

LESSON 8

Work and the Motor



CORBIS/ANNIE GRIFFITHS BELT

Are the cyclists in this picture doing work?

INTRODUCTION

To most people, work is the physical or mental effort it takes to get something done. If you ask a scientist, work takes a little more time to explain. In this lesson, you will learn and use the scientific definition of work and learn how to calculate work.

You will make a number of measurements to use in calculating work. Calculating is important in science. This lesson will require you to use your math skills. Good science combines facts and figures. Mathematics is a great tool of science because it helps to describe how things behave and it helps scientists predict how some objects or processes will behave in the future. Italian astronomer Galileo and English physicist and mathematician Sir Isaac Newton were among the first to realize the combined power of math and science.

OBJECTIVES FOR THIS LESSON

Define “work.”

Describe the units of measure for work.

Use force and distance measurements to calculate work.

Compare the work done by different forces.

Compare the force exerted by a motor that is connected to three batteries in series with the force needed to lift a small sled.

In Lessons 5, 6, and 7, you studied four different forces and learned something about how each force behaves. Those forces have different properties, but they also have something in common—they can all do work. In this lesson, you will learn how forces do work and how to calculate the amount of work being done. You will calculate the work done by three of the forces you studied—gravity, motors, and friction.

Getting Started

1. In your group, discuss the meaning of the word “work.” List examples of work being done. Share examples with the class.
2. Read “The Meaning of Work” in this lesson. When you finish, review the examples of work you listed earlier. Do your examples match the scientific meaning of work? Discuss this with the class.
3. With the class, review how to calculate a value for work and explain the units of measure for work.
4. Work out this problem: Alice pulls a sled with a force of 12 N. She pulls the sled through a distance of 5 m. How much work does Alice do on the sled? In your notebook, write down your calculation and check your answer. Keep this sample as a reference for when it is time to calculate work.

MATERIALS FOR LESSON 8

For you

- Your completed copy of Student Sheet 6.1: What a Drag!
- 1 copy of Student Sheet 8.1a: How Much Work Was Done?
- 1 copy of Student Sheet 8.2: Lifting a Load

For your group

- 1 electric motor with wire leads and alligator clips
- 1 motor pulley with nail
- 1 motor clamp
- 1 knife switch
- 1 pegboard assembly
- 3 machine screws with wing nuts
- 3 D-cell batteries

- 3 D-cell battery holders
- 5 insulated connector wires with alligator clips
- 1 large paper clip
- 1 piece of string
- 1 piece of masking tape
- 14 large washers, 30 g
- 1 0- to 10-N spring scale
- 1 meterstick
- K’NEX® parts for sled (see Appendix A: Directory of K’NEX® Parts):
 - 1 orange connector (C3)
 - 14 red connectors (C4)
 - 8 yellow connectors (C10)
 - 8 green rods (R1)
 - 4 white rods (R2)
 - 3 blue rods (R3)
 - 4 red rods (R6)

THE MEANING OF WORK

It isn't hard to understand what most people mean when they talk about work—

"I'm going to work."

"This job is hard work."

"I worked hard to study for this test."

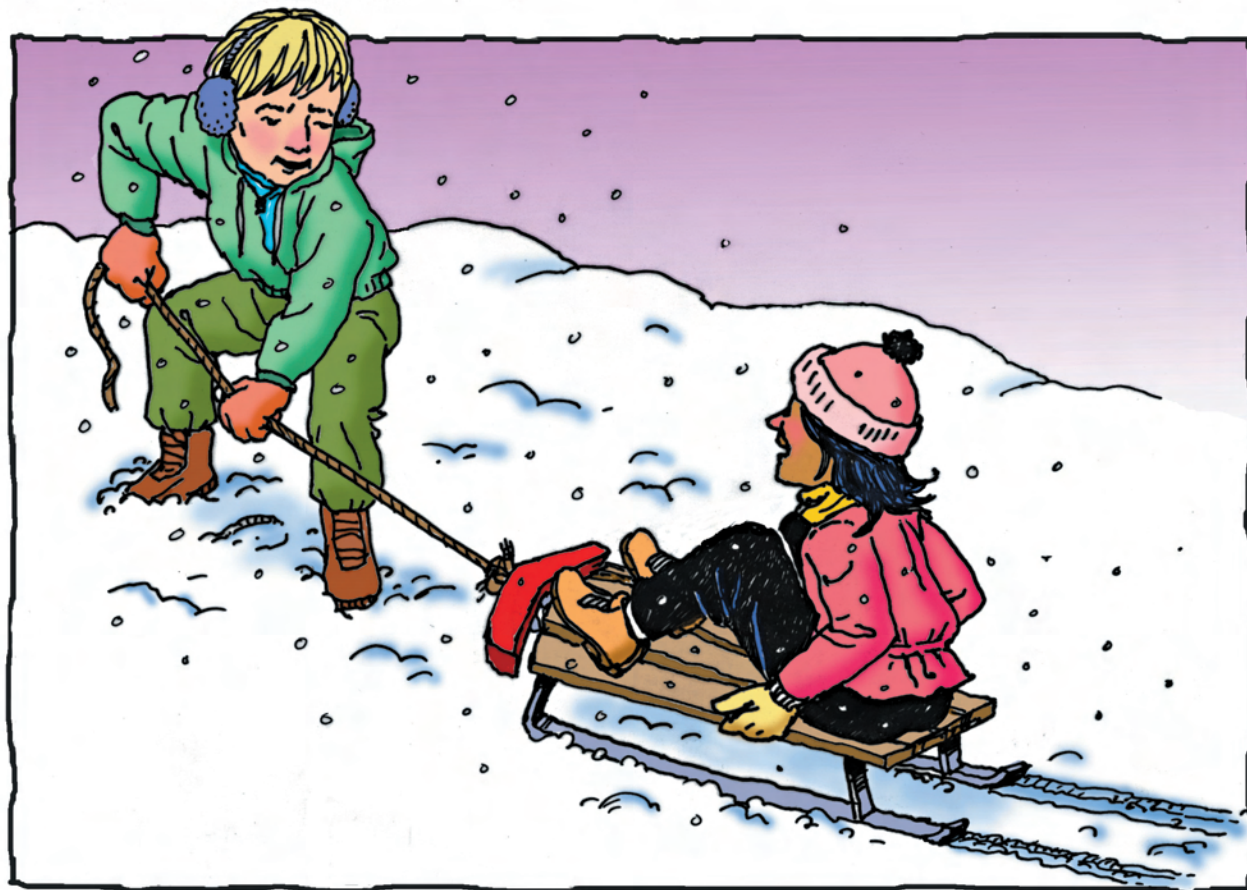
In everyday speech, the word "work" refers to the effort it takes to get things done. Manual labor is seen as work; so is mental labor.

But in science, "work" has a narrow definition. Work is done on an object, a scientist would say, when a force acts on an object and it moves some distance. To calculate the work done on an object, the force that pushes or pulls on the object is multiplied by the distance the object moves. Work involves both force and distance.

Activities that may seem like work to you

might *not* seem like work to a scientist. For example, if you sit quietly and study for a long time, a scientist would say that you're not doing any work at all! And you could push against a car until you were exhausted, but if the car didn't move, the scientist would say you had done no work on the car. As you can see, there is a big difference between the everyday use and the scientific use of the word "work."

Two things must happen for a force to do work on an object. First, the force must push or pull on the object. Second, the object must move some distance. Both must happen; otherwise, no work is done. For example, suppose you pick up a heavy book bag and put it on your back. Now a scientist would say that you have done work on the book bag. But exactly how much did you do?



Work is done when a force acts on an object that moves some distance while the force acts.

It's not hard to figure out. Multiply the force needed to lift the bag by the distance the object was lifted. That's it. In other words, for the scientist:

$$\text{Force (F)} \times \text{Distance (d)} = \text{Work (W)}$$

In mathematical terms, this could be expressed as

$$Fd = W$$

The amount of work done equals the product of the force (in newtons) times the distance (in meters) through which the force acts—

$$\text{Force (N)} \times \text{Distance (m)} = \text{Work (N-m)}$$

When force and distance are measured using newtons and meters, work is measured in units called newton-meters (N-m). A newton-meter is also called a joule (J), for James Joule, who made important discoveries about work and energy. Work and energy are both

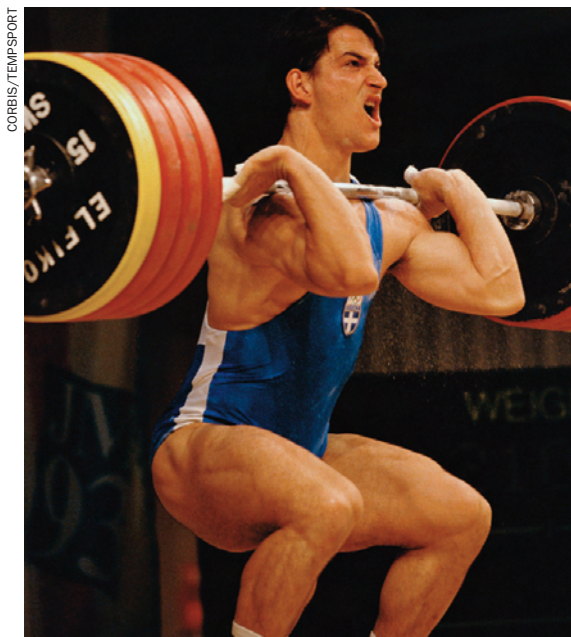
measured in newton-meters or joules. In this module you will use newton-meters as the unit of measure for work. Using this unit will remind you how to calculate a value for work. Here's an example:

Michael lifts his book bag, which weighs 25 N, from the floor to a desktop that is 0.80 m above the floor. How much work does Michael do on the bag?

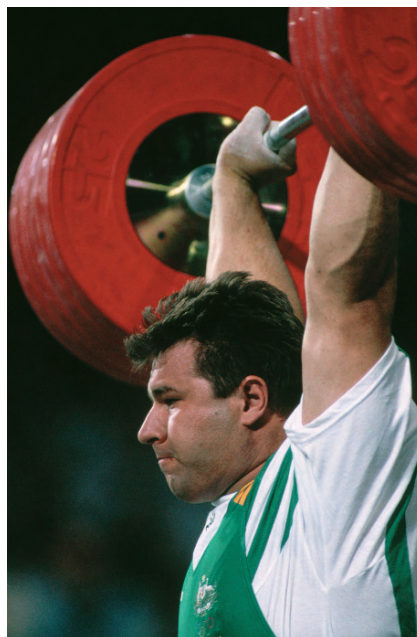
$$\begin{aligned} \text{Force} \times \text{Distance} &= 25 \text{ N} \times 0.80 \text{ m} = \\ &20.0 \text{ N-m} = \text{Work} \end{aligned}$$

Michael does 20.0 N-m of work on the book bag.

Why can the weight lifter in the photo on the right be said to be doing no work on the barbell? Because the barbell isn't moving; the weight lifter pushes upward, but the barbell stays in one place above his head. The product of force multiplied by the distance moved equals zero. Remember, according to the scientific definition, work is the product of two things—force and distance moved.



A weight lifter does a lot of work to lift a barbell above his head. The work he does is the product of the weight he lifts and the distance he lifts it.



This weight lifter is holding the barbell steady over his head. Is he doing any work on the barbell now? Why or why not?

Inquiry 8.1 Measuring the Work Done Across a Surface

PROCEDURE

1. In this inquiry, you will use the data on friction that you collected during Inquiry 6.1. In that inquiry, you calculated the average force on the spring scale as you pulled a wooden block across different surfaces. Return to Student Sheet 6.1 and find the average force data for each surface.
2. In the first data column of Table 1 on Student Sheet 8.1a, write the figure that represents the average force on the block as it moved across each surface. This is the effort force—the effort you exerted on the block to pull it across each surface.
3. You pulled the wooden block a known distance—0.27 m (27 cm)—each time. Record “0.27 m” as the effort distance for all surfaces.
4. Multiply the effort force by 0.27 m—the effort distance—to find the work done on the block for each surface (remember to use N·m as the work unit).
5. Complete the table on Student Sheet 8.1a and answer the questions.

Inquiry 8.2 Measuring the Work To Lift a Load

PROCEDURE

1. Set up a pegboard assembly as you did in Lesson 7 (see Figure 7.1). Connect three batteries in series to the motor (see Figure 8.1).

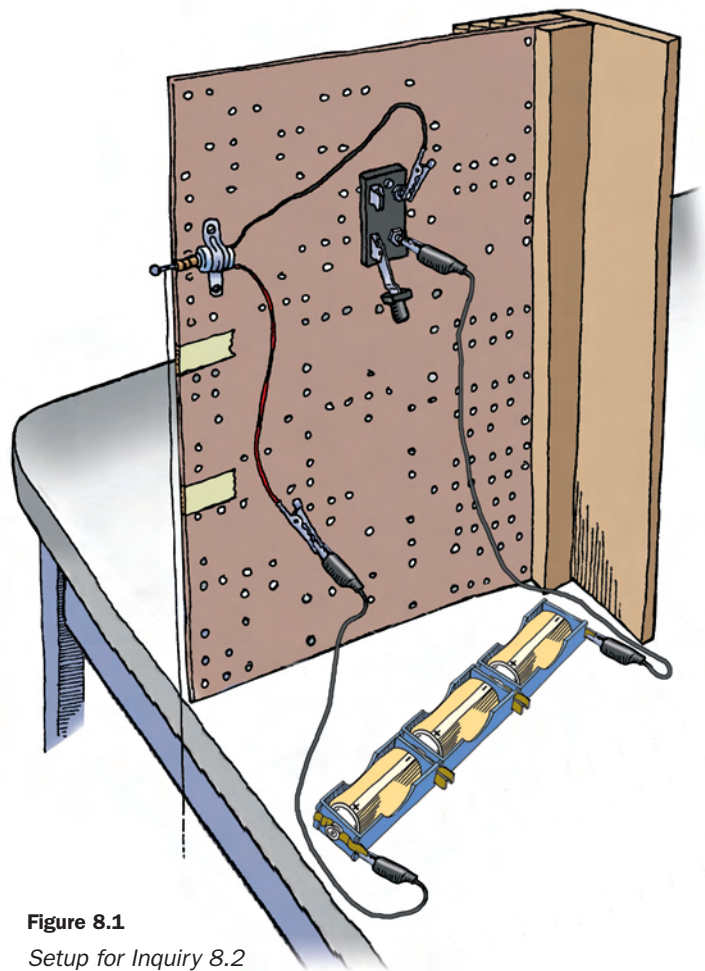


Figure 8.1
Setup for Inquiry 8.2

2. Use the tape to mark a vertical distance of 10 cm on the pegboard, as shown in Figure 8.1.

3. Use what you learned in Lesson 7 to attach the string to the motor so the motor exerts the greatest force on the washers. Attach a paper clip to the string so the bottom of the string is below the 10-cm piece of tape, as shown in Figure 8.1.
4. In Lesson 7, you measured how much force the motor exerts when it is connected to three batteries arranged in series. Record that force on Student Sheet 8.2 at Step 1.
5. Use the force the motor exerts to calculate how much work the motor does when it raises a load 10 cm (0.10 m). Record your calculation on Student Sheet 8.2 at Step 2.
6. Put six washers on the paper clip.
7. Close the switch and run the motor. Does the motor lift the washers? If not, remove a washer and try again. Keep removing washers one at a time until the motor can lift the remaining washers.
8. How much work did the motor have to do to lift the washers 10 cm? To answer that question, use a spring scale to weigh the washers. Record the weight on Student Sheet 8.2 at Step 3. Then multiply the weight by the distance (0.10 m) to get the work done in lifting the washers. Show your work on Student Sheet 8.2 at Step 4.
9. You have calculated work in two ways. One way was using the force of the motor. The other way was using the weight of the washers. How do the two values for work compare? Record your answer in your science notebook.
10. Now build your sled using K'NEX® parts and 14 washers. Follow Figures 8.3 through 8.5 to assemble the sled. The finished sled will look like the one shown in Figure 8.2.

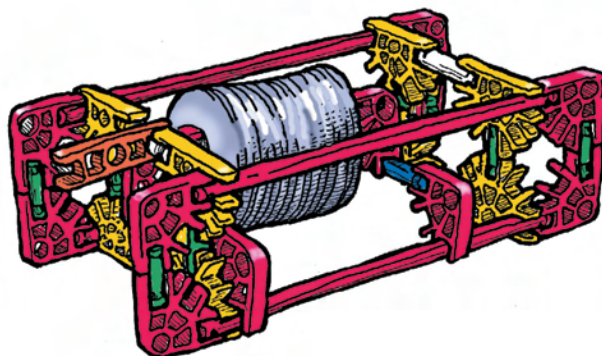


Figure 8.2 The assembled sled

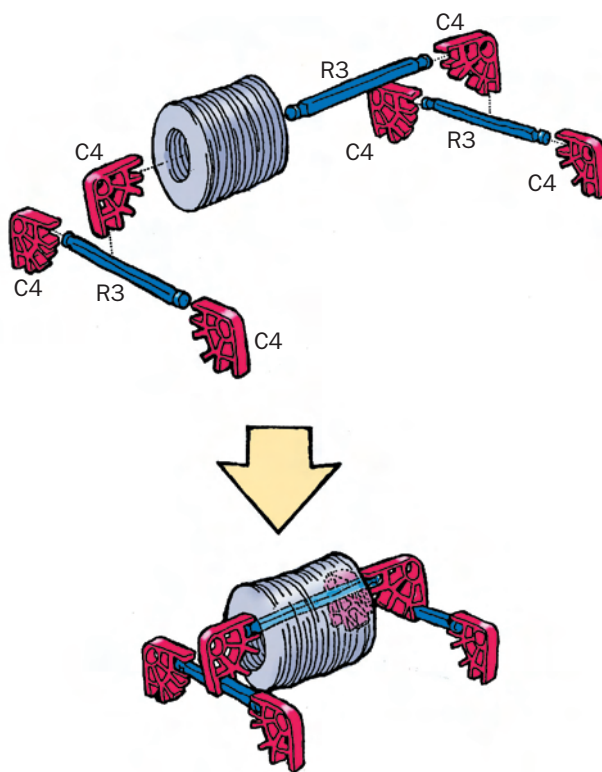


Figure 8.3 How to assemble the washer seat for K'NEX® sled

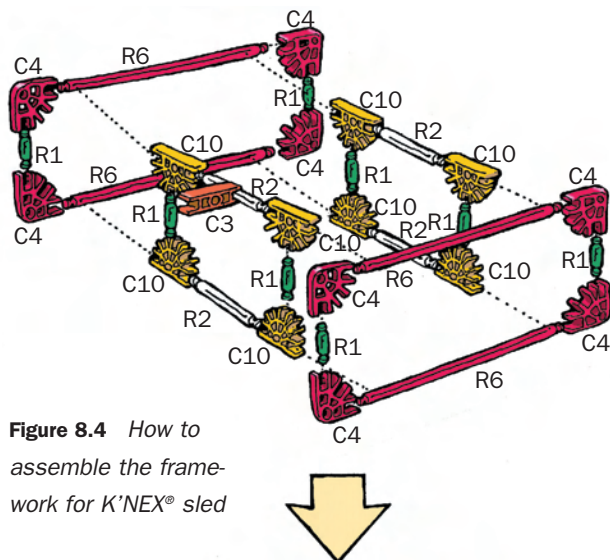


Figure 8.4 How to assemble the framework for K'NEX® sled

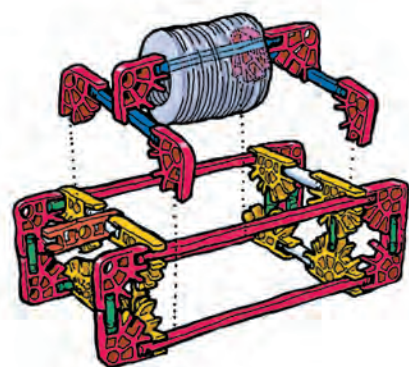
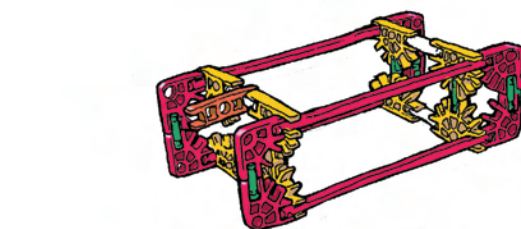
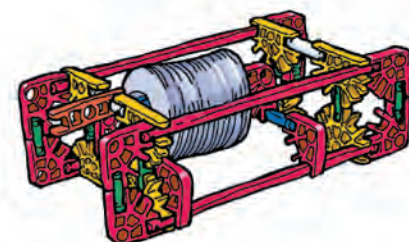


Figure 8.5 Putting the framework and washer seat together to complete the sled



- 11.** When you finish assembling the sled, estimate its weight. Describe how you made your estimate. Record your estimate on Student Sheet 8.2 at Step 5, and describe how you made your estimate in your science notebook.
- 12.** Now actually measure and record the weight of the sled using a spring scale. Record this on Student Sheet 8.2 at Step 6.
- 13.** How accurate was your estimate of the weight? Record your answer in your science notebook.
- 14.** Calculate the work it will take to lift the sled 10 cm. Show your work on Student Sheet 8.2 at Step 7.
- 15.** Try lifting the sled with the motor. Record what happens in your science notebook.

REFLECTING ON WHAT YOU'VE DONE

Discuss the following questions with your lab partner, and share your results and observations during a class discussion.

- A. Look at your table on Student Sheet 8.1a. Why do you think different amounts of work were done as you pulled the block across different surfaces?
- B. In Inquiry 8.2, when you tried to lift the sled with the motor, what happened?
- C. How much work did the motor do on the sled?
- D. Compare the maximum force of the motor with the weight of the sled. Explain why the motor could not do the work it takes to lift the sled.
- E. Since the motor cannot exert a greater force, think of ways to get the motor to do the work to lift the sled. List your ideas.

MEASURING UP

You can't get very far in science if you don't know how to measure and count accurately. And accurate measurements aren't worth anything if they can't be expressed in a way that anyone—even someone working on a similar problem around the world—can understand. In other words, scientists need standardized units of measure. Here is some information about the units of measure in the metric system, which you are using in this module.

The metric system is part of the International System of Units, a measuring system used throughout most of the world. The names of metric units identify what they measure. Meters (m), milliliters (mL), and kilograms (kg) are examples of metric units.

Some metric units are named after a scientist who made important contributions to a particular field. For example, Sir Isaac Newton explained how forces act on objects and the unit of force in

the metric system is the newton (N). James Joule explained the relationship between work and energy, and the unit of energy and work is—you guessed it—the joule (J). André Ampère gave his name to the “ampere,” the unit of electrical current (“amps,” for short). Italian scientist Alessandro Volta gets credit for the volt, which is used to express the electric potential of a battery. The unit of power is the watt (W), named after the Scottish engineer James Watt. □

QUESTIONS

1. Why are units of measure needed?
2. There are other metric units named for scientists. Look up the metric system and find a unit named for a scientist. What was the scientist's complete name? What did he or she study?

KLAMATH FALLS— A Real Hot Spot

Klamath Falls, Oregon, gets its share of snow every winter. But not all the residents of this city of 18,000 have to worry about shoveling their sidewalks or getting out the snowplows to clear the roads. Geothermal energy, pumped through a system of hot water pipes flowing underground, melts the snow and ice on some sidewalks and roads.

Geothermal energy is heat energy that comes from inside the earth. The deeper into the earth one goes, the warmer it becomes. Scientists think that the temperature at the very core of the earth may be as high as 5000°C (9000°F). In areas of geothermal activity such as Klamath Falls, water that has been heated deep under ground comes close enough to the earth's surface to be put to work. Sometimes the water even bubbles up above the surface of the earth and forms hot springs.

The people in Klamath Falls are not the first to use geothermal energy. It has been used in North America for more than 10,000 years. Archaeologists have found evidence that early Native Americans used hot springs to keep warm. They also used the water for cleaning and cooking. Early European settlers in the western United States built spas and resorts around natural hot springs. Some people believe that these waters have healing powers. Everyone who visits these spas finds that the warm



PHOTO COURTESY HERALD AND NEWS, KLAMATH FALLS, OREGON

A worker lays down pipes that will carry hot water beneath the streets and sidewalks of Klamath Falls to keep them free of ice and snow in the winter.

water, which has a high mineral content, provides an invigorating natural bath.

In Klamath Falls, geothermal energy is put to practical uses as well. In addition to reducing the need for snowplows, it helps heat public buildings. Geothermal water is piped into a heat exchanger, which transfers the heat energy from the hot

groundwater to clean water in a pipe network. The heated water circulates through the pipes and heats buildings around the city.

Some businesses in the city use geothermal energy in creative ways. Geothermal water is piped through greenhouses to keep them warm in winter. The fish-growing industry uses the water to heat tanks. Fish raised in these tanks grow faster than do those raised in colder tanks. Other businesses use heat from geothermal sources to dry vegetables and lumber.

In the United States, some western states have geothermal power plants that use steam pressure that has come from beneath the earth to turn a turbine that operates an electrical generator. Geothermal power plants produce electricity in many other countries, including Iceland, New Zealand, Italy, Argentina, Japan, and Kenya.

Even though geothermal energy has been used



CORBIS/BOB KRIST

In Iceland, a woman bakes bread using a geothermal oven.

for thousands of years, its potential is still mostly untapped. As people become more concerned about controlling pollution and making the best use of natural resources, geothermal energy is bound to become more widely used. □

CORBIS/ROGER RESSMEYER



Bathers in Iceland enjoy the warm waters outside a geothermal power plant. The water stays warm throughout the winter.