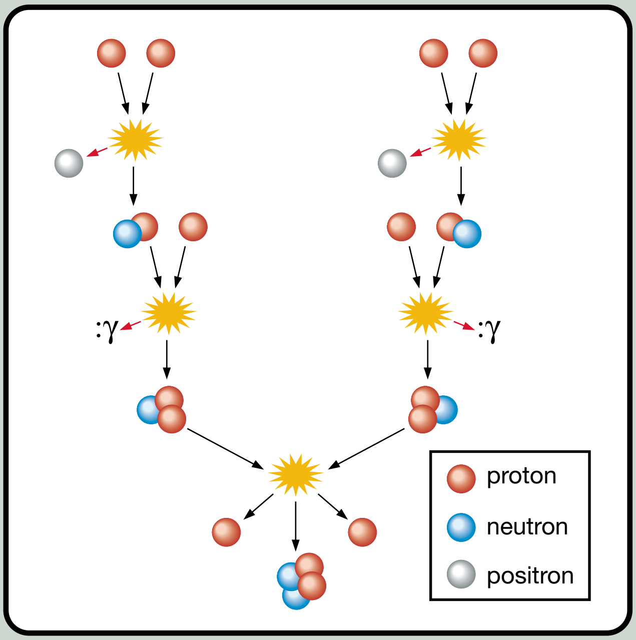
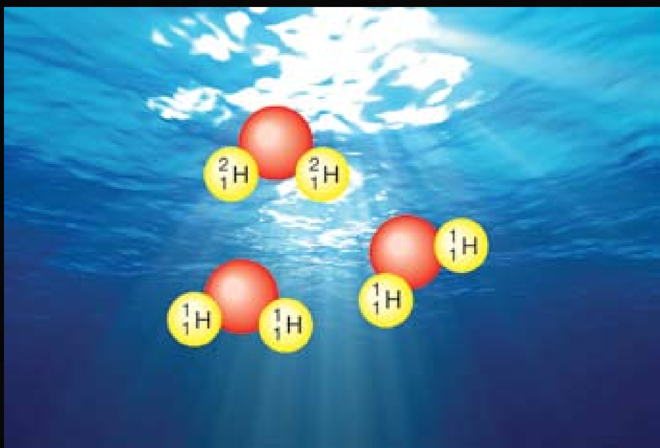


Figure D1.41

The series of fusion reactions shown in Figure D1.41 identifies the conversion of some of hydrogen—which makes up over 70% of the Sun's mass—into helium. Fusion reactions like those occurring within the Sun's core are considered to be possible energy-releasing reactions for reactors in power plants on Earth.

From the Science 30 Textbook CD, view the "Nuclear Fusion" applet to see a simulation of the conditions that must be created within a fusion reactor. In the "Is Fusion the Energy Source of the Future" activity, you will investigate the state of fusion research and the potential for energy from fusion to meet world energy demands.



It might surprise you to know that the deuterium necessary for fusion reactions is plentiful in seawater. Deuterium and other isotopes to be considered for use in fusion reactions are considered inexhaustible, making fusion a **renewable energy** source. Energy production that relies on the combustion of fossil fuels or nuclear fission is considered to be **non-renewable energy**. In the next chapter you will learn more about technologies to develop renewable energy sources.

renewable energy: energy derived from continuously available sources that can be replenished in a short period of time

non-renewable energy: energy derived from sources that will become depleted because they are not able to be replenished in a short period of time

Utilizing Technology

Is Fusion the Energy Source of the Future?

Science Skills
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Purpose

You will investigate the current state of fusion research and the development of electricity generation from fusion reactions.

Procedure

Use the Internet, library, or other sources to research this issue. You may work on your own or within in a small group. Use the focus questions as a guide to develop an information package, brochure, model, or brief presentation to identify the status of the development of systems that use fusion power.

Focus Questions

1. What is nuclear fusion? Identify the reactants used in fusion reactions currently being studied.
2. Describe the conditions necessary for fusion to occur. Describe the challenges in attempting to create a fusion reactor that can sustain these conditions.
3. Describe the status of current efforts to produce a reactor that can sustain a fusion reaction.
4. Identify advantages and disadvantages of fusion power as an energy source.

1.4 Summary

Radiation refers to the energy released during nuclear reactions. Ionizing radiation released by nuclear reactions takes three main forms: alpha, beta, and gamma. The energy provided by nuclear fission reactions is currently used to generate electricity in many countries, helping to meet the world's energy needs. Fission and other nuclear reactions result in some mass being converted into energy. The amount of energy associated with a reaction can be calculated using the equation $\Delta E = \Delta mc^2$. Nuclear fusion may, some day, join fission as a process for meeting the world's energy needs.

1.4 Questions

Knowledge

1. For the nucleus ${}^{92}_{36}\mathrm{Kr}$, identify the
   - **a.** atomic number
   - **b.** charge
   - **c.** mass number
   - **d.** number of nucleons
2. Define the following terms.
   - **a.** radioactive decay
   - **b.** nuclear fission
   - **c.** nuclear fusion
3. List the similarities and differences between a coal-fired power plant and a nuclear power plant.
4. Describe how the fission chain reaction is controlled in a CANDU nuclear reactor.
5. Identify and explain one risk and one benefit associated with the use of nuclear fission reactions for generating electricity.

Applying Concepts

6. Balance each reaction and identify the unknown product, ${}^{a}_{z}X$. For each reaction, state the type of nuclear change shown.
   - **a.** ${}^{14}_{6}\mathrm{C} \rightarrow {}^{0}_{-1}\mathrm{e} + {}^{A}_{Z}X$
   - **b.** ${}^{241}_{95}\mathrm{Am} \rightarrow {}^{A}_{Z}X + {}^{237}_{93}\mathrm{Np}$
   - **c.** ${}^{3}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{1}_{0}n + {}^{A}_{Z}X$
   - **d.** ${}^{A}_{Z}X + {}^{1}_{0}n \rightarrow 3\,{}^{1}_{0}n + {}^{107}_{44}\mathrm{Ru} + {}^{130}_{50}\mathrm{Sn}$
   - **e.** ${}^{90}_{38}\mathrm{Sr} \rightarrow {}^{A}_{Z}X + {}^{90}_{39}\mathrm{Y}$
   - **f.** ${}^{226}_{88}\mathrm{Ra} \rightarrow {}^{A}_{Z}X + {}^{222}_{86}\mathrm{Rn}$
   - **g.** ${}^{129}_{53}\mathrm{I} \rightarrow {}^{0}_{0}\gamma + {}^{A}_{Z}X + {}^{129}_{54}\mathrm{Xe}$
7. Is nuclear energy from the fission of uranium a renewable or non-renewable energy source? Provide a reason for your answer.
8. A possible reaction for fusion power involves a fusion between helium-3 and deuterium nuclei. The products of the reaction are helium-4 and a proton.
   - **a.** Present the process described as a balanced nuclear equation.
   - **b.** Calculate the change in mass and the corresponding energy change for the fusion between helium-3 and deuterium nuclei.
9. The following table shows the amount of energy released by physical, chemical, and nuclear changes. Identify the type of change for each, and determine how many times greater the energy release is compared to condensing water vapour.

Change	Energy Released (kJ/mol)	Type of Change (physical, chemical, or nuclear)	How Many Times Greater Than Condensing Water Vapour
condensing water vapour $H_2O(g) \rightarrow H_2O(l)$ + energy	40.7		
combusting methane (a component of natural gas) $CH_4(g) + 2\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(g)$ + energy	802		
fission of uranium-235 ${}^{1}_{0}n + {}^{235}_{92}\mathrm{U} \rightarrow 3\,{}^{1}_{0}n + {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba}$	1.67×10^{10}		
fusion of deuterium and tritium ${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{1}_{0}n + {}^{4}_{2}\mathrm{He}$	1.82×10^{9}		

Chapter 1 Summary

Since the Industrial Revolution, new technologies, changes in lifestyle, and human population growth have caused an exponential increase in energy use. The world's demand for energy is largely met by the combustion of fossil fuels, like coal and oil. As part of the effort to supplement fossil fuel energy, nuclear technologies have also been used. In the next chapter you will examine renewable resources, how they have helped meet world energy demands, and how likely they will take on an increasing role in the future.

Summarize Your Learning

In this chapter you learned a number of new terms, concepts, and techniques for problem solving. You will have a much easier time recalling and applying the information you have learned if you take some time to organize it into some sort of pattern. Now that you have come to the end of the chapter, this is an appropriate time to focus on the patterns within the things you have learned.

Since the patterns have to be meaningful to you, there are some options about how you can create this summary. Each of the following options is described in "Summarize Your Learning Activities" of the Reference Section. Choose one of these options to create a summary of the key concepts and important terms in Chapter 1.

Option 1: Draw a concept map or a web diagram.	**Option 2:** Create a point-form summary.	**Option 3:** Write a story using key terms and concepts.	**Option 4:** Create a colourful poster.	**Option 5:** Build a model.	**Option 6:** Write a script for a skit (a mock news report).

Chapter 1 Review Questions

Knowledge

1. Define *energy*. Then list and define the types of energy studied in Chapter 1.
2. Describe the general trend in world energy use between 1850 and 2000. Provide a reason for the trend.
3. Compare total energy use and per capita energy use between developing countries and developed countries.
4. Provide reasons why Canada's per capita energy use is higher than that of the United States.
5. Define *energy efficiency*. Identify examples that promote improved energy efficiency. Explain how improvements to energy efficiency would affect total energy use in Canada.
6. Describe the relationship between a country's gross domestic product (GDP) and its total energy use.
7. How does per capita energy use in Alberta compare to other Canadian provinces? Account for any differences.
8. Predict the effect that a rapid industrialization of developing countries will have on the world's total energy use during the next few decades.
9. List the non-renewable energy sources described in Chapter 1.
10. State the main fuel used by First Nations communities before the arrival of Europeans.
11. For each energy source given, state how it is formed and how it is used.

    a. coal **b.** petroleum **c.** natural gas
12. Which fossil fuel, listed in question 11, is currently the world's top energy source?
13. Explain why extracting petroleum from oil sand is much more energy intensive than conventional drilling.

14. List some applications of hydrocarbons other than as energy sources.

15. Explain why energy conversions can never be 100% efficient.

16. Describe the energy transformations that occur in a coal-fired power plant during the production of electricity.

17. Define each term given, and provide a technological application.

 a. radioactive decay **b.** nuclear fission **c.** nuclear fusion

18. Compare nuclear fission with nuclear fusion.

19. List the series of energy transformations that occur within a generating station that uses a CANDU nuclear reactor.

20. Identify technical difficulties associated with developing fusion power.

Applying Concepts

21. List the factors you would need to consider in order to estimate the energy required to manufacture a paper coffee cup and lid.

22. Refer to Figure D1.42. Describe the trends for predicted changes to population and electricity demand in China. Provide an explanation for the prediction for electricity demand in light of the predicted population change.

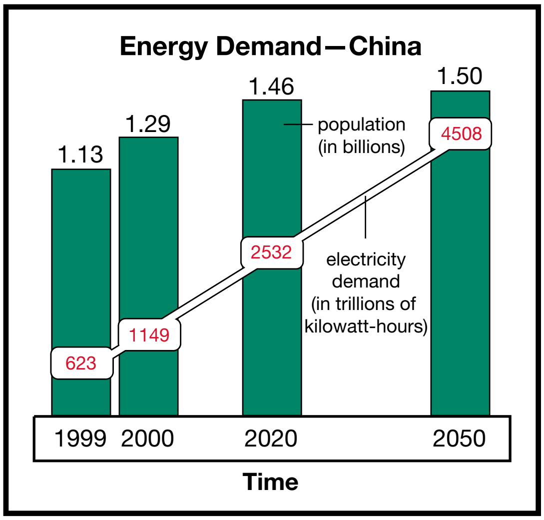


Figure D1.42

23. Describe the sequence of energy conversions for energy radiated by the Sun that becomes energy used to heat up leftover chili in your microwave oven.

24. Use the Internet to research the following questions.

 a. Describe how hybrid automobiles work differently than conventional gas-powered automobiles.

 b. Compare the fuel economy of hybrid automobiles with conventional gas-powered automobiles.

 c. Provide a reason why individuals would be motivated to purchase hybrid cars.

25. Use standard heats of formation and the balanced combustion equations to calculate the energy change per mole for the combustion of the fuel listed.

 a. ethane, $C_2H_6(g)$ (a component of natural gas)

 $C_2H_6(g) + 3.5\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$

 b. propane, $C_3H_8(g)$ (a common barbecue fuel)

 $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$

26. Draw an energy diagram for the combustion of propane that demonstrates the products have a lower chemical potential energy than the reactants and shows the energy released during the reaction.

27. Use your answer from question 25.b. to calculate the efficiency of a barbecue that produces 795 kJ of useful output energy for cooking when it burns 1 mol of propane.

28. Calculate the chemical potential energy necessary for a power plant to generate 1.6×10^9 J if it is 44% efficient.

29. Radium was discovered in the early 1900s and was at one time used in many consumer products because of its luminescence. The use of radium in consumer products stopped when it became known that it produces ionizing radiation. Write a balanced nuclear equation for the alpha decay of radium-226.

30. The deuterium-deuterium fuel cycle proposed for nuclear fusion is as follows:

$${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{1}_{0}n + {}^{3}_{2}\mathrm{He}$$

Calculate the energy change of this reaction per mole of helium-3.

Chapter 2 Dreams of a Sustainable Future

Can you spot the sources of renewable energy in this photograph? You most likely identified the wind turbines that punctuate the skyline; but through careful observation, you may have also identified that the entire upper surface of the car is covered with photovoltaic cells. This futuristic car is an experimental race vehicle that runs entirely on solar energy. The lessons learned from experimental vehicles like this may, some day, help engineers to come up with alternatives to the conventional automobiles that rely on fossil fuels. A much less obvious form of renewable energy in this photo is the crop of corn in the background. Corn can be used to make ethanol—a renewable fuel. Ethanol can be used to supplement or possibly even replace petroleum.

With so many hungry people in the world, is it wise to turn a potential food into fuel? Are there other questions surrounding the widespread use of wind turbines, photovoltaic cells, biomass, or other renewable energy technologies? What kinds of questions need to be asked before you can decide which technologies are suitable choices for meeting current and future energy demands?

In this chapter you will have an opportunity to investigate many sources of renewable energy that are alternatives to the use of non-renewable fuels. This knowledge will offer you more than just a way to look to the future; it will also provide you with a valuable opportunity to summarize many key concepts from the entire course.

Try This Activity

Process Maps

Background Information

Earth is a closed system. This means that matter must be continuously cycled. The water cycle and the carbon cycle, which you studied in previous courses, are examples of biogeochemical cycles for matter. Energy, in most cases from the Sun, is important to the cycling of matter.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

In this activity you will prepare process maps depicting the energy and matter changes for photosynthesis, combustion of fossil fuels, and nuclear fission.

Procedure

Obtain three copies of the handout "Process Map" from the Science 30 Textbook CD.

step 1: On the first copy of the handout, write "Photosynthesis" in the box in the centre.

step 2: In the upper-left quadrant of the diagram (Energy Input), identify the energy inputs for photosynthesis. You may use a list or arrows to indicate flow or changes that occur.

step 3: Repeat step 2 for the other quadrants: Energy Output, Matter Input, and Matter Output.

step 4: Repeat these steps for the combustion of fossil fuels and for nuclear fission.

Analysis

1. On your process maps, identify matter outputs or energy outputs that may harm the biosphere.
2. Identify any process that is able to use the energy output as an energy input. (Can energy be recycled?)
3. Can the matter output from any of the processes be transformed back into a matter input? (Can matter be recycled?) If so, compare the rates for the processes. (Can the matter be replenished as quickly as it is being used?)
4. Recall the definition for renewable energy. Identify the processes that are renewable. Identify which processes could be used to meet energy needs in the short term and over the long term. Give reasons for your answers.

2.1 Describing Sustainability

Figure D2.1: A mountain meadow in Banff National Park

What kind of impact could humans have on an established ecosystem like the one shown in Figure D2.1? A mountain meadow does not require people to input raw materials or to remove wastes because matter is cycled in biogeochemical cycles. Artificial lights are not required because green plants are able to transform the energy in the Sun's photons into chemical potential energy through photosynthesis. Photosynthesis provides a way for energy to be passed on to other organisms through the food chain. Since an ecosystem is capable of maintaining itself indefinitely, it is said to be **sustainable**. Barring disruption, as long as the Sun shines and matter continues to be cycled, an ecosystem like this one continues to exist.

sustainable: capable of being maintained at length without interruption, weakening, or loss of essential characteristics (such as matter and energy)

An established ecosystem stands in stark contrast to most of the current systems set up to maintain the towns and cities most people live in. In a city, matter is not cycled. This is evident in the armies of transport trucks that bring goods into the city and in the legions of garbage trucks depositing waste daily at the local landfill.

As far as energy is concerned, fossil fuels may not be dependable energy sources for future generations if society continues to consume them at the current rate. Because of the current usage patterns for materials and energy, the vast majority of human settlements in industrialized countries are described as being **non-sustainable**. These systems have the potential to break down because the supply of raw materials and the non-renewable sources of energy will eventually become exhausted.

Does it make sense to be so dependent upon resources that will one day run out? Is it appropriate for the current human population to deplete the supply of limited resources, leaving a long list of environmental problems for future generations? Should continued development of non-sustainable human systems be questioned? What are the long-term consequences of abusing Earth's life-support system?

You may hear people asking questions like these when discussing the growth of cities or the expansion of industry within your local area. These questions indicate a growing concern among people and a willingness to consider new approaches to development. Approaches that consider meeting human needs today while balancing the long-term implications, including possible harm to the environment, demonstrate **sustainable development**. Many people regard sustainable development as one of the most important ideas of our time because it is like a crossroad—the place where pressing ecological, societal, and economic issues all meet.

non-sustainable: incapable of being maintained at length due to interruption, weakening, or loss of essential characteristics (such as matter and energy)

sustainable development: the development of industrial and natural resources that meets the needs of the present generation without compromising the ability of future generations to meet their own needs

Practice

1. Two next-door neighbours utilize very different strategies when it comes to landscaping their front yards. One neighbour plants a front lawn of lush green grass that requires regular watering and fertilizer application. The other neighbour uses stone pathways that wind through a variety of drought-resistant wildflowers and shrubs that are native to the area.
   a. Explain which neighbour has the more sustainable front yard.
   b. Describe the cumulative effects of many people utilizing non-sustainable landscaping practices on both the local environment and the biosphere.
2. To some people, Earth is considered to be a fragile spaceship that is the home for humans and many other life forms. Use the notion of "spaceship Earth" to explain the importance of sustainable development.

Demonstrating Sustainable Development

One example of how a community can move in the direction of sustainable development can be found in the town of Okotoks, Alberta. Like many communities surrounding Calgary, Okotoks has experienced rapid population growth. What makes this community different is that its administrators have made a conscious decision to control the growth of the town—keeping it in step with the ability of the environment to support the population. In addition, the creative use of renewable-energy technologies within the community has attracted national and international attention. You will learn more about the sustainable development occurring in Okotoks in the next activity.

Utilizing Technology

Okotoks—Moving Toward Sustainable Development

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will watch a video to identify and analyze examples of sustainable development that have been utilized by the town of Okotoks, Alberta.

Procedure

Before you begin, read the Analysis questions and determine strategies you will use to identify parts of the video where useful information is located. View the video "Road Stories: Green Cities" on the Science 30 Textbook CD.

Analysis

1. Identify the natural resource that was chosen when the town of Okotoks established limits on its maximum size.
2. Describe some of the strategies used to ensure the long-term sustainability of the resource identified in your answer to question 1.
3. Identify the renewable-energy technologies used to meet the energy needs of municipal buildings in Okotoks.
4. Describe how the design of municipal buildings has allowed for renewable-energy technologies to be used.
5. Drake Landing Solar Community in Okotoks has taken a unique approach to utilizing the Sun's energy. Obtain the "Drake Landing Solar Community" handout from the Science 30 Textbook CD. Match the labels provided on the handout with locations on the diagram of the energy capture and distribution system used at Drake Landing.
6. Describe other features of the homes in Drake Landing Solar Community that enable them to reduce annual greenhouse emissions by 83%.
7. Sustainable development involves consideration of other aspects of human activity in addition to energy. Communities like Drake Landing Solar Community can be rated in terms of how close they come to perfectly illustrating sustainable development. A score of 10 out of 10 represents the ideal sustainable-development community, and a score of 0 represents the complete opposite.
   a. List the activities designed to reduce environmental impact in which the citizens of Okotoks participate.
   b. Determine a score out of 10 for the Drake Landing Solar Community in terms of its ability to incorporate sustainable development. Justify your score.
   c. Determine a score out of 10 for the community where you live in terms of its ability to incorporate sustainable development. Justify your score.

Evaluating Energy Technologies for Sustainability

As you saw in the preceding activity, if a community like Okotoks pursues a community plan to promote sustainable development, access to sustainable sources of energy must be part of the strategy. How are decisions made when choosing one energy source—or a technology that uses that energy source—over another? What criteria could be used to compare different technologies and their sustainability?

The overall sustainability of an energy source is determined by examining its

- ecological sustainability
- societal sustainability
- economic sustainability

Ecological Sustainability

ecological sustainability: functioning in such a way as to not adversely affect air, water, land, biodiversity of organisms, or natural ecosystems

An energy technology demonstrates **ecological sustainability** if its use enables the protection of the three key components of the biosphere: land, water, and air. In addition, the use of the technology should maintain biodiversity, promote the survival of species at risk, and protect fragile ecosystems. It follows that environmental sustainability involves protecting organisms from the harmful effects of pollution and ionizing radiation. The following list of statements describes an energy source that supports ecological sustainability.

An energy technology that demonstrates ecological sustainability

- is based on a renewable energy source
- maintains the quantity of surface water
- maintains the quality of surface water
- does not contribute to acid deposition
- does not contribute to the presence of persistent organic pollutants in water, soil, or air
- does not contribute to the presence of heavy metals in water, soil, or air
- recycles liquid and/or solid waste products
- does not contribute to deforestation or habitat destruction
- does not contribute to greenhouse gas emissions
- does not contribute to emissions of ozone-depleting materials
- does not contribute to emissions of particulate matter
- does not contribute to photochemical smog
- does not threaten the survival of species at risk
- does not contribute to the destruction of fragile ecosystems
- does not contribute to the release of ionizing radiation
- does not contribute to the mass of radioactive waste produced

Societal Sustainability

In your studies throughout this course, you examined many technologies that convert energy from one form into other forms. Coal-fired power plants and nuclear power plants are two examples of energy technologies that generate electricity that, in turn, supports communities. Human communities can maintain themselves only if their populations have their needs met in terms of health and education. Sustainable societies ensure that people can support themselves with a reasonable standard of living so that families have access to affordable housing. A sustainable society is one that shows respect for the diversity of the cultural values within the community. The following statements describe aspects of **societal sustainability** in reference to how energy is provided.

societal sustainability: the ability of a group to support adequate living standards for its members; includes housing, health care, and respect and maintenance of cultural values

An energy technology that demonstrates societal sustainability

- does not decrease life expectancy through exposure to pollution
- stimulates a healthy economy, enabling adequate health care
- requires a highly trained workforce
- requires the workforce to adapt to change through continuous training
- reduces excessive land use (e.g., urban sprawl)
- encourages per capita energy consumption to be reduced
- stimulates a healthy economy, enabling affordable housing
- requires co-operation of diverse cultural groups in decision making

Economic Sustainability

Just as individuals need to provide for themselves economically, communities of people must be able to maintain economic activities over time. Indicators of **economic sustainability** include adequate employment opportunities for the population and opportunities for economic growth, which include goods and services that can add to the GDP. The following list of statements describes energy sources that support economic sustainability.

economic sustainability: the ability to provide employment opportunities and have access to goods and services in a manner that does not decrease the availability of natural resources

An energy technology that demonstrates economic sustainability

- supports full-time employment for the population
- enables a higher proportion of the workforce to be paid reasonable wages
- has a relatively low cost per megajoule (MJ)
- enables development of other industry or opportunity
- reduces the import of energy, contributing positively to the GDP
- enables the export of energy, contributing positively to the GDP
- can be used in a variety of locations that are well-suited to industry
- allows for continuous, around-the-clock production
- does not decrease the availability of natural resources

In the next activity you will have an opportunity to evaluate an energy resource for ecological, societal, and economic sustainability.

Try This Activity

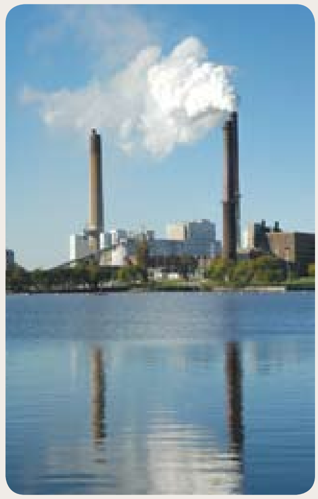
Determining the Sustainability of Coal-Fired Power Plants

Science Skills
✓ Analyzing and Interpreting
✓ Communication and Teamwork

Purpose

You will use a detailed checklist to determine the sustainability of generating electricity using coal as a source of energy. You will then compare your results with other students.

Background Information



From your previous work in Units B and C, you are already quite familiar with coal as an energy source. In this activity you will rely on your knowledge of key concepts covered in this course to complete a checklist outlining criteria that are essential for ecological, societal, and economic sustainability. Completing the checklist will enable you to determine the sustainability of this technology.

Procedure

Obtain the document “Determining Sustainability of Technologies” from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of coal-fired power generation. **Note:** Keep your completed checklist because you will be asked to refer to it throughout this chapter.

Analysis

1. Justify the weightings you chose for each type of sustainability. Given the results of other students, would you revise your weightings if you were to repeat this activity?
2. Identify the sources responsible for the variability in the overall score for sustainability in this activity. Include an explanation as to why there is no “right answer” in terms of the overall score for sustainability for a given energy resource.

Making Sense of Sustainability Scores

You just determined the sustainability of coal-fired electricity generation. The point of the activity was not to arrive at a pre-determined "right answer," but rather to stimulate discussions with others and to validate the use of the checklist. These skills will be beneficial when determining the sustainability of other energy technologies. Even though individual students may not completely agree with the weightings for the categories of ecological, societal, and economic sustainability, the common sets of criteria shown in the checklist allow you and your classmates to compare various energy sources. Is it possible for other technologies to score higher than coal-fired power plants? Which technologies show the greatest potential for providing human communities with a sustainable future? The rest of this chapter will largely be focused on helping you answer these questions.

Practice

In Chapter 1 you discovered that CANDU reactors use nuclear fission to generate electrical energy.

Before completing questions 3 and 4, review the energy conversions and processes involved in the operation of a CANDU reactor.

3. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of nuclear fission as a source of electricity. **Note:** Keep your completed checklist for nuclear fission because you will be asked to refer to it throughout this chapter.

4. Compare your assessment of the sustainability of nuclear fission as a source of electricity with your evaluation for coal-fired electricity generation from the "Determining the Sustainability of Coal-Fired Power Plants" activity.

- **a.** Identify which technology is more sustainable. Justify your selection.
- **b.** Compare your answer to question 4.a. with other students. Did other students agree with your answer and your justification? Identify any major differences between conclusions and justifications.

Earth's Heat—Geothermal Energy

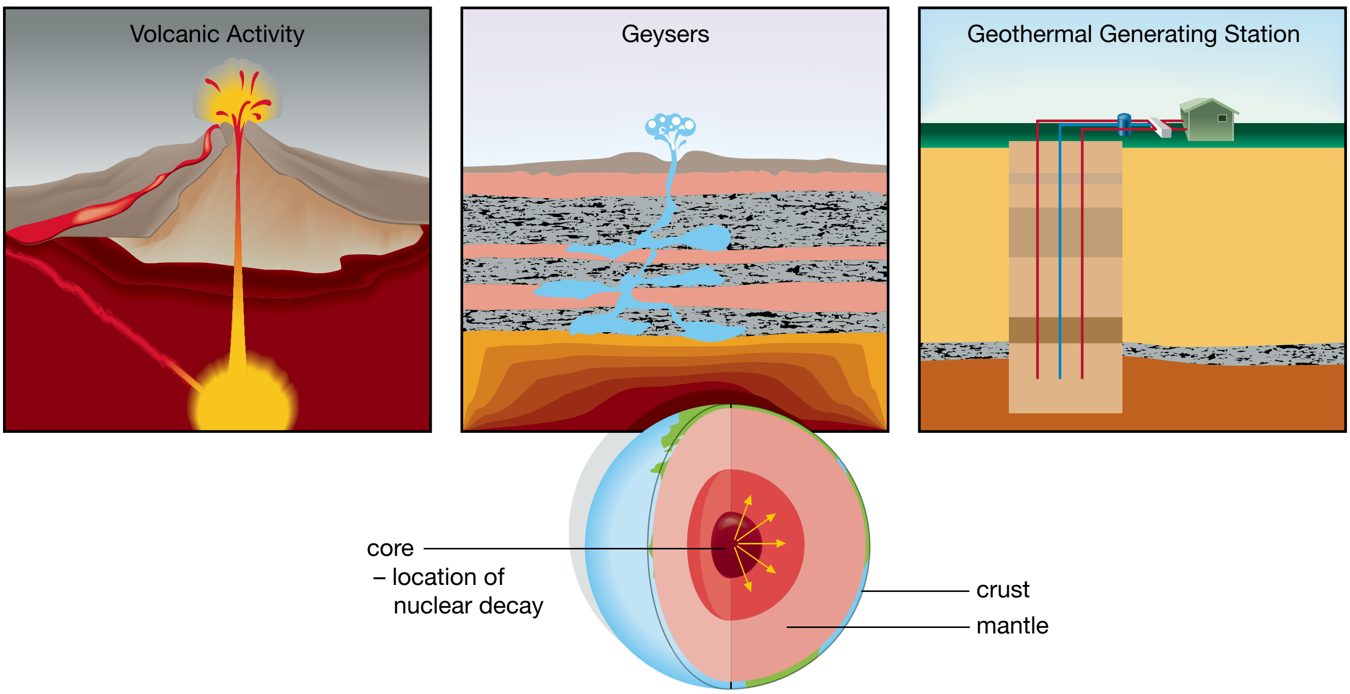
You may recall from previous science courses that geothermal energy is responsible for the movement of Earth's tectonic plates, in addition to other spectacular displays, like volcanic eruptions and geysers. The plumes of hot rock and lava sent into the air from active volcanoes or the periodic blasts of high-temperature water and steam from geysers originate from nuclear decay reactions that occur thousands of kilometres below Earth's surface.

Figure D2.2: Volcanoes and geysers are examples of the large quantity of energy available from geothermal sources.

Evidence suggests that the radioactive decay of unstable isotopes within Earth's core helps maintain the temperature of Earth's inner-most layer at about 5000°C. Heat from the nuclear reactions in the core drives convection currents within the molten rock of the mantle—Earth's middle layer. These convection currents cause the crustal plates to move. **Geothermal energy** tends to collect at the boundaries between these plates where Earth's crust is thin or fractured. The condition of the crust at these boundaries often provides pathways for geothermal energy to reach the surface.

geothermal energy: heat that originates from radioactive decay in Earth's core

Geothermal Energy—Heat from Within Earth



DID YOU KNOW?

The decay of the isotopes potassium-40, thorium-232, uranium-235, and uranium-238 produce geothermal energy.

For individuals, industries, and governments around the world looking for ways to diversify energy and fuel production, geothermal energy may be an alternative. Despite the fact that the nuclear isotopes responsible for the production of heat are limited, current estimates predict they will not be depleted for millions of years.

Figure D2.3: Bathers in Iceland relax in natural hot water, which is the result of geothermal energy from deep within Earth reaching the surface. In the background is a large power plant that uses the geothermal energy to generate electricity.

Figure D2.4: Iceland's largest city, Reykjavik, uses sustainable geothermal energy to heat its buildings and generate its electricity.

Geothermal energy is used either for heating or generating electricity in over 30 countries around the world. In the Philippines, geothermal energy provides 27% of the country's electricity. In Iceland's capital city, Reykjavik, geothermal energy heats over 80% of the buildings and is used to generate nearly all of the electricity. In the United States, geothermal energy provides approximately $1 billion worth of electricity in California, Hawaii, Nevada, and Utah each year. In 2000, the United States' government set a goal to increase geothermal energy use from 0.45% to at least 10% of the electricity production in the western United States by 2020.

DID YOU KNOW?

Geothermal Electricity in Canada

Canada does not currently use geothermal energy to generate electricity. Areas with the greatest potential are found in British Colombia's coastal mountains. To date, the Meager Mountain area appears to hold the greatest potential for geothermal electricity. A 100-MW facility may eventually be built in this area.

Using Geothermal Energy

At first blush, geothermal energy seems to have some significant advantages as an energy source. Since Earth's energy can be used to produce pressurized steam, the need for fuels to heat water is eliminated. If it is possible to construct a generating station close to the fissure and to the source of hot water, electricity generation can be relatively inexpensive to set up and can be very efficient.

However, since geothermal generating stations often utilize steam from deep within Earth's crust, emissions of hydrogen sulfide, $H_2S(g)$, and carbon dioxide, $CO_2(g)$, often occur. Even though these emissions come from a natural source, they represent only a fraction of those from comparably sized fossil fuel-fired installations. As you determined in Unit B, $H_2S(g)$ and $CO_2(g)$ can react to form acids, causing corrosion of metals used in a geothermal facility and acid deposition within the surrounding area.

Perhaps the greatest drawback of geothermal energy is that it is a localized resource. It is only cost-effective in areas where geological hot spots already exist. Since many populated areas in the world are not located along the boundaries of crustal plates, geothermal energy is not a practical alternative.

DID YOU KNOW?

The mean temperature of Earth's crust increases by 3°C every 100 m as you move closer to the core.

The exception to this trend occurs in California. As you may recall, a large portion of California's population lives near the San Andreas Fault, close to the border between the North American Plate and Pacific Plate—which contains many geothermal hot spots. The transformation of geothermal energy in California made the United States the world's largest producer of electricity from geothermal sources in 2003. Other countries that are major users of this energy source include Iceland, the Philippines, Mexico, Indonesia, Italy, Japan, and New Zealand. In spite of what seems to be an ample supply of heat, geothermal hot spots can decrease in temperature if they are not properly managed and, thus, reduce the energy available for transformation.

DID YOU KNOW?

Sacred Waters

First Nations peoples have used hot springs for thousands of years. Many naturally heated waters have long been revered for their sacred, healing properties. First Nations people were the first to introduce European explorers to the Miette Hot Springs near Jasper.

Practice

5. Identify a way geothermal energy is used other than to generate electricity.
6. Identify which part of Canada is believed to have the greatest potential to exploit geothermal energy on a large scale. Concisely explain why.
7. Identify two advantages and two disadvantages of geothermal energy.
8. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of geothermal energy as a source for producing electricity. **Note:** Keep your completed checklist for geothermal energy because you will be asked to refer to it throughout this chapter.

Tidal Energy

Figure D2.5: It's low tide at Alma Harbor, New Brunswick, on the Bay of Fundy. The highest tides in the world occur in the Bay of Fundy, located between New Brunswick and Nova Scotia.

Although it may appear that some form of natural disaster has left these fishing boats stranded, their position is due to the cycle of the **tide** in the Bay of Fundy. The extreme tides in this area are due to the way water moves—because of the unique shape of the bay and the natural cycle of the tides. The result is an effect similar to pushing a child on a swing, amplifying the energy of the original movement. Oceanographers have determined that the energy within a wave entering the Bay of Fundy returns to the mouth of the bay in just under 13 hours.

tide: the deformation of land and water due to the gravitational fields of the Moon and Sun acting on every part of Earth

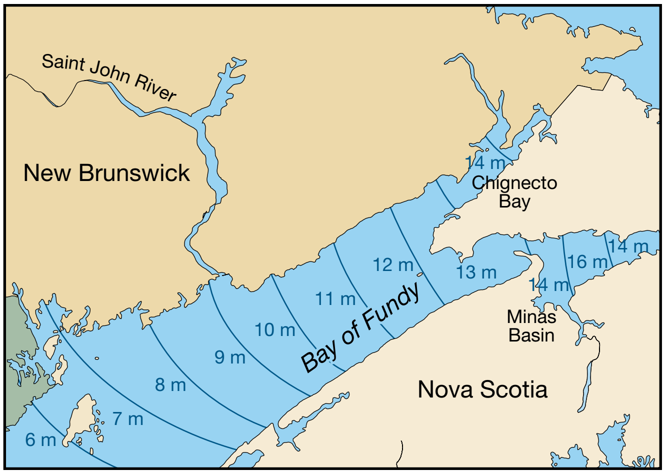
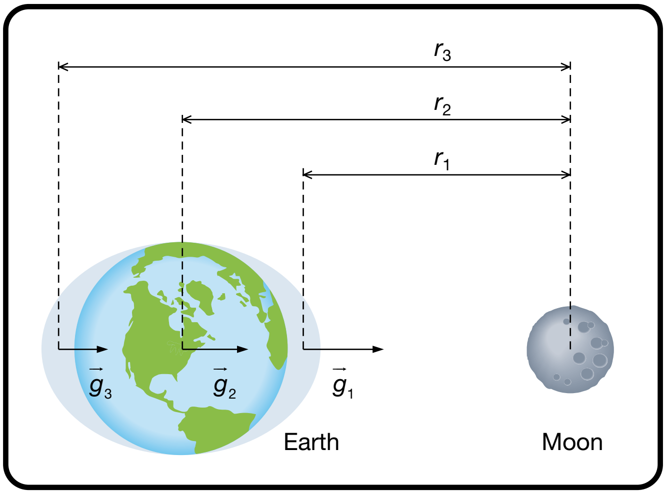


Figure D2.6: This map of the Bay of Fundy shows the difference between high tide and low tide for various locations.

Since the time between one high tide and the next is 12 hours 25 minutes, the rhythm of Earth's tides is precisely tuned to this particular bay. The natural frequency of the movement of water in the bay becomes amplified by the energy in the pulse of the tides. Why is the time between adjacent high tides exactly 12 hours 25 minutes?

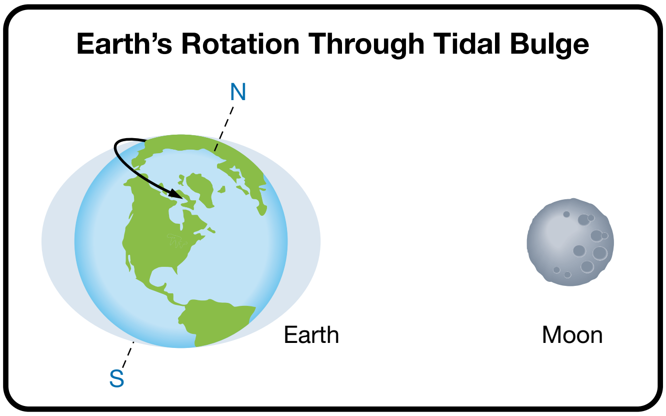


Tides are the result of the gravitational fields of both the Sun and Moon acting on every part of Earth. Recall from Unit C that the gravitational field of a source weakens as the distance from the source increases. Since the Moon is closest to Earth, it accounts for most tidal effects. The explanation provided in this course will focus only on the effects of the Moon on tidal patterns.

As mentioned in Unit C, a field is defined by the behaviour of a test object within it. In a tidal system, the Moon is the source of the gravitational field and the test object is Earth's water. Since approximately 70% of Earth's surface is water, two portions of Earth are considered when analyzing tides: the water on the side of Earth closest to the Moon and the water on the side of Earth farthest from the Moon. Also, the mass of Earth must be considered when analyzing this system.

The water on Earth's surface closest to the Moon is subjected to the strongest gravitational field, $\vec{g}_1$. The centre of Earth is farther from the Moon, so the Moon's gravitational field, $\vec{g}_2$, is weaker compared to the force $\vec{g}_1$. The slight difference between these two forces distorts Earth's shape and causes the water to form a tidal bulge on the side closest to the Moon.

The difference between the gravitational field acting on the far side of Earth, $\vec{g}_3$, and the field acting on the centre of Earth, $\vec{g}_2$, accounts for the bulge on the side of Earth farthest from the moon. Since the centre of Earth experiences a gravitational attraction to the Moon larger on the far side, the difference between these two forces distorts Earth's shape. In a sense, the centre of Earth is "pulled away" from the water on the far side leaving a tidal bulge.



As Earth spins on its axis, each part of the planet along a sea coast moves through two areas of high tide and two areas of low tide every 24 hours 50 minutes. The extra 50 minutes is needed to make up for the Moon's motion. The Moon takes an extra 50 minutes each day to return to its highest point in the night sky (as observed from a location on Earth).

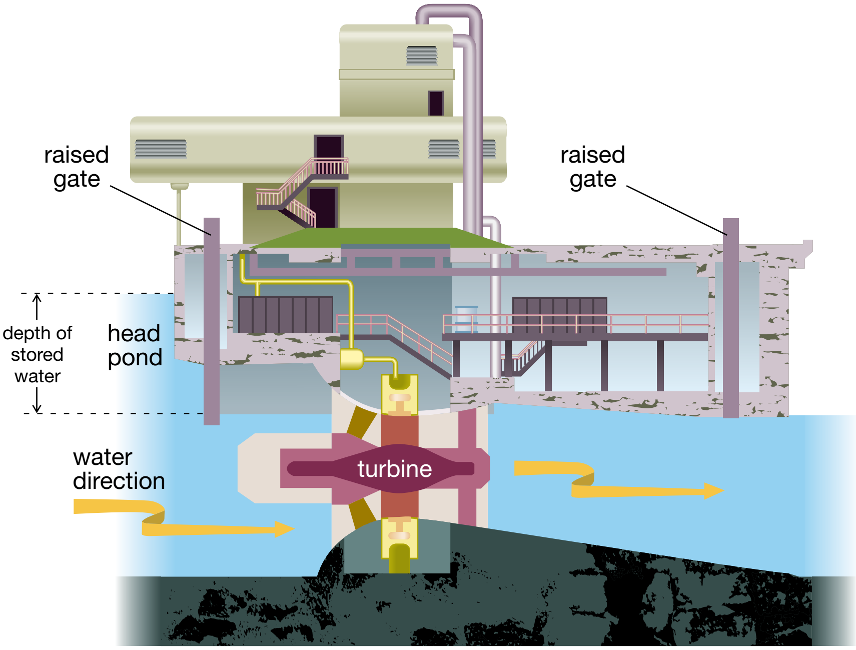
Figure D2.7: In Nova Scotia, tidal bore rafting has become a popular recreational experience. The rapids are created when incoming tidal water collides with outgoing river water.

Using Tides to Generate Electricity

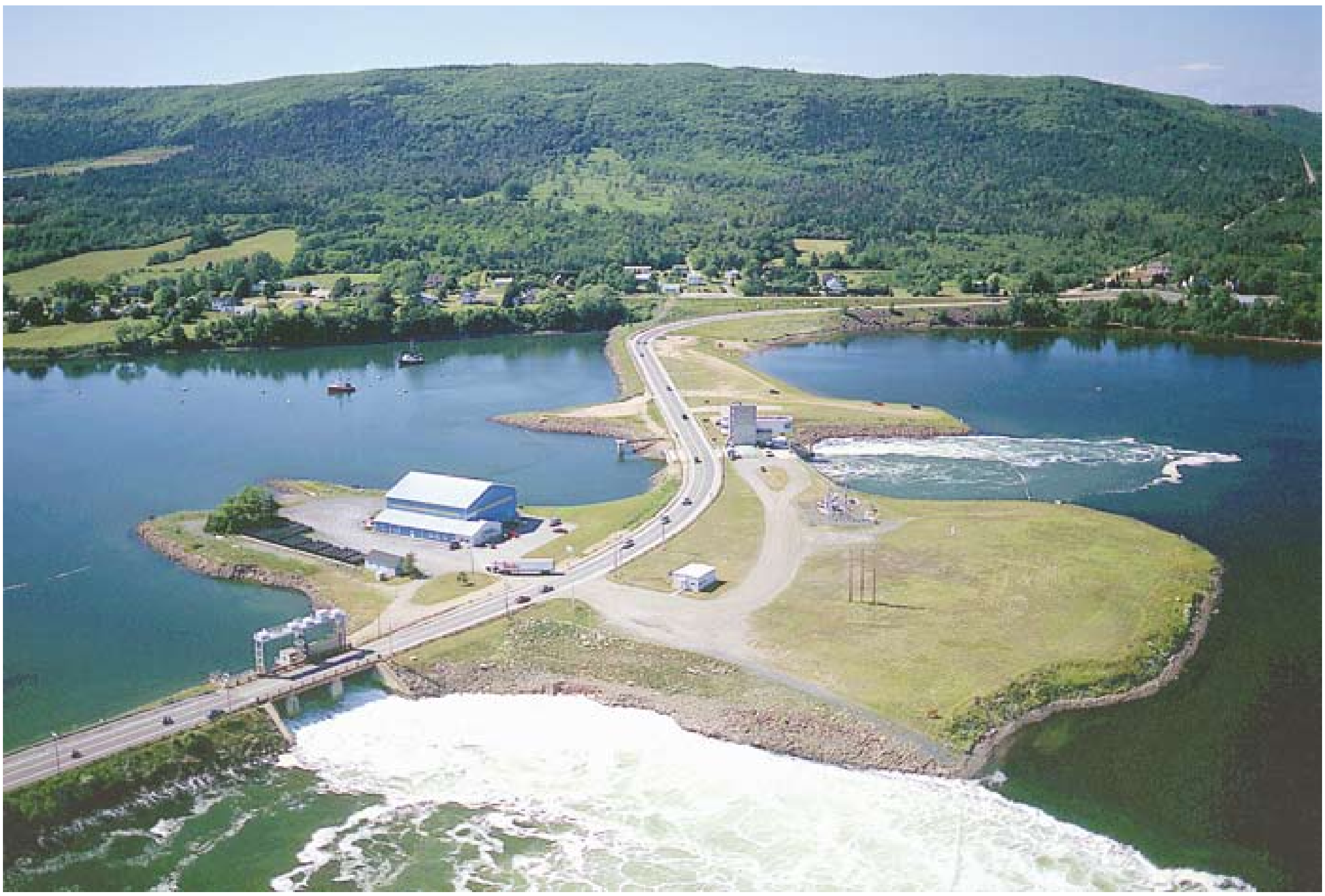
At all locations around the Bay of Fundy, massive amounts of water move in and then retreat. As the water reaches its higher level in the daily tidal cycle, it possesses increased gravitational potential energy, in contrast to its kinetic energy when it flows between high and low tide. The potential and kinetic energy associated with the rise and fall of water during ocean tides is known as **tidal energy**.

tidal energy: the gravitational potential energy and the kinetic energy of ocean water generated by tidal effects

Cross Section of Tidal Station



To harness tidal energy, a special type of barrier—often called a barrage—is constructed. When the tide comes in, electricity is generated as water flows through the turbines housed within the barrage. Water that has passed through the barrage is held in the estuary behind the barrage by gates. The gates act like valves in veins, preventing a backflow of water until it can be used to generate electricity. To generate electricity after high tide, the water held in the estuary is released through channels, flowing past the turbines connected to the generators. The Annapolis Tidal Station (seen in the photo below), located in the Bay of Fundy, generates 20 MW of electricity daily.



Assessing Tidal Energy

Like geothermal energy, tidal energy is a renewable resource. The energy of the water flowing through the turbine within the barrage is due to the potential and kinetic energy of the Earth-Moon system. Appropriate conditions for the conversion of tidal energy—a 5-m difference between low tide and high tide—only occur in a few localized areas. Even if these conditions can be met, the fact that high tides are spaced over 12 h apart means that energy from tides is only available at certain times; it is not available on a constant basis.

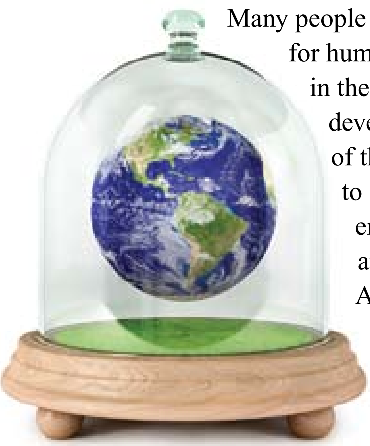
From an ecological point of view, tidal energy may appear to be a strong option because it does not involve the combustion of a fuel or produce harmful emissions. However, the presence of the barrage across the estuary could affect the ecology of the estuary—for example, it could interfere with the migration routes of fish.

Practice

9. Explain why the Bay of Fundy is one of the world's most promising tidal energy sites.

10. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of tidal energy as a source for producing electricity. **Note:** Keep your completed checklist for tidal energy because you will be asked to refer to it throughout this chapter.

2.1 *Summary*



Many people think that it is imperative for human communities to move in the direction of sustainable development. A cornerstone of this approach is for people to seek energy sources that ensure ecological, societal, and economic sustainability. Although there may be consensus that each of these categories is important, there is considerable variability in terms of the weightings that should be assigned to each category. This leads to a wide spectrum of opinions when it comes to evaluating conventional energy sources, like coal, as well as alternative energy sources, like geothermal and tidal energy.

2.1 *Questions*

Knowledge

1. Define the following terms.

- **a.** sustainable development
- **b.** geothermal energy
- **c.** tidal energy

2. Describe the energy transformations that occur to produce electricity from each of the following sources. Begin with the original source of the energy and finish with the electricity produced.

- **a.** geothermal energy
- **b.** tidal energy

3. Explain the classification of each of the following processes as being either renewable or non-renewable.

- **a.** combustion of coal
- **b.** fission of uranium-235
- **c.** fission of isotopes in Earth's core
- **d.** movement of water in ocean tides

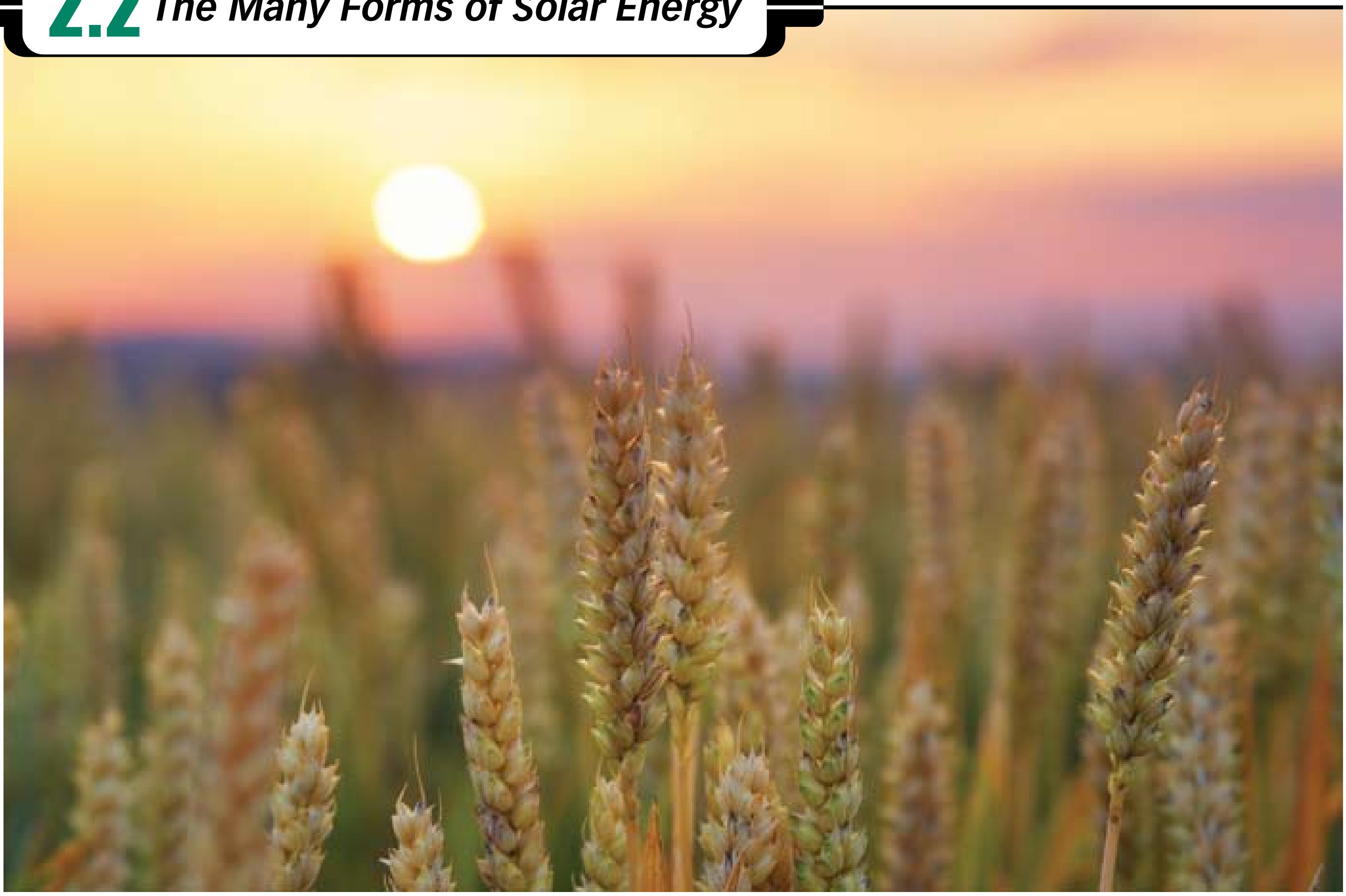
Applying Concepts

4. When energy is converted from one form into another, some of the energy is always lost. Use this idea to comment on the efficiency of a geothermal electrical generating station as compared to a coal-fired electrical generating station.

Earlier in this chapter you completed the "Determining Sustainability of Technologies" checklist to determine the sustainability of generating electricity using the following energy sources: coal energy, nuclear energy (fission), geothermal energy, and tidal energy. Review your completed checklists; then answer question 5.

5. Prepare a table that ranks the four methods from most sustainable to least sustainable. Support your ranking by writing a brief summary.

2.2 The Many Forms of Solar Energy



Every second, nuclear fusion reactions in the Sun convert about 4 billion kilograms of mass into energy. Only a tiny fraction of that energy from the Sun strikes Earth (about 1 billionth of the energy produced per year). Some of this energy reaching Earth is trapped by photosynthesis. As you have learned in previous science courses, solar energy is required either directly or indirectly by nearly all the organisms on Earth, including humans. Although only a small fraction of solar energy is captured as chemical potential energy, society's current outlook on energy involves a reliance on the combustion of fossil fuels.

Larger percentages of incoming solar energy are absorbed by land, water, and the atmosphere. Might it be possible to utilize solar energy converted into other energy forms? Could sources of solar energy eliminate the use of non-renewable energy sources (e.g., fossil fuels)? Can solar energy help make sustainable development a reality? In this lesson you will have an opportunity to survey some of the technologies that harness energy from the Sun.

passive solar energy: thermal energy derived from the Sun's radiant energy, absorbed by massive materials, and then transferred naturally to other areas by conduction, convection, and radiation

Passive Solar Energy

Have you ever noticed how a family pet seems to know where the warmest location is in its home? Often, it is near a window, where the pet can nap in the warmth provided by a sunbeam. A home's windows, walls, and floors can be designed to capture and store solar energy in the form of heat. The heat that is transferred to other areas of the building can be referred to as **passive solar energy**, since it is distributed without the need of a mechanical device. This captured energy is distributed by conduction, convection, and radiation.

During winter, the position of the Sun allows electromagnetic radiation to enter a passive solar home through the south-facing window and be absorbed by the concrete floor, as shown in Figure D2.8. When the radiation strikes the floor, the energy of the incoming photons is absorbed by the floor's molecules and transformed into thermal energy. Thermal energy within the floor is then transferred by conduction to regions of the interior space that are at a lower temperature. Thermal energy from the floor can also be transferred to the overlying air. The warmer air over the floor rises and is replaced by denser, cooler air. This creates convection currents in the room. To increase the efficiency of passive solar energy, materials used in a home's construction are designed to enhance the ability to absorb solar radiation. To prevent overheating in the summer, certain home designs (e.g., roof overhangs) help reduce the quantity of solar radiation directly entering the house.

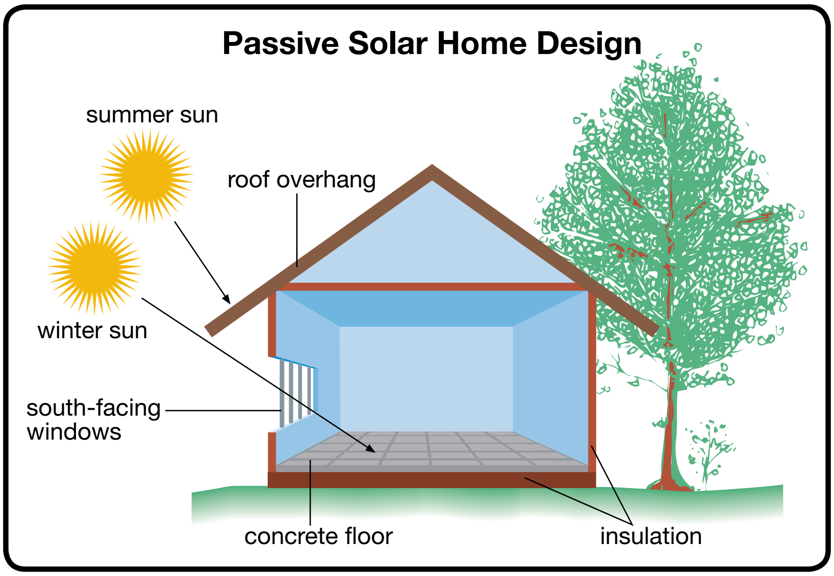
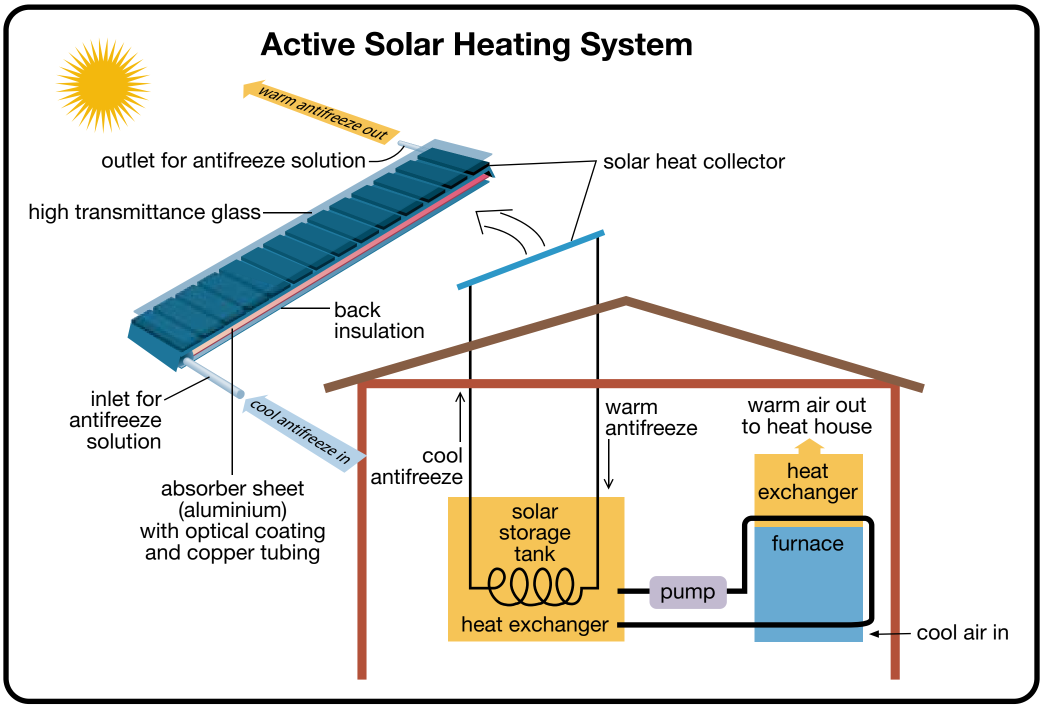


Figure D2.8

Active Solar Energy Technologies

Have you ever boarded a bus on a sunny day and found the seats to be hot to the touch? When solar radiation is absorbed (especially by a black surface), the result is heat. You may have noticed one popular solar technology—a **solar heat collector**—on some buildings. How does this device work to heat buildings? Earlier in this chapter, you saw how solar collectors are used on the roofs of garages in the Drake Landing Solar Community. In fact, over two million homes in North America are equipped with this technology.

solar heat collector: a device that absorbs radiant solar energy and converts it into thermal energy that is carried by a fluid pumped through the collector



Solar heat collectors typically consist of a flat, black box. Inside the box is a series of pipes that contains an antifreeze solution. As in Drake Landing, rooftop solar heat collectors absorb solar radiation striking the box, allowing a transfer of energy to the fluid inside the pipes. The transfer of energy heats the fluid. The fluid in the system is pumped through the collector and to a heat exchanger, where it releases thermal energy to water in a short-term storage tank. This tank could be located below the collector in the building.

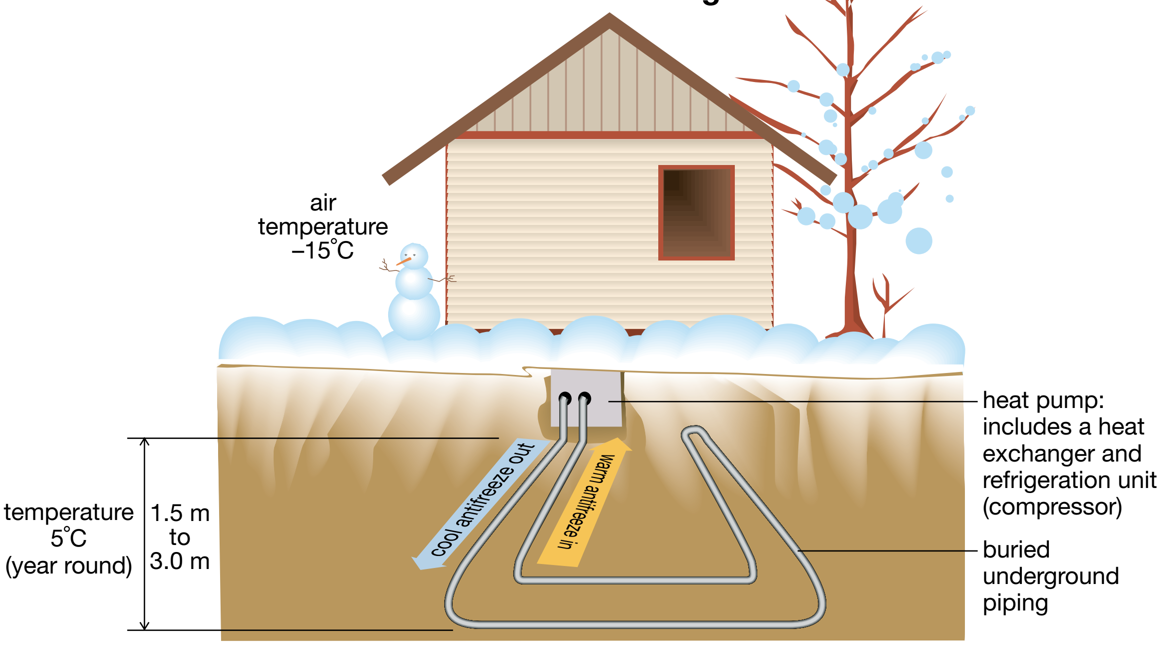
In Drake Landing Solar Community, the short-term storage tank is located in the neighbourhood's energy centre. Recall that for long-term energy storage, the community has a borehole thermal-energy storage system. Warm fluid is pumped into the deep boreholes to make an underground storage system for thermal energy. Since Drake Landing is a new community, it is expected to take years for the ground surrounding the boreholes to become fully charged with thermal energy. Once operational, the thermal energy stored from the summer months should enable the long-term storage system to meet most of the community's heating needs during the winter season.

Earth Energy Systems

Earth's surface absorbs over half of the incoming solar energy it receives. This is a huge amount of energy that, until recently, remained largely untapped. **Earth energy systems** work much like rooftop solar collectors except they use the ground like a single giant solar heat collector. Incoming solar radiation and heat radiated from inside Earth absorbed by the ground is converted into thermal energy. As you saw in your investigation of the Drake Landing renewable energy systems, warmed earth can act as an energy-storage reservoir. Weather changes that cause the atmosphere's temperature to fluctuate do not affect the temperature below ground, which remains much more constant year-round.

earth energy system: a heating system that uses a loop of piping through the ground to absorb thermal energy

Using an Earth Energy System for Winter Heating



The design of an earth energy system consists of a network of pipes installed underground to collect heat. These pipes can be arranged vertically in deep holes or horizontally in shallow trenches. The pipes are filled with a circulating antifreeze solution. During winter, thermal energy from the ground is transferred to the antifreeze where it can be extracted and used to heat the building. Although the temperature of the earth on the prairies is around 5°C, a heat-pump system similar to that used in a refrigerator, except run in reverse, concentrates the heat from the earth, allowing it to be delivered throughout the house. Earth energy systems are a proven technology, with some systems having been in operation since the 1940s. According to Natural Resources Canada, over 30 000 Canadian buildings are now heated and/or cooled using earth energy systems. Earth energy systems are expensive to install, but they require very little additional energy to operate, eventually providing a cost savings and reduced reliance on fossil fuels.

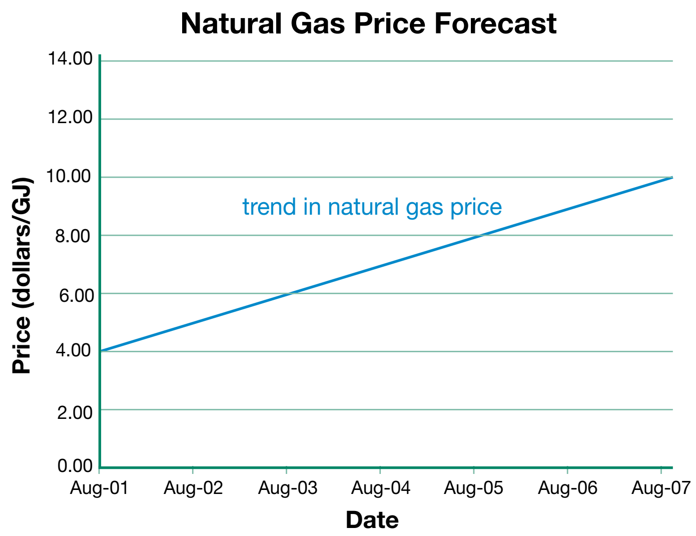
Practice

11. Explain how passive solar heating and other solar-energy systems involve the use of a renewable energy source.

12. Explain how earth energy systems are technology based on a renewable source of energy.

Use the following information to answer questions 13 and 14.

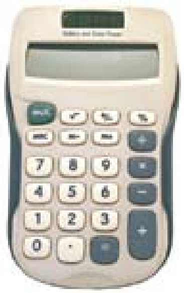
Users of natural gas in Canada often encounter price fluctuations from month to month. Due to its finite supply, the price of natural gas is undergoing an upward trend.



13. State two reasons why natural gas prices fluctuate.

14. Many consumers are concerned about increasing heating costs. Do you think that the cost of an earth energy system would fluctuate in a manner similar to natural gas prices? Provide a reason for your answer.

Photovoltaic Cells—Electricity Directly from EMR



In Unit C, a **photovoltaic cell** was used in many of the investigations that explored the properties of electromagnetic radiation (EMR). Photovoltaic cells convert radiant energy in a manner quite similar to what occurs in photosynthesis. When a photon of electromagnetic radiation is absorbed by a photovoltaic cell, atoms of the light-sensitive material within the cell eject electrons. Brighter light sources provide the cell with a larger population of photons, resulting in a larger number of electrons that are ejected. Recall that moving electrons form an electric current (Unit C). Since the energy given to each of the electrons is relatively small, the current is weak (as shown in Figure D2.9, where the cell tested has a voltage output of less than half a volt). The low energy efficiency of photovoltaic cells can restrict their use to low-power devices, such as calculators. Connecting many photovoltaic cells together, forming an array, produces more energetic electric currents; but this requires a large area.

photovoltaic cell: a device that converts electromagnetic radiation into electrical energy

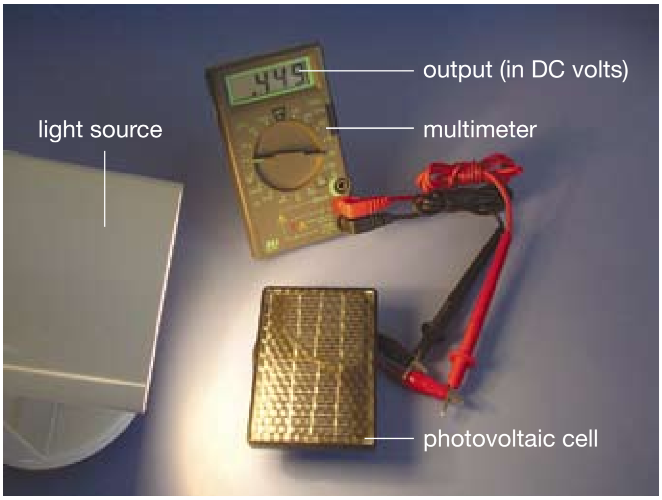


Figure D2.9

Figure D2.10: An array of photovoltaic cells can provide sufficient electrical energy for electrical devices.

Photovoltaic Cells for Home and Business

Given that photovoltaic cells are renewable sources of energy that produces no emissions during their operation, it is natural to wonder why photovoltaic cells have yet to be used on a large scale for homes and businesses.

One reason photovoltaic cells aren't used on a large scale is that they don't work in the dark. That means batteries are needed for use at night or on overcast days. Second, photovoltaic cells produce direct current (DC) electricity. Most appliances used in homes and businesses use alternating current (AC) electricity, meaning that an inverter is needed to convert the DC current into an AC current. Third, photovoltaic cells are not very efficient. Heavy-duty applications, like operating large appliances, require huge arrays of cells that cover an enormous area. This is not practical. Finally, photovoltaic cells are expensive to produce and require toxic heavy metals, like arsenic and cadmium. Strict adherence to safety guidelines is necessary to produce photovoltaic cells without harming humans or the environment.

Despite these challenges, photovoltaic cells are being used in an increasing number of applications: as energy sources for small devices and as supplemental or back-up power to primary power systems. As further improvements are made to the manufacturing process, the cost of photovoltaic cells, batteries, and inverters may decrease. This low cost will most likey make photovoltaic cells a more attractive alternative.

Figure D2.11: This garden lantern uses a photovoltaic cell to charge a small battery pack during the day so it is able to light a walkway at night.

DID YOU KNOW?

The area of photovoltaic arrays used to provide electrical energy to the International Space Station (ISS) is slightly larger than the end zone of a Canadian football field. The reflection of unabsorbed sunlight from the surface of the arrays on the ISS makes it the brightest object in the night sky when viewed from Earth. You can use the Internet to find the time and position from which the ISS can be seen in the night sky.

Practice

15. When white light lands on the surface of a photovoltaic cell, photons from all regions of the visible spectrum deliver energy to the light-sensitive materials.

- **a.** Sketch a diagram to show red, green, and violet photons landing on the surface of a photovoltaic cell.
- **b.** Which type of photon—a photon of red light or a photon of violet light—delivers the most energy to the photovoltaic cell.

16. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of photovoltaic cells as an energy source. **Note:** Keep your completed checklist for photovoltaic cells because you will be asked to refer to it throughout this chapter.

Hydroelectric Power

Moving water possesses kinetic energy. One of the oldest technologies to utilize water's energy is the water wheel. Earliest records of water wheels date back to 400 BC, when they were used by Greeks to grind grain. Later, in Europe, water wheels powered the saws, pumps, and machinery in a variety of mills.

Kinetic energy of flowing water is an important energy source that is often used to generate electricity. Hydroelectric power supplies about 19% of the world's electricity. Over 95% of Quebec's electrical energy production comes from the energy of flowing water—the largest percentage of any province. The ability to produce excess electricity beyond provincial demand enables Quebec to sell much of the electricity it generates to cities in the United States.

Figure D2.12: Water wheels have been used throughout history to power a variety of machines. As water falls from a higher elevation to a lower elevation, the wheel converts the water's gravitational potential energy into kinetic energy.

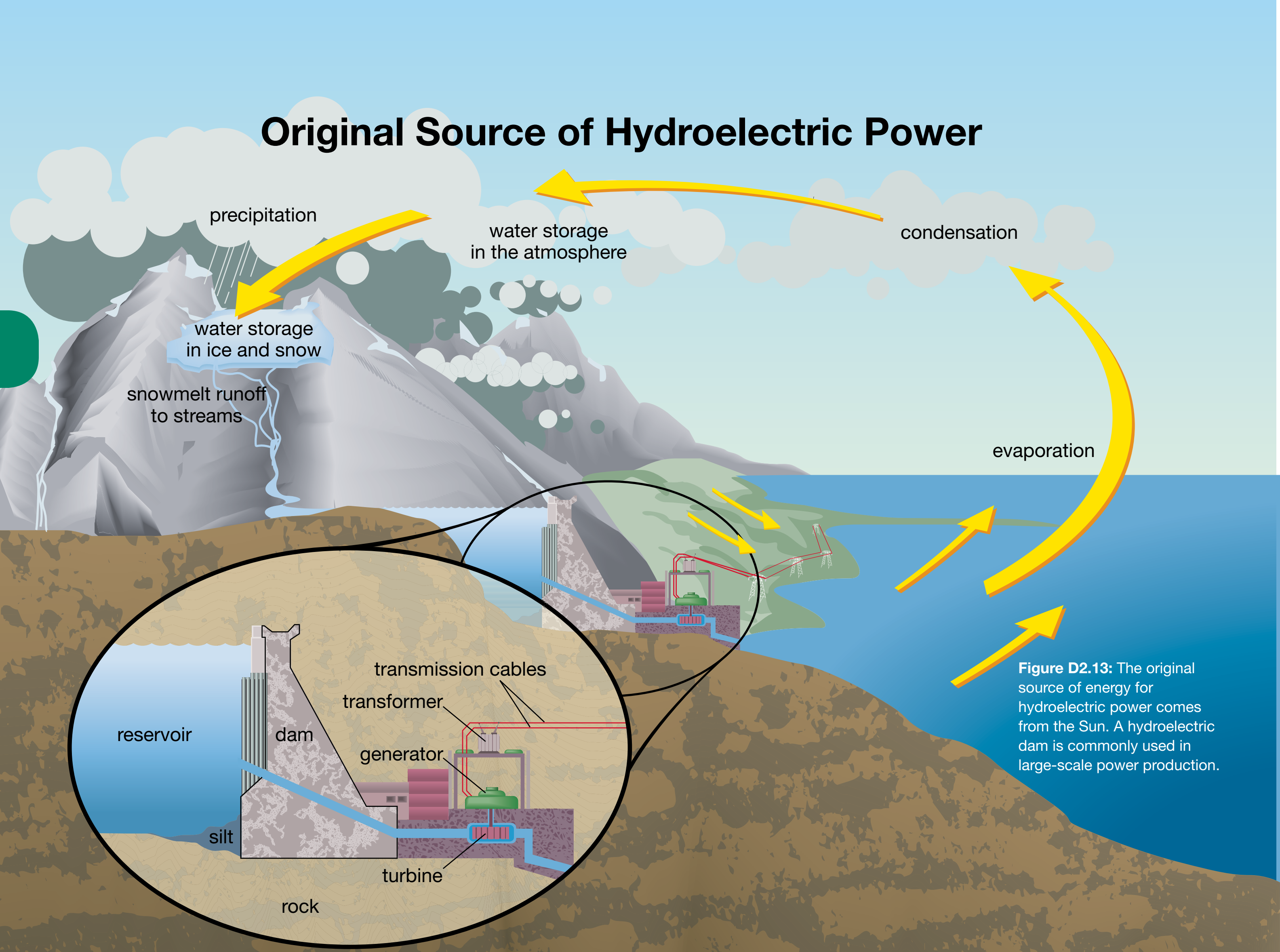


Figure D2.13: The original source of energy for hydroelectric power comes from the Sun. A hydroelectric dam is commonly used in large-scale power production.

In Lesson 2.1 you prepared process maps for some technologies that convert energy. What would a process map for hydroelectric energy look like? Is hydroelectric power a renewable energy? It may surprise you to know that the original energy source for hydroelectric power is the Sun. Water heated by solar radiation at lower elevations evaporates, allowing it to rise and be carried by air currents in the atmosphere, often over great distances. Eventually, water vapour condenses, forming clouds and precipitation. Precipitation that falls at higher elevations has gained gravitational potential energy, which can be converted into kinetic energy once it begins to run downhill. Since the energy from the Sun is inexhaustible, hydroelectric power, like other solar-based technologies, are processes providing renewable energy.

Dams are commonly used to convert gravitational potential energy of water into electricity. Dams can concentrate and control the energy in moving water by storing it in a large reservoir. In some dams, the difference in height between the reservoir and the turbines is over 200 m. The higher the water level, the faster the water flows through the turbine (increasing the kinetic energy). The force of the flowing water pushes against turbine blades, causing them to turn. As with other technologies you have evaluated, the turbines are attached to generators that convert the kinetic energy into electrical energy. The electrical energy from the generators is transferred to transformers that increase the voltage so that energy loss due to resistance in the transmission lines is minimized.

Hydroelectricity in Alberta

Hydroelectric dams in Alberta currently supply about 5% of the province's electricity. This low value, which is less than many other provinces, may be the result of the plentiful supply of coal in Alberta, which is used to generate over 75% of Alberta's electrical energy. Although some people suggest that Alberta should be utilizing more hydroelectric power, as you'll see in the next activity, the development of large-scale hydroelectric projects requires careful consideration of ecological, societal, and economic risks and benefits.

Assessing Hydroelectric Power

As an energy source, hydroelectric power has many strengths:

- The underlying energy source is the Sun, making it a renewable source of energy.
- Power production does not release any harmful emissions into the environment.
- The water used is not polluted or consumed as it passes through the turbines and is able to re-enter the water cycle.
- Very little waste heat is generated, meaning that this is a very efficient process. (Over 80% of the gravitational potential energy of the water is transformed into electrical energy.)
- The high energy efficiency enables the cost per kilowatt-hour of energy produced to be relatively low.

Major criticisms of hydroelectric power focus on the environmental impact resulting from the reservoir of water held behind the dam. As the reservoir fills, large areas of land are covered with water. This may include usable farmland, forests, and even cities. The action of flooding such areas may have an impact on the natural aquatic ecosystem. Dams impede the movement of nutrient-rich silt carried by the flow of the river that is important to the fertility of land downstream. In some situations, leaching of metal ions occurs from soils in the flooded area, affecting the quality of water in the river. These factors can put enormous stresses on species living upstream and downstream of the reservoir. Societal concerns include the potential for the forced relocation of entire communities that may have inhabited the area for long periods of time, resulting in the loss of archaeological sites and cultural artifacts.

Any area to be developed for the collection of hydroelectricity must demonstrate suitable geography and rainfall patterns. In addition, the location should be geologically stable to reduce possible damage to the structure from the effects of earthquakes.

Figure D2.14: The Oldman Dam near Pincher Creek, Alberta, provides 25 MW of electrical energy as well as water for irrigating crops in southern Alberta.

Try This Activity

Making a Decision About Hydroelectric Dam Construction

Purpose

In this activity you will review a document summarizing a decision made in response to a proposal to build a hydroelectric dam on a river in northern Alberta. Many impacts of hydroelectric dams are identified within the decision.

Problem

What are the risks and benefits of hydroelectric dams? What perspectives are considered when making decisions regarding the development of hydroelectric projects?

Procedure

Read the "Hydroelectric Dam Construction" handout from the Science 30 Textbook CD.

Analysis

1. Prepare a risk-benefit analysis of hydroelectric dams.
2. Prepare a list of perspectives considered in the decision.
3. Evaluate the decision made regarding the proposed hydroelectric project. In your evaluation, comment on whether relevant risks and benefits was accurately assessed and whether a suitable range of perspectives was considered in making this decision.

Practice

17. In Figure D2.13 showing the original source of hydroelectric power, a large transformer is shown above the generator.

a. Explain why a transformer is vital to the transmission of electricity from the hydroelectric plant to distant consumers.

b. Determine whether a step-up transformer or a step-down transformer is required.

18. Obtain the document “Determining Sustainability of Technologies” from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of hydroelectric dams as an energy technology. **Note:** Keep your completed checklist for hydroelectric power because you will be asked to refer to it throughout this chapter.

Use the following information to answer questions 19 to 21.

The Three Gorges Dam spans the world’s third-largest river, the Yangtze River in China. This project began in 1997 and, when completed, will be the largest dam in the world. The Three Gorges Dam will span 2 km, and the power plant will be capable of generating 18 000 MW of electrical energy.

ENERGY DATA FOR CHINA

Electricity Production (2006)	
2.83×10^5 MW	
Energy Source for Electricity Production	**Percentage of Energy Produced**
coal	83%
hydro	14%
nuclear	2%
other	1%

Four Criticisms of the Three Gorges Dam

I. 1.3 million people have been displaced by the construction of the dam and flooding of the reservoir.
II. The flooded reservoir area contains former factories, industrial centres, and garbage dumps, resulting in pollution to the Yangtze River.
III. The construction of the dam could result in the extinction of some rare species of fish.
IV. The location of the Three Gorges Dam is near six seismic faults that have demonstrated activity.

19. Calculate the percentage of China’s electricity production that could be met once the Three Gorges Dam is operating at full capacity.

20. Identify the impact that power production from the Three Gorges Dam could have on China in terms of societal and ecological impact.

21. Respond to one of the criticisms of the Three Gorges Dam project listed, by defending the project.

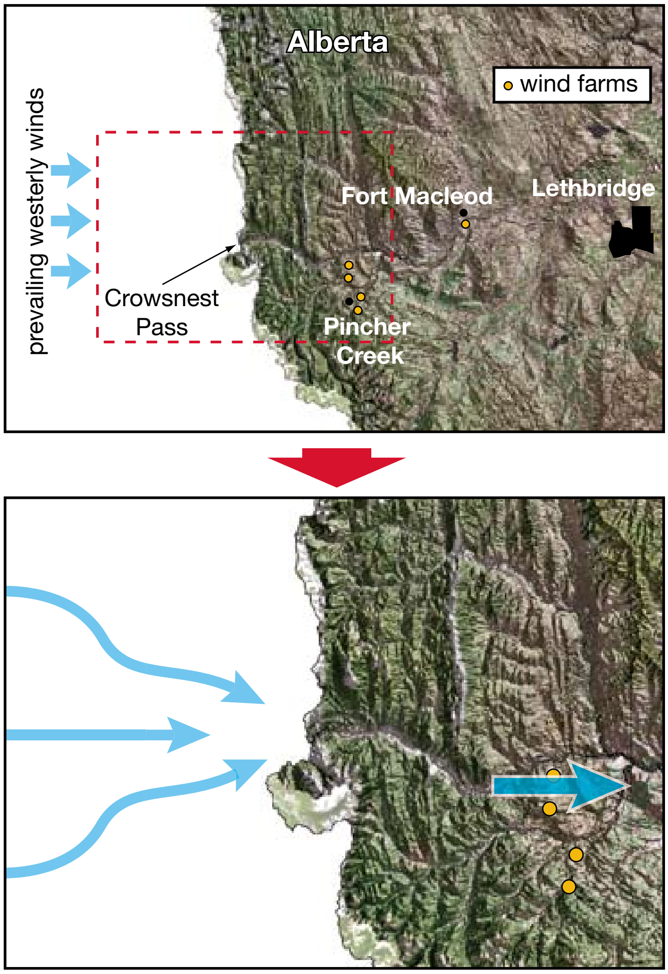
Wind Energy

Have you ever been on the streets of a large city on a windy day? Tall buildings can dramatically intensify the speed of the wind, turning some streets into virtual wind tunnels. The effect that buildings have on wind is similar to the change to water flowing down a stream that suddenly narrows. Since the same volume of water is rushing through a narrower opening, its speed must pick up. You might be surprised to know that this same effect makes the southwestern corner of Alberta one of the best places on Earth to harness wind energy.

Figure D2.15: These wind turbines, along with hundreds of others, generate electricity by converting the energy from the steady, high winds in certain regions of Alberta.

Earlier you reviewed the effect that thermal energy has in creating air currents. Solar energy can be converted into thermal energy, which affects the kinetic energy and density of molecules in the air. As air molecules absorb thermal energy, they move faster and take up more space, thus decreasing in density. In Unit B you learned that the predominant direction of winds across the prairies is from the west, and that these winds are created by the combination of global convection currents and Earth's rotation. In some parts of Alberta, the westerly winds are especially strong and have become a source of energy.

Locations of Larger Wind Farms in Southern Alberta



In western Canada, numerous ranges of mountains form natural barriers to these westerly winds. However, when the prevailing winds encounter a gap between mountains, like at Crowsnest Pass, the energy of the wind becomes concentrated as it is funnelled through the narrow opening between mountains. The wind follows the valleys and travels east into southern Alberta. Elevation drops as the mountains give way to the foothills and then to the prairies. Other atmospheric effects further intensify the kinetic energy of the wind. The end result is that places like Pincher Creek, Fort Macleod, and Lethbridge have wind conditions ideally suited to run wind turbines. The kinetic energy of the moving air pushes against the blades of a wind turbine and causes the blades to spin. As is the case with all electric generating apparatus, a spinning turbine connected to a generator converts the kinetic energy of the spinning blades into electrical energy.

Figure D2.16: Two technicians inspect the enormous blade of a wind turbine.

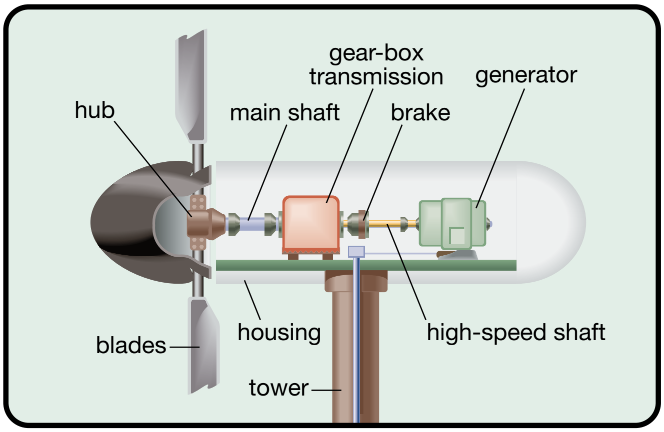


Figure D2.17: The kinetic energy of the spinning blades is transferred to the generator, which transforms it into electrical energy.

There is a great deal of interest in wind energy. Currently, wind energy is the fastest growing form of electricity generation in Canada. However, it provides only a small portion of Canada's electricity. As you learned earlier, the ultimate source of energy for wind power is the Sun, making wind energy a renewable resource. It is impossible for air to be "used up" during the process and there are no harmful emissions. Wind energy is also very versatile. Large wind farms—made up of hundreds of turbines—have the ability to supply electricity to communities; and single, smaller turbines can be used to meet the electricity demands for a single isolated home.

The limitations of wind energy are similar to those of other renewable sources. As you have learned, only certain locations have the proper conditions to allow for suitable, nearly constant winds. Wind energy also shares two drawbacks associated with photovoltaic cells: the energy source can be quite variable from day to day and the conversion into electrical energy is not very efficient. In the case of wind energy, only about 30% of the energy in the wind is transformed into electrical energy. This means that generating a significant amount of electrical energy requires many wind turbines that occupy a large area. Although the land used for a wind farm can also be used for grazing livestock or for other agricultural activities, it still must be set aside.

Other effects of wind energy have emerged since the technology has been used. In Alberta, scientists at the University of Calgary have been investigating the effect that the moving blades of the turbines have on bat populations. Similar concerns exist over the number of birds killed by the blades of wind turbines. Some landowners report that the noise produced by the rotating blades can be annoying and that the site of the giant turbines is a form of visual pollution—as it ruins the view of the landscape.

Practice

22. Describe the factors that make the area around Pincher Creek well-suited for harvesting wind energy.

23. Obtain the document "Determining Sustainability of Technologies" from the Science 30 Textbook CD. Follow the instructions in the document to determine the overall sustainability of wind energy as an energy source. **Note:** Keep your completed checklist for wind energy because you will be asked to refer to it throughout this chapter.

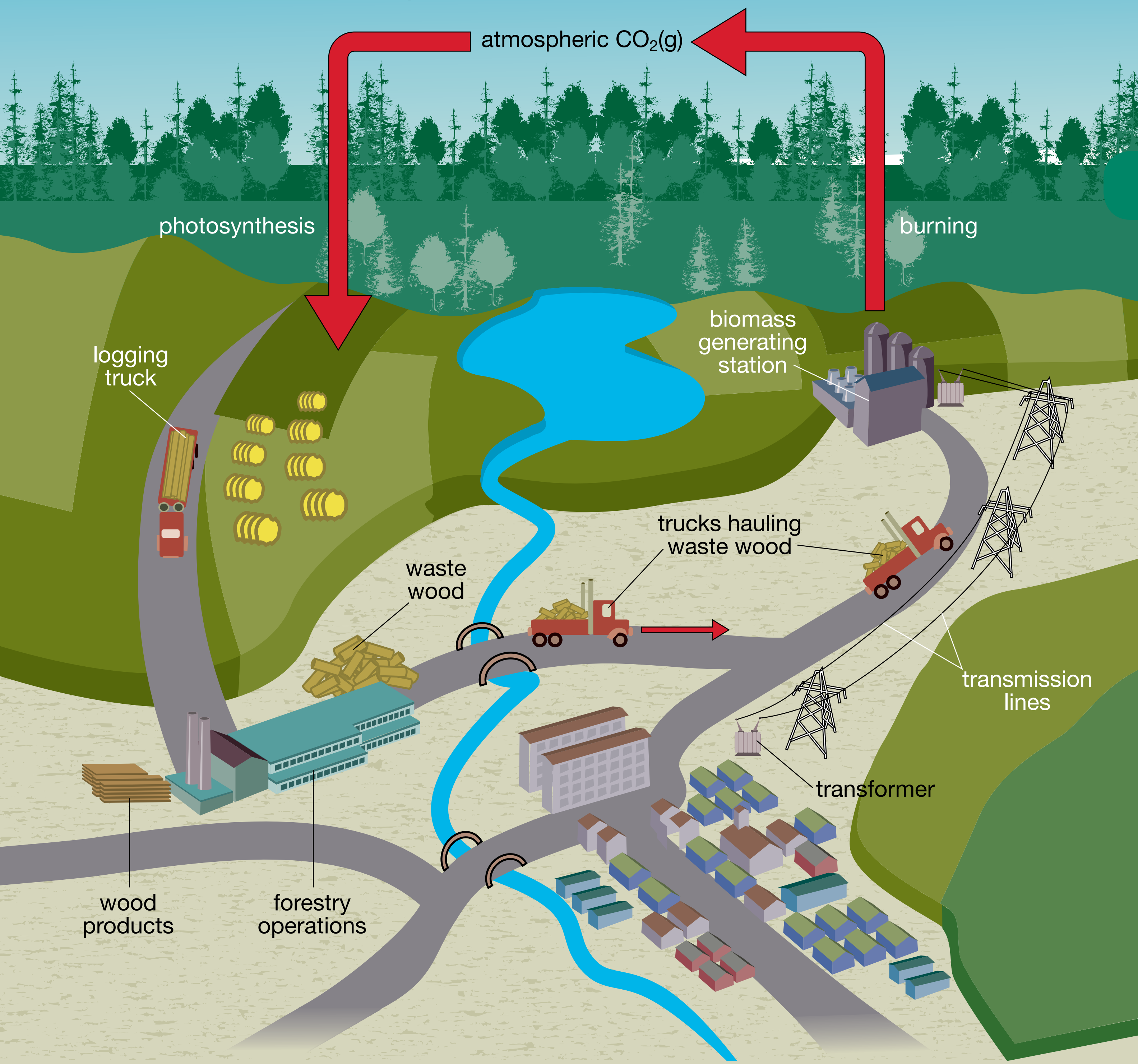
Biomass

You have learned that many energy sources used by society can be traced back to solar energy. Photosynthesis—the chemical reaction that converts the Sun's radiant energy into chemical potential energy—allows plant material to be used as an energy source either as food or as **biomass**. The chemical potential energy within recently living organic material such as wood, corn, or organic waste can be used as a source of renewable and potentially sustainable energy.

biomass: plant matter or agricultural waste from recently living sources used as a fuel or as an energy source

Figure D2.18: Wood, an example of biomass, was likely the first fuel used by humans for heating and cooking.

Biomass Energy—Emission and Absorption of CO_2



DID YOU KNOW?

Biomass refers to organic matter from living or recently living sources. Fossil fuels are not considered biomass because they were derived from plants and animals that died millions of years ago.

Direct Combustion—Generating Electricity Using Biomass

Modern forestry operations produce waste wood products, such as timber debris, sawdust, and wood chips. Waste wood can be sent to a landfill or be combusted on site, but neither of these processes provides an opportunity to reduce emissions or use the energy remaining in this biomass.

The generating station (shown in Figure D2.19) in Whitecourt uses waste wood from nearby forestry operations to produce electricity. The combustion of the waste wood within a furnace is used to heat boilers that produce the steam needed to drive turbines connected to generators. The Whitecourt Generating Station utilizes modern emissions-control technology to reduce the release of particulate matter and oxides of nitrogen.

Although the plant material is combusted, resulting in carbon dioxide emissions, biomass can be produced in a sustainable manner. Sustainability involves the absorption of carbon dioxide by the next generation of plant material. Earlier in this lesson you prepared a process map demonstrating the interrelationship between combustion and photosynthesis. The combination of combustion and crop planting to absorb carbon dioxide make biomass energy use a “carbon-neutral” process. When biomass fuels are used in place of fossil fuels, the carbon in the non-renewable fossil fuels stays in the ground. Estimates indicate that biomass power production is not exactly carbon-neutral, releasing just under 40 g of carbon dioxide per kilowatt-hour of electrical energy produced. As you discovered in Unit C, this value compares favourably to conventional coal-fired plants, which emit about 1000 g of carbon dioxide for every kilowatt-hour of electrical energy produced.

Figure D2.20: Waste wood piled outside a mill

Figure D2.19: The Whitecourt Generating Station uses waste wood products as a fuel to produce steam for electricity production.

Practice

24. Refer to the illustration “Biomass Energy—Emission and Absorption of CO_2” on page 547.

a. Identify any activity depicted in the illustration that increases CO_2 emissions, affecting the ability of the process depicted to be carbon-neutral.

b. The illustration focuses on the energy derived from waste wood products. Identify other sources of biomass that could also be used to generate electricity.

25. Obtain the document “Determining Sustainability of Technologies” from the Science 30 Textbook CD. Follow the instructions given in the document to determine the overall sustainability of generating electricity from biomass. **Note:** Keep your completed checklist for biomass because you will be asked to refer to it throughout this chapter.

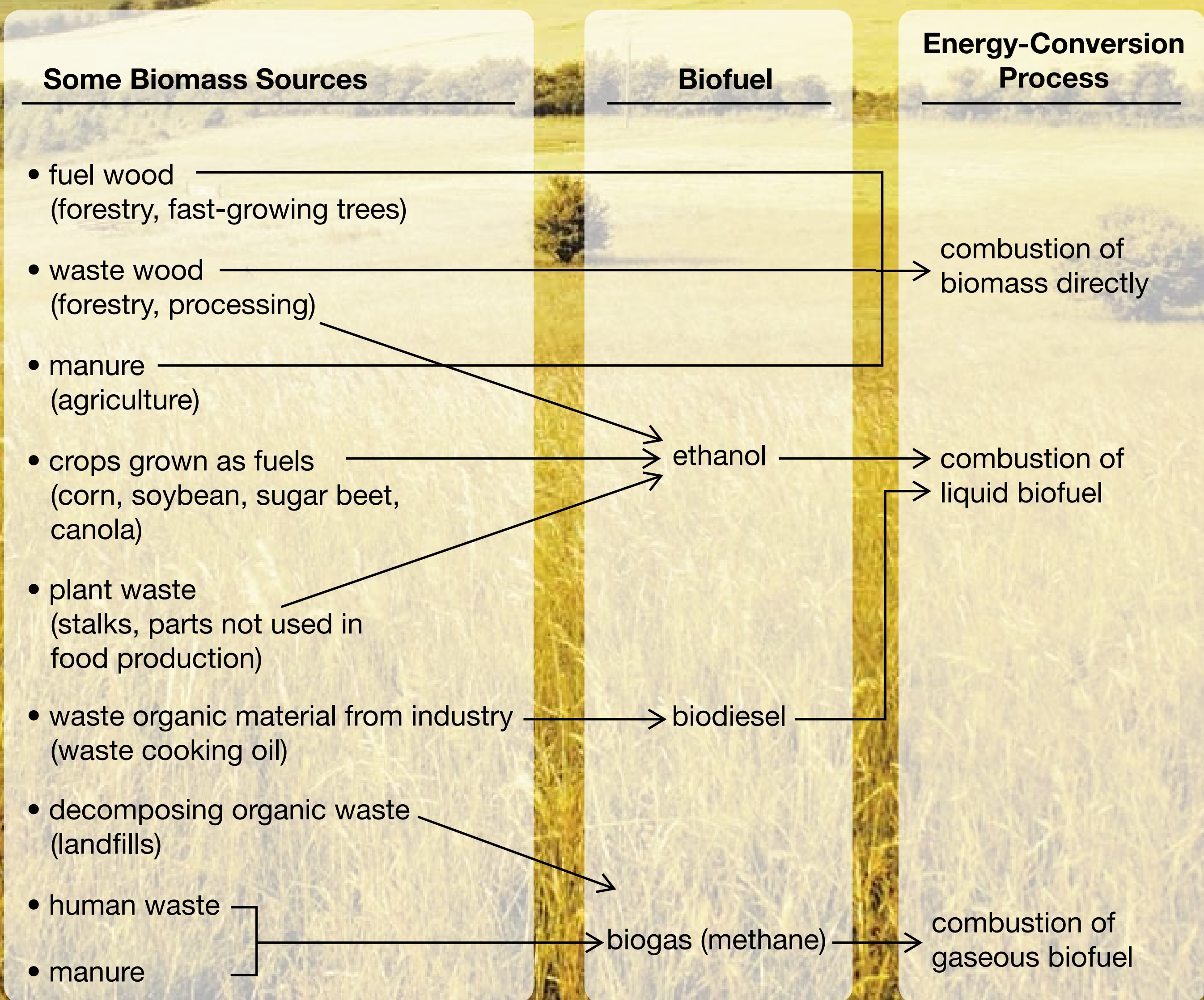
Biofuels

Biomass as an energy source has many advantages. Usable sources of biomass tend to be readily available; and since most forms are combustible, complex technology is not required to use them. If society is to consider using biomass fuels to develop improved energy sustainability, the largest advantage of biomass is the ability to convert it into a **biofuel**. Methane, ethanol, and the mixtures in biodiesel are composed of high-energy molecules. This means that the biomass energy they produce can be applied to a great number of technologies including automobiles.

biofuel: a fuel produced from renewable biological resources, including biomass

DID YOU KNOW?

The quantity of solar energy absorbed by photosynthesis is almost ten times greater than the current world energy demand. Using biomass makes some of this energy available for use.



Ethanol in Gasoline

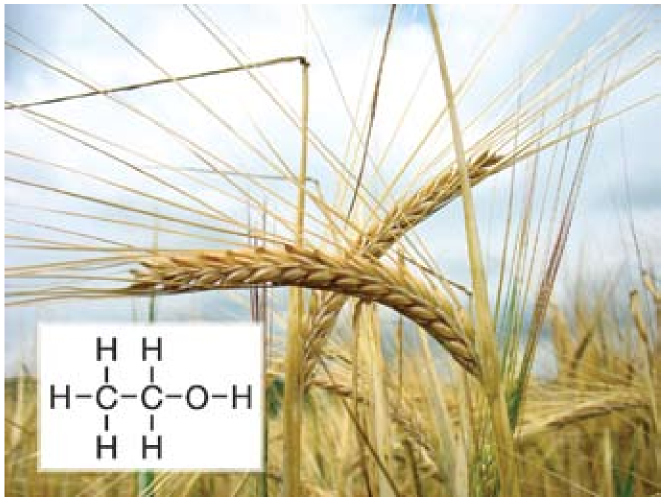


Figure D2.21: Ethanol, $C_2H_5OH(l)$, can be produced by fermenting grain, corn, wood, or other plant products. Ethanol can be combusted directly or blended with gasoline as a way to reduce the content of nonrenewable substances in gasoline.

In Unit B you studied alcohols. Ethanol, an alcohol, is a highly usable biofuel that can be produced using yeast to ferment the sugars within organic matter like crop plants and even waste wood. Humans have used yeast to produce ethanol to make alcoholic beverages for thousands of years. As you learned, alcohols like ethanol are combustible, making them an excellent fuel.

Ethanol produced from biomass is currently blended with gasoline. New automobiles can operate with gasoline containing up to 10% ethanol, with some special models being able to use gasoline containing up to 85% ethanol. Small amounts of ethanol can also be added to diesel; but at high percentages, modifications to the engine are necessary.

Ethanol from biomass is considered to be a renewable energy source because it is derived from crops that can be continually grown. In Brazil, ethanol for gasoline is produced using sugar cane. The growth of new crops absorb carbon dioxide from the atmosphere, enabling the production of new biomass and making the process sustainable. Brazil's use of biomass has significantly reduced the country's reliance on oil imports and has reduced its contribution to global climate change.

A major criticism of biomass energy focuses on the large amount of land needed for the growth of the crops and on the decision to use a potential food source as a fuel for transportation. Throughout your studies in Unit B, you discovered that current agricultural practices include the use of fertilizers, herbicides, and pesticides. These practices can have adverse effects on the environment. It is hoped that any increase in crop production for use in making biofuels will be accompanied by sustainable agricultural practices.

An additional concern involve the loss of efficiency in the making of a biofuel. You have learned in this unit that whenever energy is converted, there is a loss of some of the input. Critics of biofuel production cite two sources of inefficiency. First, biofuels produce methane and ethanol, which contain few carbons, making them low-energy molecules compared to the complex organic molecules from which they were derived. Second, high concentrations of ethanol are toxic to many organisms, including the yeast involved in the fermentation process. This toxicity means that it is difficult to produce sufficient ethanol to meet projected demands. Currently, scientists are working on developing strains of micro-organisms that will continue to ferment biomass at higher ethanol concentrations. It is hoped that efforts to develop these micro-organisms will improve the efficiency of biofuel production and increase the potential for biomass use.

Landfill Gas

Garbage in a landfill is sealed off from oxygen by the layers of garbage and dirt above it. Under these oxygen-free conditions, bacteria digest organic waste and release methane—the main component of natural gas. This biogas can be collected using a network of pipes and then used as a fuel for the production of electricity. Many major cities, like Calgary, Edmonton, and Grande Prairie, have constructed landfills to allow for the collection of biogas. At the Clover Bar Landfill in Edmonton, a 4.8-MW biogas facility produces enough electricity for 4600 Edmonton homes.

Biogas can also be collected from feedlots or other intensive agriculture operations where manure is allowed to decompose in the absence of oxygen.

Biodiesel

The chemical potential energy within waste oils can be a source of energy. In the “Determining Heat of Combustion” investigation on page 494, you learned that organic molecules containing many carbon atoms can store a large quantity of chemical potential energy. You also learned from your study in Unit B that fats and oils are esters of large organic acid molecules joined to a glycerol molecule. In some automobile engines, waste cooking oil can be used directly as a fuel. Biodiesel is a mixture of organic acids obtained from the conversion of waste cooking oil and diesel fuel. The reaction to produce biodiesel from waste cooking oil involves breaking the bonds within the molecules of the ester functional groups within the chemical structure of the waste cooking oil. Breaking the ester bonds helps maintain the proper viscosity of the resulting biodiesel. The blending of biodiesel with conventional diesel fuel is designed to maintain the energy content of the product and decrease the amount of fossil fuels consumed.

Practice

26. Burning ethanol releases carbon dioxide. Identify aspects of ecological sustainability associated with the production and combustion of the biofuels ethanol and biodiesel (formed from canola or other vegetable oils).

27. Biogas often contains impurities like hydrogen sulfide, $H_2S(g)$. Identify possible problems associated with the combustion of biogas containing hydrogen sulfide.

Hydrogen—Fuel of the Future?

Research into the use of biodiesel is one attempt to reduce the use of fossil fuels as the main energy source for transportation. Another approach is the development of the hydrogen fuel cell.

In many ways, a fuel cell is similar to an electrochemical cell. It consists of two electrodes separated by a membrane that allows ions to pass. Electrons extracted by the reaction of the fuel in the cell flow through an external circuit to any electrical device, like a car’s electric motor. Without a constant supply of reactants, power production from a fuel cell immediately stops.

A variety of fuel cells exist, but one of the most tested types is the hydrogen fuel cell. Hydrogen enters the fuel cell at one electrode while its reactant—oxygen—enters the fuel cell at the other electrode. Within the fuel cell, the two reactants never come into direct contact; but each reactant is absorbed by opposite sides of a material containing a catalyst. The catalyst allows hydrogen to react in such a way that it provides electrons for the external circuit as well as positively charged ions that migrate through the membrane to complete the flow of charge. The changes during the operation of the fuel cell (as shown in Figure D2.22) result in a flameless combustion reaction between hydrogen and oxygen that produces an electric current rather than a flame.

In 2006, the use of hydrogen fuel cells in Canada was uncommon. Five buses equipped with hydrogen fuel cells in Victoria and Vancouver were some of very few examples where this technology was used. But with more research and development, fuel-cell automobiles may become an increasingly common sight. Currently, the application of the technology is limited by the high cost for the catalysts used in fuel cells and the size of the cells required limit application of the technology. Researchers are optimistic because the hydrogen fuel cell is a very energy-efficient device that has only one emission—water vapour.

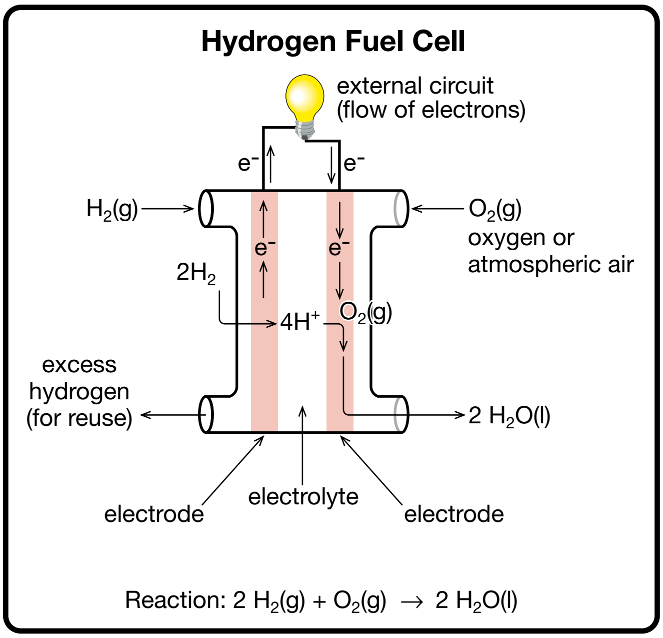


Figure D2.22

A major drawback to the wide-scale use of hydrogen fuels is the limited supply of hydrogen. Elemental hydrogen, $H_2(g)$, is not readily available; but it can be extracted from hydrocarbons or water, both energy-rich molecules. Hydrocarbons, for example CH_4, and water, H_2O, are possible hydrogen sources. The process of removing hydrogen from these two possible sources is not without controversy. Removing hydrogen from hydrocarbons can involve a process called steam reformation. Industrially, the reformation and additional reactions to produce hydrogen result in the formation of carbon monoxide, carbon dioxide, and coke (C(s)).

Decomposition of Water

$$2\ H_2O(l) \xrightarrow{\text{electrical energy}} 2\ H_2(g) + O_2(g)$$

In previous science courses, you may have observed the electrolysis of water, where an electric current is applied to water, resulting in the decomposition of water. In order for fuel cells to be a sustainable technology, the electricity used for electrolysis must come from a renewable source (e.g., wind, nuclear, solar, or hydro). In addition, the source of the water that is electrolyzed must also come from a renewable source. Concerns over drought and a decrease in drinkable water may cause seawater to become a likely source for hydrogen to power cars in the future.

Try This Activity

Producing Hydrogen Fuel

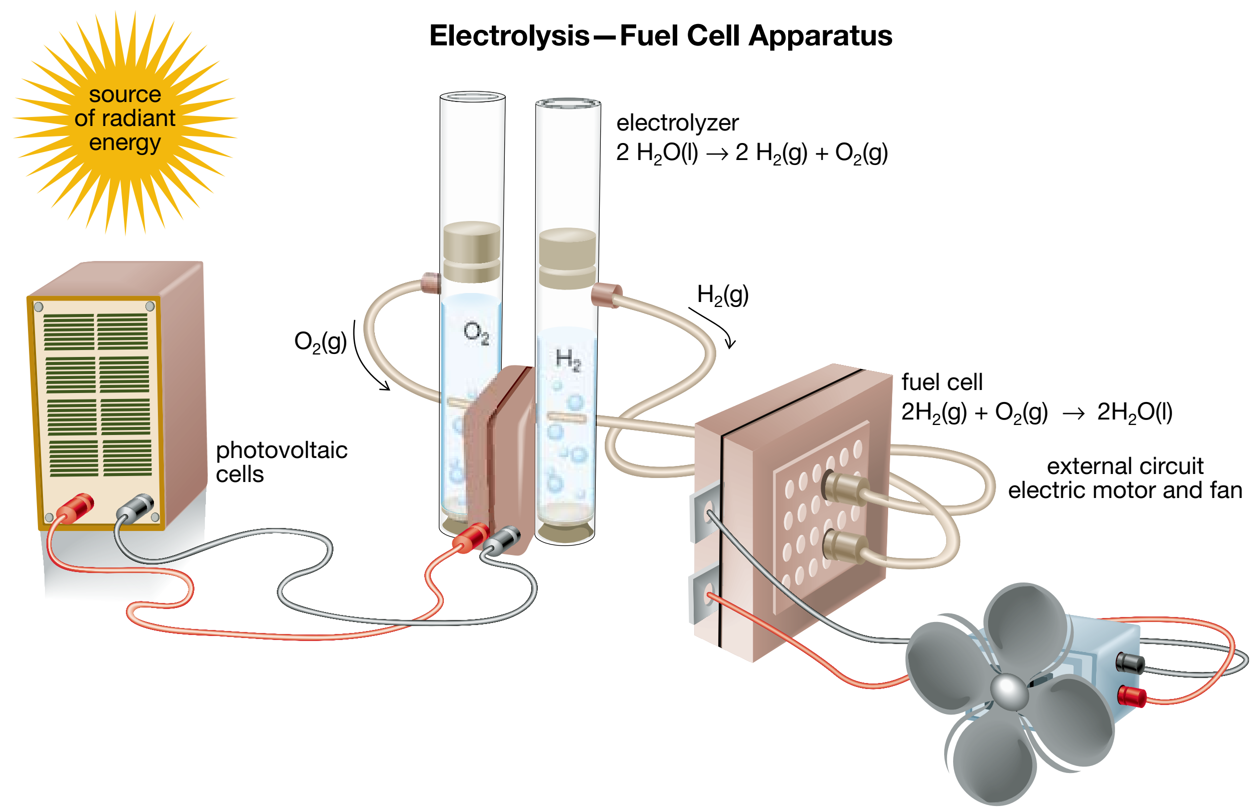
Purpose

You will examine an illustration depicting the transformation of water to produce the hydrogen needed to operate a hydrogen fuel cell, and you will identify the energy forms and transformations involved.

Science Skills

✓ Analyzing and Interpreting

Electrolysis—Fuel Cell Apparatus



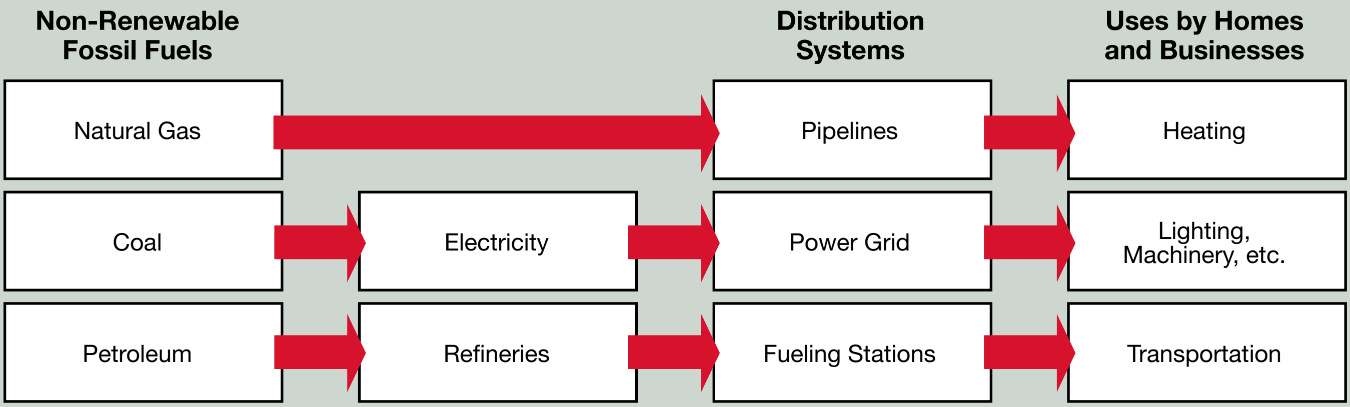
Analysis

Use an energy-flow diagram to describe the energy forms and transformations that occur during the operation of the apparatus shown in the illustration.

From the Carbon Economy to the Hydrogen Economy

Which energy sources do societies depend upon the most? Presently, particularly in Alberta, there is a heavy dependence on coal for electricity, natural gas for heating, and petroleum for transportation. All of these forms of energy are non-renewable and increase the levels of atmospheric carbon dioxide. A phrase used to describe this dependence on fossil fuels is the **carbon economy**. Due to the non-renewable nature of fossil fuels, the carbon economy is simply not sustainable.

The Carbon Economy

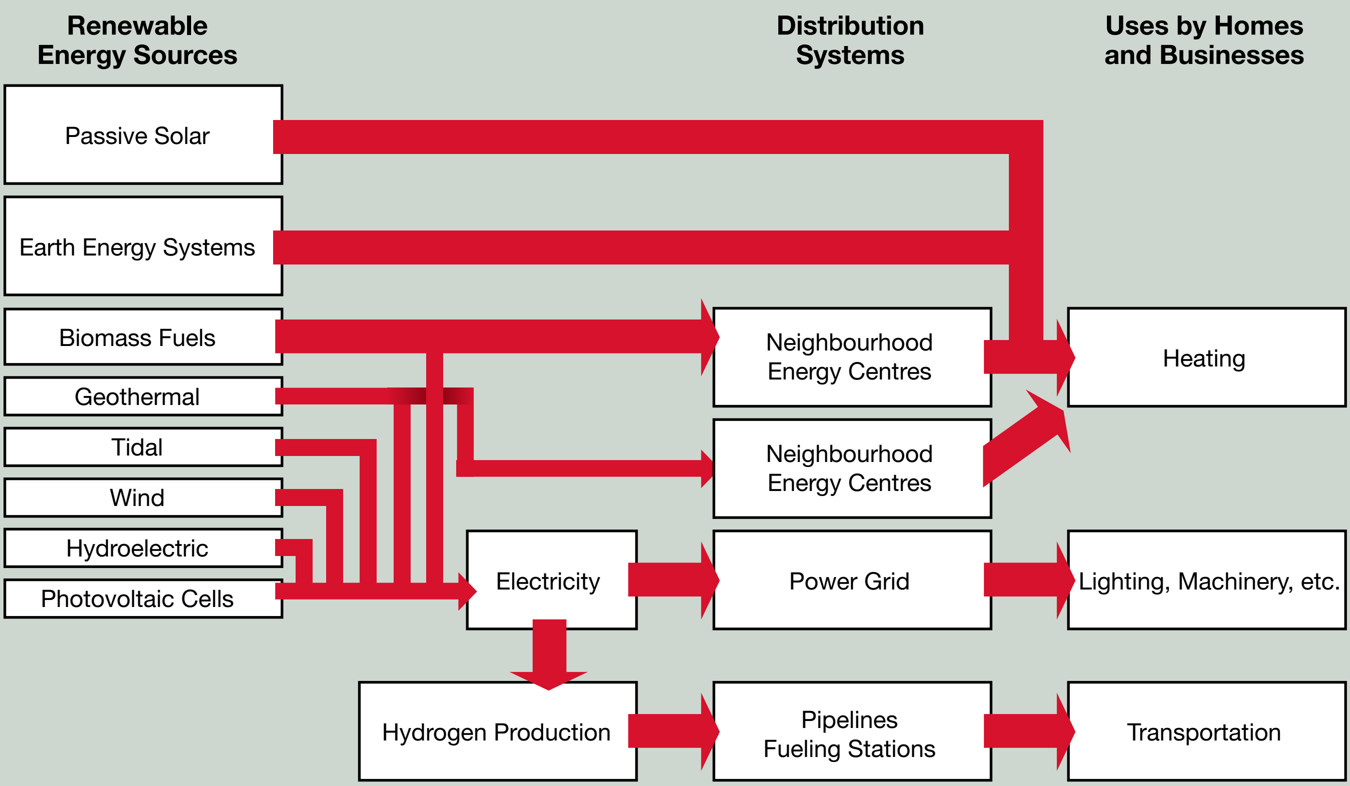


Many people think that within the next twenty years, hydrocarbons will no longer be primary sources of energy and that renewable energy sources will have increasing importance. One proposal calls for the use of renewable energy sources to generate electricity and for the use of hydrogen fuel cells in vehicles. Such a proposal would make hydrogen a primary fuel and result in the development of a **hydrogen economy**.

carbon economy: an economy that depends on fossil fuels as the primary source of energy, resulting in excessive emissions of carbon dioxide

hydrogen economy: an economy that depends on renewable sources of energy to generate electricity and depends upon hydrogen as the fuel for transportation

The Hydrogen Economy



When comparing the diagrams of the carbon economy and the hydrogen economy, you can see that a greater variety of energy sources are required to support the increased use of hydrogen. To make the proposed hydrogen economy a success, creative combinations of many energy sources must be used, along with different distribution systems. In the Drake Landing Solar Community, the energy centre provides heat to the homes in the neighbourhood. For more remote dwellings, heating needs might be met by earth energy systems located in the homeowner's backyard.

Try This Activity

Converting to the Hydrogen Economy

Science Skills
✓ Analyzing and Interpreting
✓ Communication and Teamwork

Purpose

You will work with other students to identify changes to your home or community if it were to convert to the hydrogen economy.

Procedure and Analysis

1. Identify non-sustainable energy technologies used in your home or community.
2. Identify sustainable technologies and strategies that could be used to replace the non-sustainable technologies identified in question 1.
3. Indicate major differences between the current carbon economy and the hydrogen economy.
4. Predict problems and solutions that might occur within your home or community during the conversion to the hydrogen economy.
5. Some countries in Europe have adopted twenty- and thirty-year plans that will move them toward a hydrogen economy. To fund the conversion, tax rebates are given to people who make the necessary changes to their buildings, means of transportation, and energy infrastructure. These rebates are partially funded by "carbon taxes" on technologies that are based on the old carbon economy. For example, the use of large, inefficient vehicles (like SUVs) is discouraged by high gasoline taxes. Public transportation is heavily subsidized and rebates are offered to people who purchase more-efficient, smaller vehicles with new technology. Do you think these strategies would work in Alberta?

One Future, Many Paths

What do you think your community will be like in twenty years? Will you see photovoltaic cells on nearly every rooftop? Will you see neighbourhood energy centres providing homeowners with energy from renewable sources? As you have seen, choosing which technology to use to produce energy involves many perspectives and should address aspects of ecological, societal, and economic sustainability. Finding workable solutions to energy issues may not only involve overcoming technological challenges, it may also involve changing attitudes and behaviours. Behaviours and attitudes stem from culture: the beliefs, values, and symbols passed down from one generation to the next and shared by a community. This line of thought suggests that the greatest challenges ahead relate to the cultural dimension of sustainable development. Does this sound familiar?

Earlier in this course you were introduced to traditional ecological knowledge, which involves developing an understanding of human interactions with the environment and focusing on the inseparable relationship between land, resources, and culture. It could be that a holistic approach—which brings the human aspects of knowledge, spirit, and emotion into decision making—may prove to be very helpful in making sustainable development a reality.

DID YOU KNOW?

Hydrogen fuel cells have been around since the 1960s to provide electricity for spacecraft. The *Apollo 13* crisis was a result of an explosion that reduced the supply of oxygen to the fuel cells, reducing the electricity available to maintain the spacecraft.

2.2 Summary

The quantity of solar energy reaching Earth each day exceeds the world's energy demand. The main problem is finding a way to harness solar energy that is cost-competitive with fossil fuels. Unlike fossil fuels, solar technologies are renewable and avoid many of the negative effects to human health and the environment. Solar technologies can be high tech or low tech and large scale or small scale. They also can generate heat or electricity. Solar technologies have a wide range of applications and are likely to play an important role in the world's future energy production. As renewable technologies improve and fossil fuels become more expensive because of shrinking supplies, renewable forms of energy will become more commonly used throughout the world.

2.2 Questions

Knowledge

1. Define each of the following terms.

- **a.** passive solar energy
- **b.** earth energy system
- **c.** biomass
- **d.** hydrogen economy

2. Describe the energy conversions involved during the use of each of the following technologies.

- **a.** photovoltaic cells
- **b.** hydroelectric power

3. Describe one way you could use solar energy to reduce your household energy costs without purchasing any new equipment.

4. Identify the main limitations and benefits of solar-energy technologies.

Applying Concepts

5. Explain how the operation of an earth energy system is similar to your body's circulatory system.

6. List actions that you and your family perform that are consistent with sustainable development. In each case, identify whether the action addresses ecological sustainability, environmental sustainability, societal sustainability, or any combination of these.

7. Earlier in this chapter you evaluated six energy sources—coal, nuclear fission, photovoltaic cells, hydroelectric power, wind energy, and biomass—for sustainability as sources of energy. You will need these six completed evaluations to answer questions 7.a. and 7.b.

- **a.** Summarize your findings by producing a table that compares the weighted scores for each category of sustainability as well as the overall score for each source of energy.
- **b.** Refer to your table to discuss the overall rankings, from highest to lowest, of the sources of energy. Support your findings by describing the overall reasons for your ranking.

Chapter 2 Summary

Alberta relies heavily on non-renewable energy sources. Hydrocarbons provide the main fuels for transportation, heating, and electricity. Because these sources will eventually run out and because their continued use has associated environmental costs, more sustainable energy sources and technologies are needed. Renewable technologies include hydroelectricity, tidal, wind, solar, biomass fuels, geothermal, and hydrogen fuel cells. Switching to more renewable technologies will be necessary to meet Alberta's future energy needs. Other strategies, such as increasing efficiency and reducing waste, will also be important in reducing Alberta's growing energy demand.

Summarize Your Learning

In this chapter you examined a number of new terms, concepts, and techniques for problem solving. You will have a much easier time recalling and applying the information you learned if you take some time to organize it into some sort of pattern. Now that you have come to the end of the chapter, this is an appropriate time to focus on the patterns within the things that you have learned.

Since the pattern has to be in a form that is meaningful to you, you have some options as to how you can create this summary. Each of the following summary techniques is described in "Summarize Your Learning Activities" in the Reference section.

Option 1:	Option 2:	Option 3:	Option 4:	Option 5:	Option 6:
Draw a concept map or a web diagram.	Create a point-form summary.	Write a story using key terms and concepts.	Create a colourful poster.	Build a model.	Write a script for a skit (a mock news report).

Chapter 2 Review Questions

Knowledge

1. The following table summarizes the important renewable technologies studied in this chapter. Copy and complete the table in your notebook.

Renewable Technology	Original Energy Source	Main Use (e.g., heating, electricity)	Key Advantages	Key Disadvantages
hydroelectric				
tidal				
wind				
solar				
earth energy system				
photovoltaic cell				
geothermal				
biomass				
hydrogen fuel cell				

2. The title of this chapter is “Dreams of a Sustainable Future.”
   a. Explain the meaning of the term *sustainable development*.
   b. A sustainable source of energy must satisfy criteria in three broad categories of sustainability. Describe the key characteristics that describe each of these categories.
3. Describe two renewable ways an individual household can generate electricity.
4. Describe the energy transformations that occur when electricity is produced from geothermal energy. Begin with the original source of the energy and finish with electricity.
5. Identify one way geothermal energy is used other than to generate electricity.
6. Identify the range of materials classified as biomass. Explain how each of the materials listed can be used as a source of energy.
7. Describe the energy changes associated with a hydrogen fuel cell. Identify limitations to the use of the fuel cell.
8. The “pop test” is commonly used to identify the presence of hydrogen. In a “pop test” a very small quantity of hydrogen is brought into contact with a burning splint. The combustion of the hydrogen produces a flame and a small explosion, resulting in a popping sound. Compare the reactions for hydrogen in a fuel cell with the combustion of hydrogen in a “pop test.” Which process has the greatest energy efficiency? Support your reason.
9. Describe the two main ways hydrogen can be produced for use in hydrogen fuel cells.
10. Describe how a hydrogen economy might work in the future. Identify two challenges and two benefits associated with developing a hydrogen economy.

Applying Concepts

11. Compare hydroelectric energy with tidal energy. List the similarities and differences.
12. Iceland is a country that has officially committed to switching from a carbon economy to a hydrogen economy. Briefly describe how this hydrogen economy could best be supported by sources of renewable energy in Iceland.
13. Note that nuclear fission does not appear as an entry in the hydrogen economy or in the carbon economy. Yet many people think that nuclear power could play a critical role in a period of transition between the current carbon economy and the proposed hydrogen economy.
    a. Suggest a reason why nuclear fission does not appear on the flowchart for the carbon economy or on the flowchart for the hydrogen economy.
    b. Explain the role that nuclear fission could play during a period of transition between these two economies.

Unit D Conclusion

Earth's population continues to grow. More countries are becoming industrialized, and the world's energy demand is climbing higher and higher. Yet, the world continues to rely mostly on non-renewable and ecologically damaging energy technologies.

Renewable and sustainable technologies are needed. Some renewable technologies, such as hydroelectricity and geothermal heat, have long been providing sustainable energy. More recent technologies, like tidal energy, wind power, biomass, and photovoltaic cells, are increasing their share in the world's energy market. Also, emerging technologies, such as hydrogen fuel cells, may even facilitate a global transition to sustainable economies.

The long-term health of the planet depends upon moving toward the goal of sustainable development. It will take action from regular citizens, industry, the scientific community, and governments to reconcile dreams of limitless energy with dreams of a sustainable future.

Career Profile

Welder

Destiny Golosky definitely doesn't fit the stereotypical view of a blue-collar trades person, but that doesn't bother the confident, well-spoken, 23-year-old steamfitter/pipefitter or her employer, Clearwater Welding. Given the shortage of skilled people in Alberta, Clearwater was delighted when Destiny decided to return to her hometown of Fort McMurray after spending four years learning her craft at NAIT.

Given the shortage of skilled trades people in the northeastern Alberta city, most employers would be delighted if more young people decided to follow Destiny's path into the trades. Her father, Richard, a welder, encouraged Destiny after she started to show an interest as a teenager. "My parents were very supportive," she said. "I wanted to do something that was interesting and challenging, and that paid well. And because I grew up in Fort McMurray, I got to see and meet a lot of very successful people in the trades."

Given the problems in recruiting skilled labour to northeastern Alberta, oil sands companies became forerunners in forging partnerships with Aboriginal communities to train and hire Aboriginal employees as well as conducting business with Aboriginal contractors. NAIT has also taken steps to engage these communities through its Aboriginal Student Success Initiative. "It's important to know that you can succeed if you are Aboriginal," Destiny said. "At the end of the day, I don't think anybody expects any special treatment. Most people just want a chance to prove they can do the job, whether they are a man or a woman, Aboriginal or not."

Unit D Review Questions

1. The following list summarizes some of the important terms and concepts used in this unit. In a table, define each item (including relevant symbols and equations) in one column and state any related terms and applications (e.g., examples or diagrams) in a second column. If you prefer, a table has been set up in a Microsoft® Word file titled "Unit D Key Terms" on the Science 30 Textbook CD.

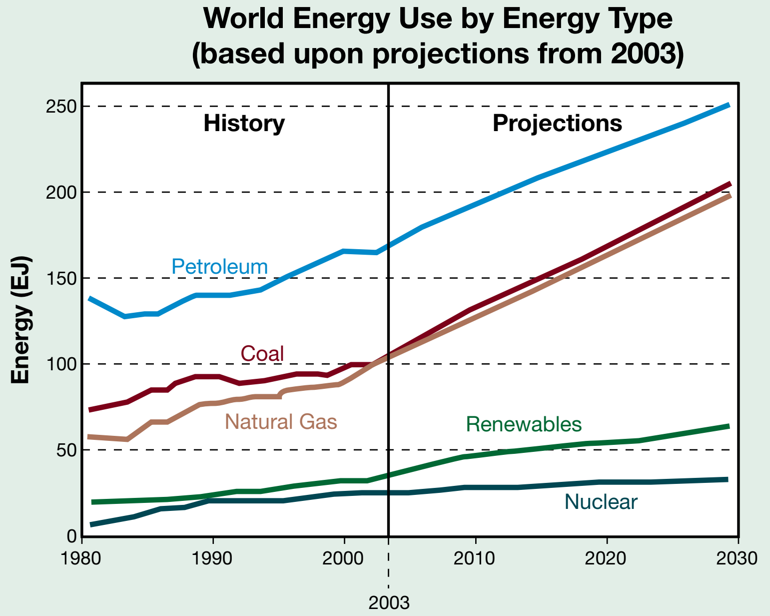
- energy
- energy efficiency
- fossil fuel (hydrocarbon)
- hydrocarbon combustion
- heat of combustion
- energy change for a reaction
- standard heat of formation
- first law of thermodynamics
- second law of thermodynamics
- radioactivity
- nucleon
- isotope
- ionizing radiation
- conservation of nucleons
- nuclear fission
- nuclear fusion
- mass-energy equivalence
- sustainable development
- biosphere

2. In this unit you studied a variety of energy technologies. Copy and complete the following table in your notebook. Remember to leave enough room for your answers.

Technology	Energy Conversions (original source to final use)	Renewable or Non-renewable	Negative Aspects	Positive Aspects
coal-fired power plant				
CANDU nuclear power plant				
hydroelectric power generating facility				
tidal power generating facility				
wind turbine				
solar collector				
earth energy system				
photovoltaic cell				
geothermal heating				
geothermal electricity generating facility				
ethanol fuel				
hydrogen fuel cell (automobile)				

Use the following information to answer questions 3 to 8.

Projections concerning energy use in the future are important because they impact the research and development of alternative fuels. The following graph shows projections of the world's use of various energy types from 2003 to 2030.



3. Suggest a possible reason for the small proportion of world energy coming from nuclear power.

4. The world's supply of coal is much more plentiful than that of natural gas, yet natural gas use could surpass that of coal. Provide a possible reason for this.

5. Calculate the percentage of the world's total use of energy that was supplied by renewable sources in 2003.

6. Calculate the percentage of the world's total use of energy that will be supplied by renewable sources in 2030.

7. Use your answers to questions 5 and 6 to determine whether the authors of this graph are anticipating a switch to the hydrogen economy.

8. Buses that use hydrogen as a fuel emit only water and heat in their exhaust. Some buses in Edmonton are electric (powered by high-voltage cables suspended above the street). At first glance, neither bus appears to generate harmful emissions. Is this impression correct? Suport your answer.

9. List some factors affecting energy use in Canada. Describe practices that could be used to reduce the need for fossil fuels as an energy source. In your answer, identify technologies that could be used, and explain how they could be used in a way that demonstrates sustainable development.