James Watt’s original design of the steam-powered piston engine changed society. Before a practical steam engine was available, most people lived in rural farming communities. After Watt’s steam engine became available, many people moved to large industrial cities. Technology does not stand still, however. The power of steam is still used in many modern technologies, but in most cases, it does not drive pistons. Instead, steam drives turbines. Pistons are still widely used, but they are not driven by steam. In this section, you will see how pistons are still important in transportation and how steam is important in generating electrical energy.

Internal Combustion Engines

The large amounts of water and fuel needed for steam engines are not practical for small vehicles. Steam engines burn fuel and heat water outside of the engine and then inject the resulting steam into a cylinder to drive a piston. Modern cars and trucks have internal combustion engines. The terms “internal” and “combustion” give you clues about how these engines work. Unlike steam engines, in the internal combustion engine, the fuel itself goes directly into the cylinder. The combustion — or burning of the fuel — occurs inside the cylinder. The sudden combustion of the fuel inside the engine converts the liquid fuel into gases as well as heating the air. The hot gases expand and push the piston down the cylinder, as shown in Figure 4.26 on the next page. Follow the four steps of the cycle of the piston in the illustration.

While studying the steps in Figure 4.26, notice that the combustion of fuel provides energy for only one of the four steps in the cycle. How does the piston move in the other three steps? Modern internal combustion engines have four, six, or eight pistons, all attached to the same crankshaft. The pistons are designed to fire at different times. At least one piston is always in its power stroke, causing the crankshaft to turn. The turning of the crankshaft causes the inactive pistons to move through their other three strokes.

Did You Know?

Major automobile manufacturers are developing gasoline-electric hybrid vehicles to dramatically lower emissions and increase gasoline engine efficiency. Toyota has produced the Prius, and Honda has produced the Insight. The success of the Insight was realized through its Integrated Motor Assist (IMA) power train. The IMA consists of a newly developed gasoline engine, a permanent magnet electric motor, and a five-speed manual transmission. The power train incorporates an electric motor to supplement the gasoline engine at low RPMs (revolutions per minute).

Both the Prius and the Insight have self-charging batteries. In the Insight, the electric motor draws power from a lightweight, nickel-metal hydride battery pack located in the rear of the car. You never have to plug the Insight into a power socket to recharge — the battery is maintained through regenerative braking. The electric motor (doubling as a generator) harnesses kinetic energy from the forward motion of the vehicle when the car decelerates.
(a) **Intake stroke**: The intake valve opens, and the piston moves downward, drawing the mixture of air and fuel into the cylinder.

(b) **Compression stroke**: The intake valve closes and the piston moves up, compressing the air-fuel mixture.

(c) **Power stroke**: When the piston is almost at the top of the cylinder, the spark plug produces a spark that ignites the mixture. The mixture burns, causing hot gases to expand and move the piston down.

(d) **Exhaust stroke**: The piston moves up, forcing the waste products from the combustion of the mixture out the exhaust valve.

Nearly all modern cars, trucks, buses, and trains have internal combustion engines. Although these engines have made it easy for people to travel freely over relatively long distances, they have also had a negative effect on the environment. Internal combustion engines release greenhouse gases and gases that contribute to smog and acid rain. (You will learn more about these environmental challenges in Unit 4.) Today’s engineers are still moving technology forward. While they are attempting to improve the capabilities of engines, they are also looking for ways to design engines that reduce negative effects on the environment. Therefore, engineers are designing and testing alternatives to the internal combustion engine. In the Ask an Expert feature at the end of this unit, you will read about fuel cells and cars that use these...
fuel cells instead of internal combustion engines. Another approach to modifying engines is to use a combination of a gasoline engine and an electric battery. These cars are called hybrid cars. They are described in the Did You Know? feature on page 164. In the future, many alternatives will be available for people shopping for a new automobile.

**Production of Electrical Energy**

Nearly all appliances, small and large, designed for the home, office, or factory, use electrical energy. Electrical energy can be generated in a location far from where it is used and transported over power lines for many kilometres. At the point where it is being used, electrical energy is clean and quiet. As you read in the introduction to this unit, modern civilization has become very dependent on electrical energy. How is electrical energy generated? What is the primary source of energy that is converted into the electrical energy that you use?

All commercial electrical energy is produced by electrical generators. You might recall from previous science courses that when electrical wires move in a magnetic field, a current flows through the wires. Electrical generators have huge magnets with coils of wire turning between the poles of the magnet. In most generators, turbines turn the coils. This kinetic energy of the coils is converted into electrical energy inside the coils of wire (see Figure 4.27).

Steam pressure drives the turbines that turn generators that produce approximately one third of the electrical energy generated in Canada. The heat that boils the water into steam comes from either the combustion of fossil fuels or from nuclear reactions. Examples of a fossil fuel-burning power plant and a nuclear plant are shown in Figure 4.28.

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**Did You Know?**

The energy contained in 150 t of uranium used in a nuclear reactor has as much energy as 2.0 million t of coal, 1.8 million L of oil, or more than 1 million m³ of natural gas. Why do you think we use coal, oil, and natural gas when uranium stores so much energy?

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**Word Connect**

We hear the term "fossil fuel" frequently, but do you know what it means? If not, look it up in a dictionary or other reference source and write the definition in your notebook. Why have fossil fuels become such an important part of our everyday lives? Will they run out some day? Why or why not?
Windmills have been used for hundreds of years, usually for pumping water. Modern windmills such as these near Pincher Creek, Alberta, look very different from the old windmills that used to pump water for farm animals. These windmills convert wind energy almost directly into electrical energy.

Hydro-electric generating stations, like the one in Figure 4.29, produce the other two thirds of the electrical energy generated in Canada. The high level of the water behind the dam creates a tremendous amount of pressure. The pressure forces the water to flow through the turbines, causing them to turn. The turbines then turn the electric generators. Hydro-electric power is clean and dependable. However, large areas of land are flooded when a dam is built. Sometimes this flooding can threaten an endangered species. The flooding can also cover many hectares of tillable land. Entire farms might be flooded.

In a few regions of Canada, strong winds are dependable enough to provide the wind energy to produce electrical energy. Figure 4.30 shows a wind farm near Pincher Creek in southern Alberta. Small electrical generators are built...
directly into the top of the windmills. As the wind turns the blades of the windmill, the axle turns the generator. Electrical circuits carry the energy from each windmill to a central unit. Wind energy is a clean, renewable source of electrical energy. However, there are not many places where the wind blows strong enough and frequently enough to make wind farms profitable. Wind will never be able to produce enough electrical energy to replace most other sources of energy. Nevertheless, using wind energy could reduce the amount of fossil fuels that must be consumed to produce electrical energy.

Canada is a very large country and different sources of energy are available in different locations. In Quebec and British Columbia, most of the electrical energy is generated in hydro-electric generating plants. In Ontario, nearly half of the electrical energy is produced by nuclear reactors. In Alberta and Saskatchewan, coal-burning power plants predominate. In some remote areas of Canada, far from large electrical generating stations, internal combustion engines turn the generators that produce electrical energy.

As technologies change, these patterns might also change. Conduct the investigation on the next page to see the changing trends in the methods for producing electrical energy in Canada over the last 50 years.
Producing Electrical Energy

The data chart below provides the history of electrical energy production in Canada over the last 50 years, as well as projections for 2010. What trends or patterns do the data indicate? Use graph paper and a calculator, or a spreadsheet and a computer graphing program, to organize and display the data.

**Apparatus**
- calculator
- graph paper
- coloured pencils
  or computer spreadsheet and graphing program

**What to Do**

Use the production chart to prepare graphs for Steps 1 and 2.

1. For each of the seven years, prepare a stacked bar graph or pie chart showing the energy sources and total production.

2. Prepare a line graph for each of the six sources of energy by year. Connect each energy source’s data points by drawing a best-fit line or curve.

3. Prepare a second chart similar to the production chart below showing the percentage of the total for each source in each year. Calculate the percentages by dividing the total for that particular source by the total for each year.

4. Prepare six line graphs as described in Step 2, using the percentage values instead of the actual values.

5. The population of Canada for the years in the chart is given below. Calculate and graph the energy consumption per capita by dividing the total production by the population for each year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>13.6</td>
</tr>
<tr>
<td>1960</td>
<td>18.2</td>
</tr>
<tr>
<td>1970</td>
<td>21.6</td>
</tr>
<tr>
<td>1980</td>
<td>24.8</td>
</tr>
<tr>
<td>1990</td>
<td>28.0</td>
</tr>
<tr>
<td>2000</td>
<td>31.0</td>
</tr>
<tr>
<td>2010</td>
<td>33.4 estimate</td>
</tr>
</tbody>
</table>

**Analyze**

1. Which energy source has become the most popular? Which source(s) show decreasing popularity? What do you think is the reason for these trends?

2. Compare the graphs of the actual values with the graphs of the percentage values. Did you remember to place the manipulated variable (year) on the x-axis on all your graphs? Explain why some sources show very different trends on the two graphs.

3. Does the increase in population account for the increase in electrical energy production? Explain the trend in per capita energy production.
Section 4.3 Summary

In this section, you learned about the changes in technology for transportation. Watt's steam engine was the first type of engine for rapid modes of transportation such as locomotives and steamboats. Modern vehicles have internal combustion engines. You learned about the common four-cycle piston that is found in most cars, trucks, and buses. You then reviewed the methods used in Canada and much of the world, for generating electrical energy. Each technology — combustion of fossil fuels, nuclear power, and hydroelectric generation of electrical energy — has some negative effects on the environment. The demand for electrical energy is increasing, so scientists and engineers are always looking for ways to improve current technologies and to develop new technologies.

Check Your Understanding

1. Describe two significant differences between steam engines and internal combustion engines.

2. Describe one similarity and one difference in the generation of electrical energy when using fossil fuels and when using nuclear fuels.

3. List potential environmental challenges created by the generation of electrical energy by (1) the burning of fossil fuels, (2) nuclear fission reactors, and (3) hydro-electric generation in dams.

4. Apply Do some research to find out the source of electrical energy where you live. Find out if there are any environmental issues involving the electric generating station nearest you.

5. Thinking Critically Find out how much more hybrid cars cost than a typical car with an internal combustion engine. What criteria would you use in deciding how much more you would be willing to pay for a hybrid car in order to help protect the environment?
Now that you have completed this chapter, try to do the following. If you cannot, go back to the sections indicated in parentheses after each part.

(a) Explain how the first patented steam engine — Savery's engine — worked. (4.1)

(b) Thomas Newcomen's steam engine was often called an atmospheric engine. Describe the role played by atmospheric pressure in Newcomen's engine. (4.1)

(c) State the most important difference between Watt's steam engine and Newcomen's steam engine and explain why it was so important. (4.1)

(d) Describe the improvements that were necessary for Watt's steam engine before it could be used to power much larger machines such as the steam locomotive. (4.1)

(e) Describe the ways in which the steam engine influenced (1) the Industrial Revolution, (2) farming, and (3) transportation. (4.1)

(f) Briefly outline the basic concepts of three theories of heat that preceded the kinetic-molecular theory. (4.2)

(g) Describe Count Rumford's observations that caused him to reject the caloric theory of heat. (4.2)

(h) Explain the differences between Count Rumford's observations and Mayer's observations that both led to the same conclusion about the nature of heat. (4.2)

(i) Explain the difference between the everyday concept of work and the scientific definition of work. (4.2)

(j) Briefly describe the kinetic-molecular theory of heat. (4.3)

(k) State the first and second laws of thermodynamics in two different ways. (4.2)

(l) Describe how an internal combustion engine causes a drive shaft to turn. Start with the combustion of the fuel. (4.3)

(m) State the three most common sources of energy that are transformed into electrical energy in Canada. (4.3)

Prepare Your Own Summary

- Write a short biography of one inventor and one scientist mentioned in this chapter.
- Explain and give experimental evidence for the flaws in the early theories of heat.
- Make energy flow diagrams for one or more of the modern technologies for generating electrical energy.
- Describe ways in which new technologies build on previous technologies. Describe how scientific models are modified or replaced.

Summarize the chapter by doing one of the following. Use a graphic organizer (such as a concept map), produce a poster, or write the summary to include key chapter concepts. Here are a few ideas to use as a guide:

- Make two time lines and place them next to each other. One time line should include all of the technological advances involving the application of steam energy and other forms of thermal energy. The second time line should include the scientific models and theories about the nature of heat.
- Choose one of the technologies described in the chapter and explain its functioning based on the scientific theory of heat.
Key Terms
steam engine  GRASP  thermal energy
phlogiston  calorie  heat
 caloric theory  kinetic energy  specific heat capacity
 work  kinetic-molecular theory  temperature

Understanding Key Concepts
Section numbers are provided in case you need to review.
1. What basic information was available for Newcomen and Watt that they could use to design their steam engines? (4.1)
2. What was the most important difference between Watt's engine and Newcomen's engine? How were these differences beneficial for Watt's engine? (4.1)
3. How did Watt's steam engine influence society? (4.1)
4. Briefly describe how a steam turbine works. (4.1)
5. List the flaws in the following three theories of heat: the four-element theory, the phlogiston theory, and the caloric theory. (4.2)
6. How do physicists define work? Give your answer in words and in a mathematical formula. (4.2)
7. Under what conditions would you use the graphical method for determining work instead of using the formula? Why would it be impossible to use the formula in this situation? (4.2)
8. Briefly describe how Joule determined the relationship between work and heat. (4.2)
9. State the name of the modern theory of heat. Explain the meaning of the terms used in the name of the theory as they apply to the theory of heat. (4.2)
10. State and explain the modern definition of heat. (4.2)
11. What property of a substance does the specific heat capacity reveal? (4.2)
12. Explain the difference between heat and temperature. (4.2)
13. State the first law of thermodynamics in your own words. (4.2)
14. Explain how "wasted energy" is related to the second law of thermodynamics. (4.2)
15. In what way is the internal combustion engine more practical for cars than the steam engine? (4.2)
16. What are the two main sources of energy that are used to boil water into steam for the steam turbines that drive electrical generators in Canada? (4.3)

Developing Skills
17. Choose three of the scientists (not inventors) mentioned in this chapter. Write a short paragraph on the contribution that each of them made to the field of thermodynamics.
18. Devise an experiment that could determine the specific heat capacity of an object. Hint: When an object is placed in water at a much lower temperature, thermal energy will be transferred from the object to the water until the temperatures of the two are the same. The thermal energy that enters the water will be equal to the thermal energy that left the object.
19. Design and draw diagrams that illustrate the first and second laws of thermodynamics.
20. Do research using print resources or the Internet to learn about the types of environmental challenges caused by nuclear reactors, fossil fuel-burning power plants, and hydro-electric generating stations. Compare the results and list the three methods of generating electricity in order from the least to the most challenging to the environment. State your reasons for the order that you chose.

Problem Solving/Applying

21. A crane that loads ships must exert a force of 24,550 N on a crate and lift it 22 m. How much work does the crane do on the crate?

22. You exerted a force of 15 N on your textbook while you lifted it 0.86 m to the shelf of your locker. How much work did you do on the book?

23. Two movers do 2500 J of work to move a piano 8.4 m across a room. How much force did the movers exert on the piano?

24. A weight lifter does 420 J of work to lift a barbell a height of 0.35 m. What force did the weight lifter exert on the barbell?

25. You exert a force of 100.0 N on a shopping cart. If you used 2750 J of energy, how far did you push the cart?

26. A farmer exerts a force of 125 N on a wheelbarrow. When the farmer has used 7198 J of energy, how far has he pushed the wheelbarrow?

Critical Thinking

27. The drawings and descriptions created by Hero of Alexandria show that over 2000 years ago, people knew that steam could be used to make objects move. Why do you think that it took so long for anyone to design and build a practical steam engine?

28. James Joule was an experimentalist and William Thompson was a theoretician. Explain the difference between these two types of scientists. Do you think one type or the other contributes more to the body of scientific knowledge? If so, which one? Discuss your reasoning.

29. Use print resources or the Internet to learn about research on experimental cars other than hybrid electric cars or fuel cell-powered cars. After learning about these cars, explain how they help protect the environment. How much would you be willing to pay for a car that helps preserve the environment but is more expensive than a standard car? Explain your reasoning.

Pause & Reflect

Go back to your answers to the Focussing Questions. Has your thinking changed about any of your answers? Revise your answers to reflect what you have learned.