SECTION D

ENERGY ALTERNATIVES TO PETROLEUM

Because petroleum is a nonrenewable resource, its total available inventory on Earth is finite. Thus other sources of energy must be found in order to meet the needs of modern society. In this section, you will explore several alternatives to petroleum and also learn about other ways to power personal and commercial vehicles.

The total energy used in the United States in one week is approximately 2×10^{18} J.

D.1 ENERGY: PAST, PRESENT, AND FUTURE

The Sun is our planet's primary energy source. Through photosynthesis, radiant energy from the Sun is stored as chemical energy. That is, green plants use the Sun's radiant energy to convert carbon dioxide and water into carbohydrates and oxygen gas. Thus green plants convert solar energy into chemical energy, which is stored in the bonds of carbohydrate molecules. When animals ingest and digest the plants, this chemical energy is released and used by the animals to form other organic molecules. Organic molecules found in plants and animals are called **biomolecules**.

Solar energy and energy stored in biomolecules are the key energy sources for life on Earth. Since the discovery of fire, human use of stored solar energy in wood, coal, and petroleum has been a major influence on civilization's development. In fact, the forms, availability, and cost of energy greatly influence how—and even where—people live.

In 1850, the population of the United States was 23 million.

In the past, abundant supplies of inexpensive energy were available. Until about 1850, wood, water, wind, and animal power satisfied the nation's slowly growing energy needs. Wood, then the predominant energy source, was readily available to most people, serving as an energy source for heating, cooking, and lighting. Water, wind, and animal power provided transportation and drove machinery and industrial processes. As demand for energy increased, primary fuel sources changed. Figure 22 illlustrates how U.S. energy sources have changed since 1850. In the next activity, you will explore how energy supplies and fuel use have shifted in the United States during the past 150 years.

FUEL SOURCES OVER THE YEARS

Building Skills 8

As you can see from Figure 22, there has been a definite shift away from biomass (mainly wood, but also ethanol and waste) and toward fossil fuels—coal, petroleum, and natural gas. Use this figure to answer the questions that follow.

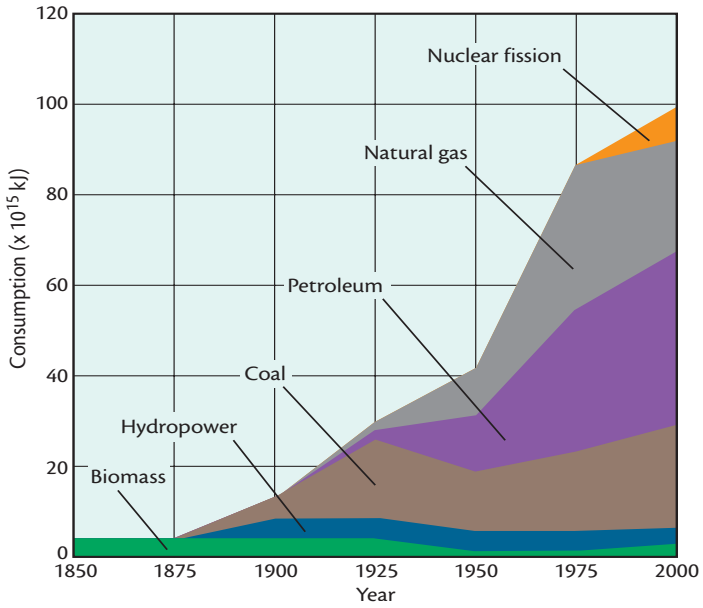

Figure 22: *Annual U.S. consumption of energy from various sources (1850–2000).*

1. a. Give the dates of the period during which biomass (mainly wood) supplied at least 50% of the nation's total energy.
   b. What were the chief modes of travel during that period?
   c. What factors might explain the decline in use of biomass after that period?
   d. What energy source increased in importance to replace biomass?
2. Compared with other energy sources, only a small quantity of petroleum was used as fuel before about the 1920s. What do you think petroleum's main uses might have been before that time?
3. Petroleum became increasingly important, and coal use began to decline, at about the same time.
   a. When did that occur?
   b. What could explain the growing use of petroleum after that date?
4. a. Which energy sources have become more important since 1975?
   b. What are the major uses of these energy sources?
5. a. Describe the trends in petroleum and coal use since 1975.
   b. What factors could explain these trends?

D.2 ALTERNATIVE ENERGY SOURCES

Everyday life in the United States requires considerable quantities of energy. As you just learned, the range of energy sources used in this country has indeed changed over time. As energy demands have accelerated, the nation has relied increasingly on nonrenewable fossil fuels—coal, petroleum, and natural gas. What is the future for fossil fuels, particularly petroleum?

The United States is a mobile society. More than 60% of U.S. petroleum is used for transportation. Although efforts to revitalize and improve public transportation systems merit attention, most experts predict our nation's citizens will continue to rely on personal vehicles well into the foreseeable future. And remember, even energy-conserving mass transit systems must have a fuel source. What options, then, does chemistry offer to extend, supplement, or even replace petroleum as an energy source?

Petroleum from tar sands and oil shale rock is an option with some promise. Major deposits of oil shale are located west of the Rocky Mountains. These rocks contain kerogen, which is partially formed oil. When the rocks are heated, kerogen decomposes into a material quite similar to crude oil. Unfortunately, vast quantities of sand or rock must be processed to recover this fuel. Moreover, current extraction methods use the equivalent of half a barrel of petroleum to produce one barrel of shale oil. Enormous amounts of water are also needed for processing—a problem where water is scarce.

A metric ton of oil shale typically contains the equivalent of 80 to 330 L of oil.

Because known coal reserves in the United States are much larger than known reserves of petroleum, another possible alternative to petroleum is a liquid fuel produced from coal. The technology for converting coal to liquid fuel (and also to builder molecules) has been available for decades, having been used in Germany more than 50 years ago. Current coal-to-liquid-fuel technology is well developed in the United States. However, the present cost of mining and converting coal to liquid fuel is considerably greater than that of producing the same quantity of fuel from petroleum. But if petroleum prices increase, obtaining liquid fuel from coal—itself a nonrenewable resource—may become a more attractive option.

Petroleum replacement candidates are not limited to other fossil fuels. Certain plants, including some 2000 varieties of the genus *Euphorbia*, capture and store solar energy as hydrocarbon compounds rather than as carbohydrates. These compounds may prove to be extractable and usable as a petroleum substitute. Other alternative energy sources currently in use or under investigation include hydropower (water power), nuclear fission and fusion, solar energy, wind energy, biomass, and geothermal energy. Alternate approaches include constructing more energy-efficient buildings, vehicles, and machines, as well as using alternative fuels. All of these initiatives are intended to further reduce the need to burn petroleum.

You have learned about some alternatives to using petroleum as a fuel source. In the next section, you will examine some specific fuel alternatives.

D.3 ALTERNATIVE-FUEL VEHICLES

As you now know, personal vehicles consume a significant portion of the petroleum burned for fuel. In recognition of the limited nature of petroleum as a resource and in consideration of the emissions produced by petroleum-burning engines, alternative-fuel vehicles are being developed, tested, and used. What are some of these fuels, and how are they used to propel vehicles? What are the advantages and disadvantages of the various

alternative fuels? The overview that follows will help you prepare your own automobile advertisement.

Compressed Natural Gas

Most passenger vehicles and buses can be converted to dual-fuel vehicles that run on either natural gas or gasoline. Natural gas, mainly methane (CH_4), is produced either from gas wells or during the processing of petroleum. Compressed and stored in high-pressure tanks, this product is commonly known as CNG (compressed natural gas). A refillable CNG tank, capable of powering an automobile up to 300 miles, can be comfortably installed in a car's trunk. Many CNG-powered vehicles are operating worldwide, particularly in government and mass transit fleets.

Among the advantages of CNG are wide availability and an 80% decrease (compared to gasoline) in carbon monoxide (CO) and nitrogen oxide (NO_x) emissions. However, refueling systems require a compressor, which increases the cost to $2000 to $4000 per vehicle.

Electric

Electric cars, including the fictitious ARL-600 vehicle featured in this unit, obtain their energy from a battery pack that is usually stored within the vehicle body and recharged with electricity at 120 or 240 volts. Powered by nickel-metal hydride (NiMH), lead-acid, or lithium-ion batteries, most electric vehicles can travel more than 100 miles on an eight-hour charge. The batteries provide energy to an electric motor, which turns the axle.

Figure 23 *An electric car being recharged.*

Although initially more expensive than gasoline-powered vehicles, electric vehicles do not require petroleum-based fuel, and their maintenance costs are lower. In addition, they do not produce any direct emissions. However, emissions may be produced some distance away at the electrical generating plant. And the limited lifetime of the batteries raises issues about recycling or disposal. The infrastructure for electric vehicles is largely in place in the form of the electrical power grid, but connections for recharging would need to be developed.

Fuel Cells

CD-ROM WWW.

Fuel Cell

An emerging option for providing electricity to power vehicles is the fuel cell. Although fuel cells were in use before 1840, they did not become a practical energy source until the 1960s, when they were used in the U.S. Space Program. Any fuel containing hydrogen (such as methanol or natural gas) can be used in a fuel cell, but only hydrogen (H_2) can be used directly.

As shown in Figure 24, one common form of fuel cell converts hydrogen fuel and oxygen gas from the air into electrical energy and water, which is its only emission. From a chemical viewpoint, such an operating fuel cell represents another way to release and harness the energy involved in "burning" hydrogen gas:

$$2\,H_2 + O_2 \rightarrow 2\,H_2O + \text{Electrical energy}.$$

The amount of hydroxide ions consumed at one electrode equals the amount produced at the other electrode. Overall, the concentration of hydroxide ions remains constant.

The fuel cell works by using porous electrodes that catalyze the reaction. In one common type of fuel cell, electrodes are in contact with a basic solution of potassium hydroxide, KOH(aq). At one electrode, hydrogen molecules (the fuel) react with hydroxide ions (OH^-), producing water and releasing electrons. The electrons flow from the fuel cell through an external circuit (where they do useful work), returning to the fuel cell at the other electrode. That second electrode catalyzes the reaction of oxygen gas (the oxidizer) with water and electrons to produce hydroxide ions, thus completing the electrical circuit. In the hydrogen-oxygen fuel cell, more water molecules are produced at one electrode than are consumed at the other.

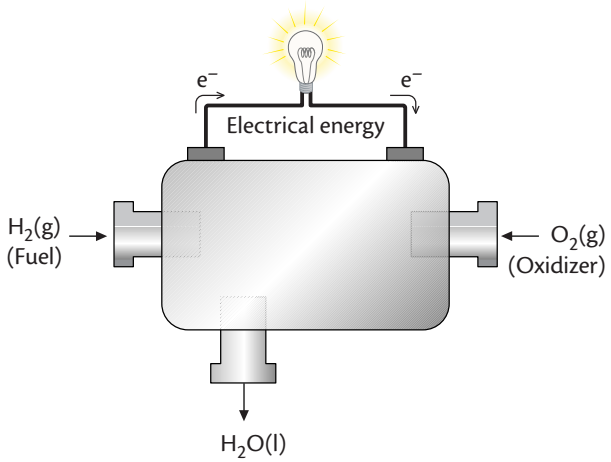

Figure 24 *The chemical reaction $2\,H_2 + O_2 \rightarrow 2\,H_2O$ + electrical energy takes place inside this fuel cell. See text.*

Fuel cells require no electrical recharging, eliminate or substantially reduce the release of air pollutants, and can obtain more useful power from a given quantity of fuel than can internal-combustion engines. However, challenges remain in developing fuel handling and processing options and reducing fuel-cell manufacturing and operating costs. The expense (in terms of high energy costs) required to obtain high-purity hydrogen (H_2) fuel for the type of fuel cell just described represents one of those key fuel-cell challenges.

Hybrid Gasoline-Electric

Some car designers believe that the hybrid gas-electric vehicle will best meet the needs of the consumer while reducing emissions and fuel costs. Hybrids come equipped with a small gasoline-burning engine as well as a battery-driven electric motor. The batteries are recharged while driving, partially through a conversion of braking friction into electricity. Hybrid vehicles typically achieve 70 miles per gallon and can travel more than 200 miles between fueling stops. Although hybrid vehicles produce the same kinds of emissions as fossil-fuel-burning vehicles, the quantity produced over a given distance is much smaller.

Questions and Answers

SECTION SUMMARY

Reviewing the Concepts

◆ **Continued reliance on petroleum as a fuel requires consideration of how to extend, supplement, or replace it as Earth's primary fuel source.**

1. The supply of petroleum for both building and burning is limited. From the alternatives that have been discussed here, choose one for burning and one for building. Discuss the advantages and problems associated with the use of each substitute you have chosen.
2. Some energy authorities recommend exploring ways to use more renewable energy sources such as hydroelectric, solar, and wind power as replacements for nonrenewable fossil fuels.
   a. Why might this be a useful policy?
   b. Which of these renewable sources is/are least likely to replace fossil fuels at this time? Why?
3. Consider coal, oil shale, and biomass as possible fuel substitutes for petroleum. Which do you think might play the most useful role in for the future? Explain.
4. a. Of the two major uses of petroleum—as a fuel and as a raw material—which one is likely to be curtailed first if petroleum supplies dwindle?
   b. Give at least two reasons for your choice.
5. Although petroleum has been used for thousands of years, it is only in recent history that it has become a major energy source. List three technological factors that can explain this.

◆ **Alternative-fuel vehicles may be powered by compressed natural gas, electricity, or fuel cells.**

6. List an advantage and a disadvantage of each of the following alternative power sources for vehicles.
   a. compressed natural gas
   b. electric
   c. hydrogen fuel cell
   d. hybrid gasoline-electric
7. Alternative-fuel vehicles are commercially available today. What factors might discourage people from purchasing them?

Connecting the Concepts

8. U.S. reserves of oil shale are approximately 87 quads, the equivalent of 150×10^9 barrels of oil. Suppose that this represented our total source of oil, from which we maintained production of 8 million barrels of oil daily.
   a. How many years would this supply last?
   b. The population of the United States is about 2.8×10^8 persons, and the United States uses about 24 barrels (about 1000 gallons) of oil per person per year. At that rate of consumption, how long would the oil shale reserves last?
   c. Why is there a difference between the answers to Questions 8a and 8b?

9. We often consider alternative energy sources to be pollution free. Choose two alternative energy sources and evaluate them in terms of possible impact on the environment.
10. What are some ways in which individuals could reduce their total consumption of petroleum products?
11. A friend claims that because she does not own a car, she does not consume any fossil fuels. Evaluate this claim.

Extending the Concepts

12. Describe several possible changes that would occur in your community if wind and solar power devices were installed on a large scale to provide power.
13. How have the relatively low cost and easy availability of petroleum affected the search for and development of alternative energy sources?
14. What characteristics of chemical substances do chemists seek in good petroleum substitutes? Why?
15. Using Internet or library resources, identify some state or federal programs that encourage development of alternative energy sources.
16. World experts disagree about how long fossil-fuel supplies will last. Research and evaluate some of the current opinions.

PUTTING IT ALL TOGETHER

Getting Mobile

If you are an average high school student in the United States, you have already viewed about a half-million television commercials, many of them for automobiles. As alternative-fuel vehicles become available, advertisements similar to the one that begins this unit may become more common.

To make informed, intelligent consumer decisions, it is important to analyze the information conveyed in such advertisements. You practiced this skill earlier in the unit as you evaluated the "petroleum-free" claim in the ARL-600 TV ad. Now you will further develop the skill by creating and defending your own product claims. You will write and produce your own automobile commercial message.

DESIGNING, PRESENTING, AND EVALUATING VEHICLE ADS

Each team of students will create and present an advertisement featuring an imaginary but plausible vehicle that uses a specific type of fuel. The fuels you can choose are electric, gasoline, hybrid gasoline-electric, or hydrogen in a fuel cell. Your vehicle must use only the selected fuel. Your commercial message will be presented to the class for analysis and comment based on concepts introduced and discussed thus far in this chemistry class.

Each commercial message must meet certain specifications. Use these specifications to guide development of your advertisement as well as evaluate the presentations of your classmates.

- **Time** The presentation of the message for your vehicle should take no more than 60 seconds of "air time."
- **Scientific Claims** All scientific claims must be accurate. Because the type of fuel (energy source) is the unique characteristic of your vehicle, you should highlight it and explain it briefly. If appropriate, compare your vehicle to those that depend solely on petroleum for fuel. Include the nature and implications of emissions released by your vehicle, as well as a reference to its fuel efficiency.
- **Comfort/Design/Safety Features** Special features can enhance customer appeal as well as challenge your design creativity. Invent a name and model for your vehicle, and give it one or more special features that you think are particularly significant.
- **Presentation** In addition to presenting a commercial message with accurate claims, your goal is to stimulate interest and vehicle sales. To accomplish this, your commercial presentation should be organized, visually stimulating, and motivating. Your script should be concise and to the point, while still presenting all necessary details.

LOOKING BACK AND LOOKING AHEAD

This unit has illustrated once again how chemical knowledge can inform personal and community decisions related to resource use and replacement. Thus far in your *ChemCom* studies, you have focused on three distinctive types of resources: water, minerals, and petroleum. The next unit explores the importance of another resouce—the thin, virtually invisible envelope of gases that surrounds Earth's surface. As you will discover, the properties and behavior of the atmosphere can be easily overlooked, but issues and concerns arising from human interaction with it merit attention.