Thomas Newcomen, James Watt, and others worked to improve steam engines to decrease the time to complete a task and the cost of operating the machines. Today, society has a much more important reason for increasing the efficiency of machines and systems. Many people are concerned about how machines for industry and transportation are polluting the environment. How can machines be modified or changed to reduce damage to the environment?

One sure way to reduce pollution would be to stop using machines. People could perform tasks manually, as shown in Figure 6.5. However, very few people would be willing to sacrifice the labour-saving devices we enjoy today. In addition, the world’s population is so large that it would be nearly impossible to provide food, clothing, and shelter for everyone without using modern machinery. Therefore, a better option is to improve the efficiency of today’s machines.

**Efficiency of Some Common Technologies**

**Internal Combustion Engines**

Would you be surprised to discover that, on average, cars are only about 20 percent efficient? Only 20 percent of the chemical potential energy stored in the gasoline is transformed into the mechanical kinetic energy of the car it fuels. Where does the other 80 percent of the energy go?
When the fuel is ignited in a cylinder of a car's engine, the gases become very hot and expand, pushing down the piston. When the piston has moved the entire distance of the cylinder, the gases are still extremely hot. In fact, the gases are so hot that the engine will be damaged unless a liquid coolant is pumped through the engine to absorb the heat. The coolant absorbs the heat in the engine and then flows through the radiator and releases the heat to the outside air. About 36 percent of the energy from burning the fuel is lost through the coolant. The exhaust gases are still very hot. When they leave the exhaust pipe, they carry away about 38 percent of the original energy. The other six percent of the energy is lost due to friction between the moving parts of the engine.

**Electrical Devices**

In Practice Problem 1 on page 227, you calculated the efficiency of a standard (incandescent) light bulb. Were you surprised to discover that only about five percent of the electrical energy used by the light bulb is converted into light energy while 95 percent is converted into heat? Compact fluorescent bulbs are much more efficient. However, they convert only 20 percent of the electrical energy into light energy. Nevertheless, replacing one million 75 W incandescent light bulbs with 20 Watt compact fluorescent bulbs for one year, would save a lot of energy. The amount of energy saved would be about the same as the amount of electrical energy generated by a coal-burning plant in one year. Note also, that a 20 W compact fluorescent bulb produces as much light as a 75 W incandescent bulb.
Replacing an old motor with a new, high-efficiency motor would save money by using less electrical energy. Companies that replace old motors can often save the entire cost of the new motor within three to four years.

Look around your home and school and other places that you visit. How many devices are driven by electric motors? Fans in ventilation systems, furnace fans, hair dryers, electric razors, and computer fans use motors. Industries use much larger electric motors for many purposes such as drilling and sawing. In fact, nearly half of all the electrical energy generated in North America is used to drive electric motors.

Electric motors are between 50 percent and 90 percent efficient in converting electrical energy to mechanical kinetic energy. When you consider the large number of motors, think about how much electrical energy they use. An increase in efficiency of only a few percent in all motors would greatly reduce the total amount of electrical energy used. Also, if electric motors are not properly matched to the job they perform, they waste energy. For example, if the motor is too powerful for the job it is doing, it will use more energy than is necessary for the job. Proper use and maintenance of motors can save money and reduce the amount of electrical energy consumed. Reduced use of electrical energy reduces the amount of pollutants released from electrical energy-generating plants.

Generating Electrical Energy

How efficient are the energy transformations that generate electrical energy? As you read in Chapter 4, the three most common forms of electrical energy generation in Canada are coal-burning generators, nuclear reactors, and hydro-electric generation. Both coal-burning furnaces and nuclear reactors produce heat to boil water into steam. The steam then drives turbines. The steam turbines turn electrical generators. These two technologies have similar efficiencies — they are approximately 30 percent efficient. Hydro-electric generation of electrical energy is much more efficient — about 90 percent efficient. In the investigation on page 235, you will analyze these three systems and look for reasons why energy is lost in each system.
Energy Transformations in Electrical Energy Generation

Think About It

The diagrams below show the major steps in the generation of electrical energy in (A) a coal-burning plant, (B) a nuclear reactor, and (C) a hydro-electric plant. In (A), the chemical potential energy is released from coal by burning it. In (B), nuclear potential energy is released in a fission reaction. In a fission reaction, an atom of uranium or plutonium splits into two atoms and releases large amounts of energy. In (C), gravitational potential energy is released when water flows downward under the influence of gravity. You will use these diagrams to analyze the individual steps in converting potential energy into electrical energy. You will then draw conclusions about why energy is lost.
What to Do

1. For each diagram, list as many energy transformations or energy transfers as you can.

2. For each energy transformation that you listed in Step 1, predict how energy might be lost before it can be transformed into electrical energy. In each case, estimate the percentage of the original energy that might be lost.

3. List environmental problems that each of the three systems causes.

Analyze

1. Compare the three systems and explain the differences in efficiency that you read about in the paragraph before the investigation.

2. Rate the three systems based on their negative effects on the environment.

3. Which system is the most acceptable when all considerations are combined? Explain your reasoning.

Extend Your Skills

4. Do research in print sources or on the Internet, or interview someone in the energy industry. Find out the costs of constructing and maintaining the three types of electrical energy-generating plants.

5. How does this new information affect your answer to question 3 above?

Drawing Conclusions about Efficiency

What did you conclude about systems that convert potential energy into thermal energy to generate electrical energy? Did you discover that these systems have a low efficiency? After the thermal energy has turned a turbine or moved a piston, the steam or hot gases still contain much of the thermal energy. This thermal energy is usually lost to the environment.

Efficiency of Energy Transformations in Living Plants

In the Model Problem on page 225, you discovered that living cells are only about 38 percent efficient in transforming the energy from glucose to make ATP. How efficient do you think plants are in using energy from sunlight to form glucose?

As you read, glucose is broken down in many steps in living cells. Similarly, glucose is formed in many steps in the cells of living plants. The process is known as photosynthesis. The summary reaction of photosynthesis looks like the reverse of the breakdown of glucose that you saw in the Model Problem. However, the individual steps are quite different:

$$6\text{CO}_2 + 6\text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$$
Research reports about the efficiency of photosynthesis can be quite confusing because different researchers report the results in different ways. For example, some reports consider all of the light that is available to a plant. Much of this light does not reach the leaf and therefore cannot be utilized. Also, the necessary measurements are very difficult to perform. Nevertheless, scientists who study photosynthesis have made some good attempts.

If you consider only the light that is actually absorbed by the chlorophyll in the leaves, the maximum possible efficiency of the plant is 26 percent. However, plants absorb only about 34 percent of the light that actually falls on the leaf. If you include all of the light that falls on the leaf, whether or not it is absorbed, the efficiency drops to just over eight percent. These are maximum values. Sometimes light energy reaches the plant faster than the systems inside the cells can use it. So, in reality, the efficiency of plants is probably closer to one percent than eight percent. Despite this low efficiency, nearly all of the energy used by society originally came from the Sun and was stored by plants.

Trapping and Converting Solar Energy

Scientists and engineers continue to search for ways to convert several forms of potential energy into electrical energy. Since solar energy is a very dependable form of energy, some researchers are trying to find more efficient ways of trapping and converting solar energy into electrical energy. For example, some scientists have even suggested using molecules similar to chlorophyll to trap solar energy in artificial systems. How difficult is it to trap solar energy and efficiently convert it into another form of useful energy? Completing the investigation on the next page should give you some insights into the challenges that scientists meet in their research.

DidYouKnow?

The bodies of lizards act as solar traps. Most lizards bask in the sun to raise their body temperature. They position their bodies so that the maximum area is receiving sunlight. As well, they orient themselves so the solar rays are perpendicular to their body surface. One type of lizard can absorb enough sunlight to raise its body temperature to as much as 30°C above the air temperature.
Building a Solar Trap

Enormous amounts of energy from the Sun reach Earth’s surface every second. This energy can be used only when the Sun is shining. Can the Sun’s energy be captured and used at other times? This is possible through the use of solar traps. They convert light energy to something that can be stored and used later. The most popular and convenient conversion is to thermal energy.

**Challenge**

Design and build a model solar trap. The trap will capture sunlight and convert it to thermal energy. You will then measure the increase in the air temperature in your trap. Your goal is to produce the highest air temperature using only 20 min of sunlight.

**Safety Precautions**

- Use care with sharp objects when constructing your solar trap.

**Design Specifications**

A. Sunlight is the only input energy source you can use.

B. Choose only materials that are readily available for constructing your solar trap.

**Plan and Construct**

1. Design a solar trap. Prepare a drawing and a list of materials. Make the design as complete as possible.

2. Have your teacher approve your design.

3. Construct your trap including a method for measuring the temperature inside the trap.

4. When your trap is completed, place it in the Sun for 20 min. Compare the highest temperature of each trap.

**Evaluate**

1. What factors were most important in the design of the solar traps? Which features provided the greatest temperature gain?

2. Suggest modifications to your design that would improve its performance.

3. Try exposing the traps for 30 min. Does the extra time provide higher temperatures?

4. How high do you think the temperature could go? Why can the temperature not rise indefinitely?

5. As a class, discuss the best features of each solar trap. Design and build one new solar trap that incorporates as many of the best features of all the solar traps as possible.

6. How does the new solar trap compare to your original solar trap?
Saving Energy

Saving energy not only saves money, it also reduces environmental pollutants and conserves natural resources. However, improving the efficiency of machines is not always possible or practical. In some cases, the cost of building a machine with a slightly higher efficiency is so expensive that no one could afford to buy it. Therefore, many researchers and engineers have tried to think of different ways to perform the same task. Some examples are described below.

Cogeneration

Along with producing electrical energy, a coal-burning plant produces thermal energy or heat that is released to the environment. In another large facility, fossil fuels are burned to heat buildings. Why not combine the two processes? Many industries, universities, and factories are doing just this — it is called cogeneration. The “waste” heat from the turbine of a coal-burning system is not released to the environment. Instead, the heat is directed to a heat exchanger where it heats water. The hot water or steam is then pumped through pipes to heat a building. Instead of using less than 40 percent of the input energy for just electrical energy, the system can use as much as 80 percent of the input energy for both electrical energy and space heating. The efficiency is doubled!

In the past, coal-burning plants have been located far from population centres because the plants produce pollutants. Electrical energy can be transported long distances with little loss in energy. However, thermal energy cannot be transported over long distances. Recently, industries or greenhouses have been built near coal-burning plants to take advantage of the heat the plants produce. In addition, large industries, universities, and some other facilities such as hospitals are building smaller cogeneration plants near their main buildings. These smaller plants often use gas turbines with natural gas for fuel. Burning the natural gas produces hot gases, which turn the turbines. From the turbines, the hot gases go through heat exchangers where they heat water for heating the buildings. As well as being more efficient, these gas turbines produce fewer environmental pollutants.

Canada’s Largest Cogeneration Plant

An excellent example of a new and efficient cogeneration plant is the Joffre power plant shown in Figure 6.10. Three companies have co-operated to build and operate this facility. The Joffre plant burns natural gas in two gas turbines to generate electrical energy and provide heat for a large chemical plant. The chemical plant produces ethylene and polyethylene. Surplus electrical energy is sold to the Alberta Power Pool.
Keeping a City Cool

It would be extremely uncomfortable to work in a large, downtown office building without air conditioning. Consequently, most businesses are air conditioned so employees can do their jobs efficiently. Air conditioning, however, uses tremendous amounts of energy and is very costly. Are there any alternatives?

A utility company believes there is an alternative for Toronto because it is on the shores of Lake Ontario, which is very deep. Thus, the temperature of the water near the bottom of the lake remains about 4°C throughout the year. The utility company and the city of Toronto agreed to try an experiment called Deep Lake Water Cooling. Pumps on the shore will draw 4°C water from about 70 m below the surface of Lake Ontario and send it through a heat exchanger. The lake water will cool water that runs through the air conditioning systems for many large downtown office buildings. The lake water will never leave the pipes or mix with the air conditioning water. It will be returned to the lake. By 2004, the Deep Lake Water Cooling system will pump enough lake water to cool 100 office towers in Toronto. One building is already connected to the system.

Designing a Heat Exchanger

As you have studied this unit, you have read about heat exchangers. Exactly how do heat exchangers work? What features are necessary for maximum exchange of heat between two fluids that are never mixed? In this activity, you will answer those questions. You will simulate the system for using the cold waters of Lake Ontario to cool Toronto office buildings. By completing the activity, you will develop a greater understanding of the function of heat exchangers.

Safety Precautions

- Use care when working with glassware.

Materials

beaker (1 L)
block or stand for large beaker
ice
water
beaker (250 mL)
funnel
various sizes and lengths of plastic tubing
thin-walled copper tubing
graduated cylinder (100 mL)
thermometer

Find Out

Procedure

1. Fill the 1 L beaker about two-thirds full of ice water. Be sure that there is always some ice in the water so the temperature remains near 0°C.

2. Place the beaker of ice water higher than the empty 250 mL beaker, as shown in the diagram.

3. Insert the funnel in the end of a long piece of plastic tubing. Coil the tubing in the ice water, keeping the end opposite the funnel out of the water. Put the end of the tubing in the small beaker, as shown.
4. Put 100 mL of room-temperature water in the graduated cylinder.

5. Measure and record the temperature of the water in the cylinder.

6. Pour the water into the funnel so that it runs through the tubing and into the small beaker. Be careful not to pour the water into the funnel so fast that it overflows.

7. Measure and record the temperature of the water in the small beaker.

8. Calculate the difference in the temperature of the water before and after it passes through the heat exchanger (the coil of tubing in the ice water).

9. Repeat the procedure several times with various lengths of tubing as well as tubing of various diameters. Also vary the rate at which the water flows through the tubing. (Hint: You can change the flow rate by changing the height of the funnel and the height of the end of the tubing that is going into the small beaker.)

10. Insert a few short sections of copper tubing into the plastic tubing. Repeat the procedure with some copper tubing in the heat exchanger.

What Did You Find Out? * Analyzing and Interpreting

1. How did the length of the tubing affect the temperature difference of the water before and after it passed through the heat exchanger?

2. How did the diameter of the tubing affect the temperature difference of the water before and after it passed through the heat exchanger?

3. How did the flow rate affect the temperature difference of the water before and after it passed through the heat exchanger?

4. How did the presence of copper tubing affect the temperature change of the water?

5. Describe the characteristics of an effective heat exchanger.

Extension

6. Do research in print resources or on the Internet to learn how heat pumps and heat exchangers can be used in homes and offices. Heat pumps connected to pipes in the ground can heat homes in the winter and cool them in the summer. From your research, explain how this is done.

Section 6.2 Summary

While studying this section, were you surprised to learn about the low efficiencies of commonly used machines and systems?

- The incandescent light bulb has changed very little since its invention by Thomas Edison in 1879.
- Today's cars are actually much more efficient compared to the cars built in the 1920s and 1930s. However, 20 percent efficiency is still very low.
- More and more cars are on the roads every year.
- The generation of electrical energy using fossil fuels is only about 30 percent efficient.
- Over 96 percent of the electricity generated in Alberta uses coal or natural gas as a fuel.
- Natural resources are gradually being used up and their use pollutes the environment.
- Scientists and engineers are constantly searching for other sources of energy. They are trying to design more efficient methods of transforming potential energy into electrical energy.

INTERNET CONNECT

www.mcgrawhill.ca/links/sciencefocus10

Heat exchangers and heat pumps are widely used to heat and cool buildings. To learn more about heat pumps, go to the web site above. Click on Web Links to find out where to go next.
Check Your Understanding

1. Explain why internal combustion engines have a low efficiency.

2. Compact fluorescent light bulbs are more expensive than incandescent bulbs. How is it possible to save money by using compact fluorescent bulbs?

3. Electric motors are already quite efficient. Why is there a need to improve their efficiency?

4. Briefly explain how plants use and store energy through photosynthesis. Describe and discuss the efficiency of photosynthesis.

5. What is the most efficient, commonly used method for generating electrical energy?

6. Explain the concept of cogeneration.

7. Apply Describe two things that you could do every day to reduce your use of electrical energy.

8. Apply Take a tour of your school. Learn how your school uses electrical energy and how it is heated and cooled (if it has air conditioning). As a class or in small groups, submit a report including ways in which your school administrators could save energy. Include criteria in your report. For example, reduced lighting would save energy. However, darkened stairways would be a safety hazard. Reduced lighting in classrooms could cause eyestrain, which could have an effect on students’ ability to concentrate. Be prepared to defend your suggestions.

9. Thinking Critically Incandescent light bulbs and internal combustion engines in cars are very inefficient. Why do you think these devices are still used instead of being replaced with more efficient technologies for lighting and transportation?

10. Thinking Critically Do research on the Internet or in print resources to learn about technologies that scientists or engineers are studying that will provide energy with a minimal effect on the environment. Write a short summary about the information you have found.
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) State the second law of thermodynamics in terms of the efficiency of processes. (6.1)

(b) How do scientists define efficiency? State the definition in words and in an equation. (6.1)

(c) How do you determine the useful output energy and the total input energy of a system? (6.1)

(d) Explain why it is not feasible to stop using machines and return to manual methods of providing food, clothing, and shelter. (6.2)

(e) How efficient is the internal combustion engine? What happens to the waste energy? (6.2)

(f) How efficient are incandescent light bulbs? What is a more efficient alternative to incandescent light bulbs? (6.2)

(g) Approximately half of all of the electrical energy generated in North America is used to drive what device? (6.2)

(h) Compare the efficiencies of coal-burning plants and nuclear reactors to hydro electric-generating plants? (6.2)

(i) Explain how cogeneration can increase the efficiency of the use of thermal energy. (6.2)

(j) Describe some examples of technologies that are currently being developed with the goal of reducing the amount of “waste” energy. (6.2)

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Prepare Your Own Summary

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

• Choose a machine or technological device used in modern industry. Follow the history of its development and see how its efficiency of energy use has evolved.
• Compare energy usage and efficiency of living systems with technological devices.
• Find out what type of electric-generating plant supplies electrical energy to your home and school. Learn about the progress that has been made and your energy company’s plans for the future.
• Choose one piece of equipment that you use. Trace the energy transformations and their efficiencies from the source of energy — such as coal — to the final form of “useful” energy produced by the device.
Key Terms

useful energy  output energy
efficiency  resting position
input energy

Understanding Key Concepts

Section numbers are provided in parentheses below in case you need to review.

1. According to the second law of thermodynamics, why cannot any processes be 100 percent efficient? (6.1)

2. The statement that “energy is lost” often refers to the efficiencies of devices. According to the first law of thermodynamics, energy cannot be created or destroyed. What, then, is the meaning of “lost” energy? (6.1)

3. When you calculate the efficiency of an object or process, your answer has no units. Why is it critical to use the same units for the total input and useful output energies in the calculation? (6.1)

4. Identify the useful output energy and the input energy for (a) a gas stove and (b) a satellite-launching rocket. (6.1)

5. Describe the energy transformations that occur when a pendulum is swinging. How would a “perfect” pendulum differ from a real pendulum? (6.1)

6. If a classmate told you that the answer to an efficiency calculation was 105 percent, how would you know that there was an error in the calculation? (6.1)

7. When you are solving a problem involving efficiency, what must you do before performing any mathematical calculations? (6.1)

8. What is the difference in how incandescent light bulbs and fluorescent bulbs produce light that results in differing efficiencies? (6.2)

9. Why are the efficiencies of coal-burning plants and nuclear reactors that generate electrical energy similar? (6.2)

10. Give two reasons why reports in scientific literature about the efficiency of green plants could differ significantly. (6.2)

11. Explain the concept of cogeneration. How does cogeneration save energy? (6.2)

12. How can heat exchangers transfer heat from one liquid to another while not allowing the liquids to mix? (6.2)

Developing Skills

13. The “machine” in the diagram is called a perpetual motion machine because it provides its own energy while also performing a task. It is designed to run perpetually (forever). Analyze the diagram and explain how it is supposed to work. Explain, based on the first and second laws of thermodynamics, why such a machine cannot exist.

14. Do research in print resources or on the Internet to learn how energy, released by one process, is used by another process in the Joffre cogeneration plant. Write a paragraph about these processes.

15. Design a machine in which the input energy is the kinetic energy of a falling pendulum bob and the output energy is gravitational potential energy. Sketch your machine. Include labels and a caption.
16. List all of the energy transformations that occur when you heat food in a microwave oven.

17. By using a pulley system like the one shown here, you could lift a 100 N weight by exerting a force of only 25 N on the rope. Analyze the pulley system carefully. When you lift the weight with the pulley system, is the gravitational potential energy gained by the weight four times greater than the work you did on the rope? Explain why or why not.

**Problem Solving/Applying**

18. A portable stereo uses 586 J of energy while playing a CD. If it produces 327 J of sound energy, what is the efficiency of the stereo in transforming electrical energy into sound energy?

19. A kerosene lantern uses 984 J of chemical potential energy and produces 75 J of light energy. How efficient is the lantern in transforming chemical potential energy into light?

20. A crane uses $1.15 \times 10^6$ J of chemical potential energy in the fuel to lift a 985 kg crate a distance of 27 m. What is the efficiency of the crane?

21. A falling block with a mass of 2.4 kg drops a distance of 1.7 m onto a spring and compresses the spring. If 32 J of elastic potential energy are stored in the spring, what was the efficiency of the transformation of gravitational potential energy into elastic potential energy?

22. An archer does work on a bow by exerting an average force of 175 N over a distance of 0.62 m to stretch the string and bend the bow. In the process, elastic potential energy is stored in the bow. When the archer releases the 0.065 kg arrow, its initial speed is 49 m/s. What was the efficiency of transforming the archer's work into the arrow's kinetic energy?

23. A toy uses a spring to shoot an arrow with a suction cup on the end. The toy shoots a 35 g arrow and gives it a speed of 5.5 m/s. If the efficiency of the toy is 66 percent, how much elastic potential energy was stored in the spring?

24. A 145 g ball is thrown directly upward with an initial speed of 8.63 m/s. If the ball reaches a height of 3.34 m above the point of release, what is the efficiency of the transformation of kinetic energy into gravitational potential energy?

25. A cyclist is standing still at the top of a hill and then begins to coast down the hill. The mass of the cyclist and bicycle is 64 kg. The cyclist's gravitational potential energy is converted into kinetic energy with an efficiency of 48 percent. What is her speed when she reaches a point that is a vertical distance of 12 m lower than the point at which she started?

**Thinking Critically**

26. Since hydro-electric generation of electrical energy is so efficient, you might think that it would be used more extensively. Find out why many people are opposed to the construction of dams and power plants in many locations. After learning about the various perspectives of other people, develop and defend your own position on the building of hydro-electric plants.

27. As a society, we continue to use large amounts of fossil fuels in systems that have very low efficiencies. Although some efforts are being made to develop more efficient systems and processes (such as cogeneration), progress is slow. What do you think should be the role of government, industries, universities, and the general public in developing methods to conserve energy?

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**Pause & Reflect**

Go back to the answers you wrote for the Focussing Questions. How would you change your answers now that you have finished this chapter?
Dr. Steve Bergens knew he wanted to be an astronaut or a scientist. He opted for science and earned his B.Sc., M.A., and Ph.D. in chemistry. He then conducted postdoctoral research at Harvard. Now he’s a professor in the University of Alberta’s top-ranking chemistry department. For the past seven years, Dr. Bergens and four graduate students have been doing research in the field of fuel cells.

Q: How did you become interested in your field?
A: I learned about fuel cells while doing postdoctoral research at Harvard. It’s good to learn as many different things as you can while you’re doing this research. The professor I worked with at Harvard had been working on fuel cells for a while and I thought that sounded pretty interesting. I went over there to see what was going on and decided to carry it on here.

Q: Are there by-products when you oxidize these substances?
A: When you oxidize any common fuel, you make water and carbon dioxide. So, you still make greenhouse gases, but the idea is to do it as efficiently as possible to minimize any negative impact on the environment.

Q: How are your fuel cells different from conventional ones?
A: A fuel cell is a battery, but instead of carrying the chemicals inside it, you continuously feed it fresh chemicals so it never runs out. Your watch battery runs out when the chemical reaction inside is done. With a fuel cell, you keep replenishing what’s inside and it keeps making electricity for you. The cheapest chemicals around for that are air and some kind of gasoline or fuel. We’re using methanol.

Q: Is using fuel cells an efficient way to make electricity?
A: A fuel cell, in theory, is the most efficient way to get electricity from burning a fuel. It’s about 90 percent efficient. The best they can do with a car is around 30 percent efficiency, so 70 percent of the gas you burn in your car is wasted and turned into carbon dioxide and pollutants in the atmosphere. In your car, you burn gas and use the heat energy to move your car using devices such as transmissions and pistons. In theory, if you can get a fuel cell to do it, 90 percent of the gas you burn goes directly into work to move the car. The promise is really great. It’s very quiet, it’s very clean, and it’s very efficient, in theory.

Q: How do your cells replenish the chemicals?
A: It’s a pump system. We have a gas tank full of methanol in one side and we pump that into the fuel cell. We pump air into the other side and the cell produces electricity.
Q Only in theory?
A Well, it's a tough problem to solve. The problem is that the electrochemical reaction of methanol in the fuel cell is slow — almost too slow to be practical. What we need to do is speed up that reaction with a catalyst. We're using platinum-ruthenium as a catalyst. We're trying to optimize the activity of this catalyst and also use it as efficiently as possible.

Q Do you hope to replace conventional batteries with these fuel cells?
A That's certainly the idea. A company in Vancouver is pushing hard in this direction. They're using hydrogen and methanol as fuels. The issue with hydrogen is, as everybody knows, it's a flammable gas. So to safely transport and store large quantities of high-pressure hydrogen will be a challenge. A liquid-fuel fuel cell is, at least for the immediate future, a more attractive way to go.

Q How long do you think this will take?
A I would guess around ten years. Everyone is working as hard as they can. There are so many parts to the problem. It's not only getting the fuel cell to work well. You also have to come up with a way to distribute methanol (or another fuel) around the country. You have to make sure the cells are safe in such incidents as crash tests in cars. It could be that the people working on the other parts of the problem are further ahead. So it could be sooner than ten years.

Several companies in Canada are actively developing fuel cells. One of the best known is Ballard Power Systems, located in Vancouver. The technology Ballard is researching differs from Dr. Bergens's. However, Ballard Power Systems is trying to accomplish the same thing. Using reference materials and the Internet, research the Ballard fuel cell and compare it to the one described above. What are some of the advantages and disadvantages of the different cells? Continue your research and find other fuel cells being developed. List their advantages and disadvantages.

Northwest Scientific sells a solar-powered fuel cell model that can power several different devices. To increase your understanding of fuel cells, research its operation as well.

The NECAR 4 uses fuel cell technology. This prototype uses liquid hydrogen to produce electricity in a fuel cell, which is then used to power the vehicle.
Can you convert energy? You certainly can. Whenever you eat, you convert chemical potential energy to kinetic energy. In this project, however, you are to design an energy-conversion device external to your own body. The device must convert one form of energy into another, convert potential energy into kinetic energy (motion), or convert energy into work. You will calculate the efficiency of your device and suggest improvements to increase its efficiency.

**Challenge**
As part of an engineering team, you are to design and build an energy-conversion device. The conversion may be from any energy form to any other energy form, or from any energy form into work. The important point is that the energy input and the energy output must both be measurable.

**Safety Precautions**
Use care when constructing the conversion device, especially if you are using sharp objects, or if surfaces become hot.

**Materials**
any materials you will need for your approved design

**Design Specifications**
A. Your conversion device should be “useful” in that it does work or converts energy to another form that is preferred.
B. The energy input to your device must be measurable.
C. The energy output from your device must be measurable.
D. Your device must have an efficiency of at least 60 percent.
E. The suggestions to improve your device must boost its efficiency by at least 10 percent.

**Plan and Construct**
1. Working in a group of four, organize the project so that the workload will be evenly divided among members of the group.
2. Create a drawing of the device with proposed measurements and expected performance:
   - Label the energy conversion(s) that are taking place.
   - Provide a theoretical input and output calculation.
   - Predict the efficiency of the device.
   - Make a list of materials needed to create the device.
   - Have your teacher check your design.
3. Prepare a timeline for the collection of materials, construction, testing, and measurement of the device. Your teacher may provide specific deadlines you will have to meet, so be prepared.
4. Test the device and perform the necessary measurements and calculations.
5. Prepare a 5 min presentation explaining the operation of your device, its energy conversion(s), how you measured its energy input and output, and its efficiency.

Evaluate
1. As a group, discuss the effectiveness of your device. Did it perform as well as you intended?
2. Suggest modifications that could improve the efficiency of your device by at least 10 percent.
3. Prepare a set of plans or instructions that would enable others to build a device that functions like the one you have built.

Extensions
1. Fitness machines used at local gyms are often designed to waste energy. That is, the machine makes the work of moving some weights more difficult than normal in order to exercise specific muscle groups. Visit a local gym and find a machine that is designed to waste energy in this manner. Draw a diagram that shows the operation of the machine and highlight where energy is wasted.
2. Find out the total amount of electrical energy used in Alberta in a specific year. Determine the fractions of that energy provided by various sources — nuclear, fossil fuels, hydro-electric, wind power, etc. Choose one of these sources and report on its advantages and disadvantages compared to the others.

3. There are many simple machines in every household. Levers (like brooms), wheel and axles (like doorknobs and screwdrivers), and other simple machines all make life easier for us. Research some types of simple machines. Choose and describe the science behind the safe operation of a household device that illustrates this machine.

Construct two simple machines, such as a pulley and a lever. Use each machine to do work, and measure the efficiency of each. Make a compound machine by combining the two machines to do work. Measure the efficiency of your compound machine and compare it to the individual efficiencies. Note: By definition, the efficiency of a compound machine is the product of the individual efficiencies. For example, two 80% efficient machines hooked together should be 0.80 * 0.80 = 0.64 or 64% efficient.
Understanding Key Concepts

1. Why was there a need for some type of engine such as a steam engine in England during the 1600s?

2. One of the flaws in Newcomen's steam engine was the fact that the cylinder had to be heated and cooled during every cycle. What happened during the heating part of the cycle? What happened during the cooling part of the cycle?

3. Watt's steam engine was sometimes called a "double-acting" engine. Explain the meaning of "double-acting" as it applies to Watt's steam engine. In what ways was this "double-acting" process an improvement over Savery's steam engine?

4. How does a steam turbine differ from Watt's steam engine?

5. List three different applications for Watt's steam engine.

6. Describe the "four-elements" theory of heat.

7. What is a major flaw in the caloric theory of heat?

8. Joseph Black defined the calorie as a unit used to quantify the fluid called caloric. Why is this unit still used today, even though scientists now know that there is no such fluid?

9. Describe Rumford's observations that he used to develop his theory that a relationship existed between heat and energy.

10. Why was Mayer's work on the relationship between energy and heat ignored by the scientists of his time?

11. How do physicists define work?

12. Explain how to determine work graphically. What quantities must be on the vertical and horizontal axes of the graph?

13. How did Joule use water to experimentally determine the mechanical equivalent of heat?

14. Hot and cold water look the same. Based on the kinetic-molecular theory of heat, how do hot and cold water differ?

15. Explain the relationship between heat and temperature. Describe an example that illustrates that temperature is not a measure of the amount of thermal energy in a substance.

16. Describe an example that illustrates the first law of thermodynamics.

17. Sometimes students of science describe the laws of thermodynamics in a humorous way. They claim that the first law can be stated, "You can't get something for nothing." They state the second law as, "You can't even break even." Explain how these statements are somewhat appropriate for the laws of thermodynamics.

18. Engines based on Watt's design of the steam engine are not in use today. However, pistons are used, and steam is used in different applications. Describe one modern device that uses pistons and one modern device that uses steam.

19. List the major energy conversions, in sequence, that take place in a nuclear reactor generating station.

20. Why can wind energy only supplement but not replace coal-burning generation of electrical energy?

21. Explain the difference between scalar and vector quantities. Give two examples of each type of quantity.

22. Why is the distance between two points usually greater than displacement between those two points? Can the distance between two points ever be less than the displacement? Explain.

23. State the definitions of speed and velocity in words and in mathematical formulas.
24. What is uniform motion?

25. Explain how you could use a graph of position versus time to find the velocity of an object or person.

26. What is wrong with the statement, “Acceleration is the change in the speed of an object during a time interval?” State the definition correctly.

27. If the graph of position versus time curves upward, what can you say about the object’s acceleration?

28. What properties of an object determine its kinetic energy?

29. What happens to an object’s kinetic energy when you do negative work on the object?

30. How can you give a spring elastic potential energy? How do you know that it has stored energy?

31. How can you convert chemical potential energy into another form of energy?

32. When a very large nucleus fissions (splits), energy is released. In what form was that energy stored in the original nucleus?

33. Describe an example of gravitational potential energy that can be converted into a useful form of energy.

34. Define efficiency in words and in the form of a mathematical formula.

35. State the form of the input energy and the useful output energy for each of the following devices.
   (a) a battery
   (b) a lawnmower
   (c) a notebook computer
   (d) an automobile horn

36. Name one very efficient modern technological device and one inefficient modern device. What is the major difference between the two devices that causes the efficiencies to be so dissimilar?

37. Explain the concept of cogeneration.

38. In a Model Problem, you discovered that living cells are only about 38 percent efficient in converting the energy stored in glucose into the energy in ATP. Mammals, including humans, are animals that maintain a constant body temperature. Use the concept of cogeneration to explain why the use of glucose in mammals is more efficient than 38 percent.

39. In an experiment on the school track, two students try to run at constant velocities. They use the portion of the track that goes directly north. A timer records the time for each runner as he and she pass each 10 m mark. The times are recorded in the following table.

<table>
<thead>
<tr>
<th>Position (m)</th>
<th>Time for runner #1 (s)</th>
<th>Time for runner #2 (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1.3</td>
<td>2.9</td>
</tr>
<tr>
<td>20</td>
<td>2.5</td>
<td>5.7</td>
</tr>
<tr>
<td>30</td>
<td>3.8</td>
<td>8.6</td>
</tr>
<tr>
<td>40</td>
<td>5.0</td>
<td>11.4</td>
</tr>
</tbody>
</table>

(a) Plot a position versus time graph for each runner.
(b) Use the graph to determine each runner’s average velocity.
(c) How well did the runners achieve a constant velocity? Explain how you determined your answer from the graph.
(d) Was either runner accelerating? Explain how you determined your answer from the graph.
40. Describe the energy conversions that occur as the cars and riders in an amusement park ride complete a vertical loop.

41. Draw a concept map that shows how the following terms are related: (a) work (b) elastic potential energy (c) gravitational potential energy (d) thermal energy (e) chemical potential energy (f) kinetic energy (g) efficiency

42. Design an experiment for determining the efficiency of a spring in converting elastic potential energy into gravitational potential energy.

43. James Watt defined the unit horsepower to describe the rate at which work is done by a machine. Do research in print resources or on the Internet to find out how he defined the term and how he applied the concept to his steam engines.

Problem Solving/Applying

44. A weightlifter exerts a force of 883 N on a barbell over a distance of 0.65 m. How much work did the weightlifter do on the barbell?

45. With a single pulley, you lift a crate. If you exerted a force of 455 N and did 3276 J of work, how far did you lift the crate?

46. A student rides her bicycle 825 m north and stops to talk to a friend. She then rides 382 m north but realizes that she was supposed to pick up a book at another friend's house. She rides 540 m south. After picking up the book, she rides 1450 m north. What distance did the student ride? What was her displacement?

47. A turtle walks 0.44 m[E] in 3.5 min. What was the turtle's velocity?

48. If you walk at an average velocity of 1.4 m/s[S], how long will it take for you to go 2.1 km[S]?

49. A runner passes one trainer at a velocity of 0.35 m/s[W]. The trainer's stopwatch registers 16 s. The runner passes the second trainer at a velocity of 1.8 m/s[W]. The second trainer's stopwatch reads 24 s. Both trainers started their stopwatches at the same time. What was the runner's acceleration?

50. A car slows from 27 m/s[W] to 10.0 m/s[W] before reaching a highway exit. If it took the car 6.5 s to reach the exit after starting to slow down, what was the car's acceleration?

51. In the Career Connect on page 187, you read that Teri MacDonald-Cadieux's car crashed into a wall at a speed of 200.0 km/h. If the car came to a complete stop in 0.55 s, what was her acceleration? Assume that the car was travelling in the positive direction.

52. A 5.4 kg bowling ball is rolling at 1.8 m/s. What is the kinetic energy of the bowling ball?

53. How fast would a 0.250 kg billiard ball have to be rolling to have the same kinetic energy as the bowling ball in problem 52?

54. A 4.5 kg chandelier hangs from the ceiling of a large ballroom. If the chandelier is 12 m above the floor, what is its gravitational potential energy relative to the floor?

55. How high would you have to lift your 0.55 kg textbook to give it 119 J of gravitational potential energy?

56. The 200.0 kg roller coaster car shown on the next page is sitting motionless at point A, 15.0 m above the ground. If the car starts to roll down the track, what will its speed be when it reaches point B, 6.0 m above the ground?
57. A 102 kg soapbox derby car starts at the top of a hill. The starting point is a vertical distance of 40.0 m higher than the finish line. The car is going 11 m/s when it crosses the finish line. With what efficiency did the car convert its gravitational potential energy into kinetic energy?

58. A 3.8 kg steel ball is dropped on a spring and compresses the spring. As a result, the compressed spring stores 72 J of elastic potential energy. If the gravitational potential energy of the steel ball was converted into elastic potential energy of the spring with an efficiency of 80.5 percent, from what height was the steel ball dropped?

59. If a light bulb is 5.2 percent efficient and it emits a total of 6.24 × 10^3 J of light energy, how much electrical energy does it use?

Critical Thinking

60. A company's management wants to build a factory by a river that runs through the city where you live. The management claims that the factory will create over 100 new jobs for the city. However, the factory will generate thermal energy that could lead to thermal pollution of the river. What information would you want to know before permission is granted to the company to build the factory? What suggestions might you make to the company to reduce the impact of the factory on the environment?

61. The use of some form of electric vehicles offers the following advantages. For each of the advantages listed, explain whether the primary advantage is economic, environmental, or energy efficiency. Provide reasons for your choice.

   (a) electric cars reduce air pollution
   (b) electric cars can be designed to convert kinetic energy into chemical energy of a battery while braking
   (c) electric motors do not consume energy when the car is not moving
   (d) electric cars do not produce as much waste heat as do internal combustion engines
   (e) some electric car batteries can be recharged from a variety of sources, including wind and solar energy
   (f) electric motors are quieter than internal combustion engines.