

SECTION 2

Nuclear Energy

Objectives

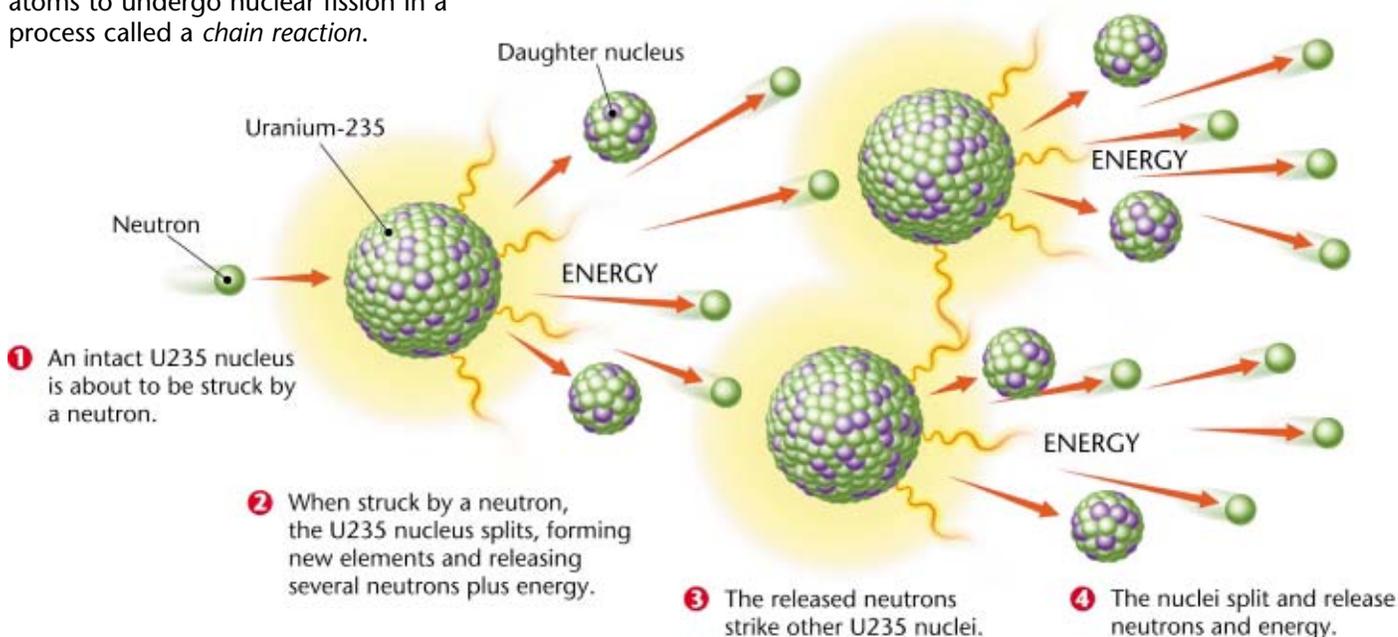
- ▶ Describe nuclear fission.
- ▶ Describe how a nuclear power plant works.
- ▶ List three advantages and three disadvantages of nuclear energy.

Key Terms

nuclear energy
nuclear fission
nuclear fusion



Figure 13 ▶ Neutrons are released from the fission, or the splitting, of a uranium atom's nucleus. Some of these neutrons then cause other atoms to undergo nuclear fission in a process called a *chain reaction*.



In the 1950s and 1960s, nuclear power plants were seen as the power source of the future because the fuel they use is clean and plentiful. It was predicted that a nationwide network of nuclear power plants would provide electricity that was “too cheap to meter.” But in the 1970s and 1980s, almost 120 planned nuclear power plants were canceled, and about 40 partially constructed nuclear plants were abandoned. What happened? In this section, you’ll learn how nuclear power works and why about 17 percent of the world’s electricity comes from nuclear power today.

Fission: Splitting Atoms

Nuclear power plants get their power from **nuclear energy**, the energy within the nucleus of an atom. The forces that hold together the nucleus of an atom are more than 1 million times stronger than the chemical bonds between atoms. In nuclear power plants, atoms of the element uranium are used as the fuel.

The nuclei of uranium atoms are bombarded with atomic particles called *neutrons*. These collisions cause the nuclei to split in a process called **nuclear fission**. A fission reaction is shown in **Figure 13**. Nuclear fission releases a tremendous amount of energy and more neutrons, which in turn collide with more uranium nuclei. If a fission reaction is allowed to continue, this chain reaction will escalate quickly. One example of an uncontrolled fission reaction is the explosion of an atomic bomb. In contrast, nuclear power stations are designed so that the chain reaction produces a controllable level of energy.

How Nuclear Energy Works

A nuclear reactor is surrounded by a thick pressure vessel that is filled with a cooling fluid. The pressure vessel is designed to contain the fission products in case of an accident. Thick concrete walls also surround reactors as shown in **Figure 14**.

Inside a reactor, shown in **Figure 15**, metal fuel rods that contain solid uranium pellets are bombarded with neutrons. The chain reaction that results releases energy and produces more neutrons. The reactor core contains control rods, which are made of a material such as boron or cadmium that absorbs the neutrons to prevent an uncontrolled chain reaction. When the control rods are lowered between the fuel rods, they slow the fission reactions. If the control rods are lowered completely, they prevent fission and shut down the reactor.

The heat released during nuclear reactions is used to generate electricity in the same way that power plants burn fossil fuels to generate electricity. In a nuclear power plant, energy released from the fission reactions heats a closed loop of water that heats another body of water. As the water boils, it produces steam that drives a steam turbine, which is used to generate electricity.

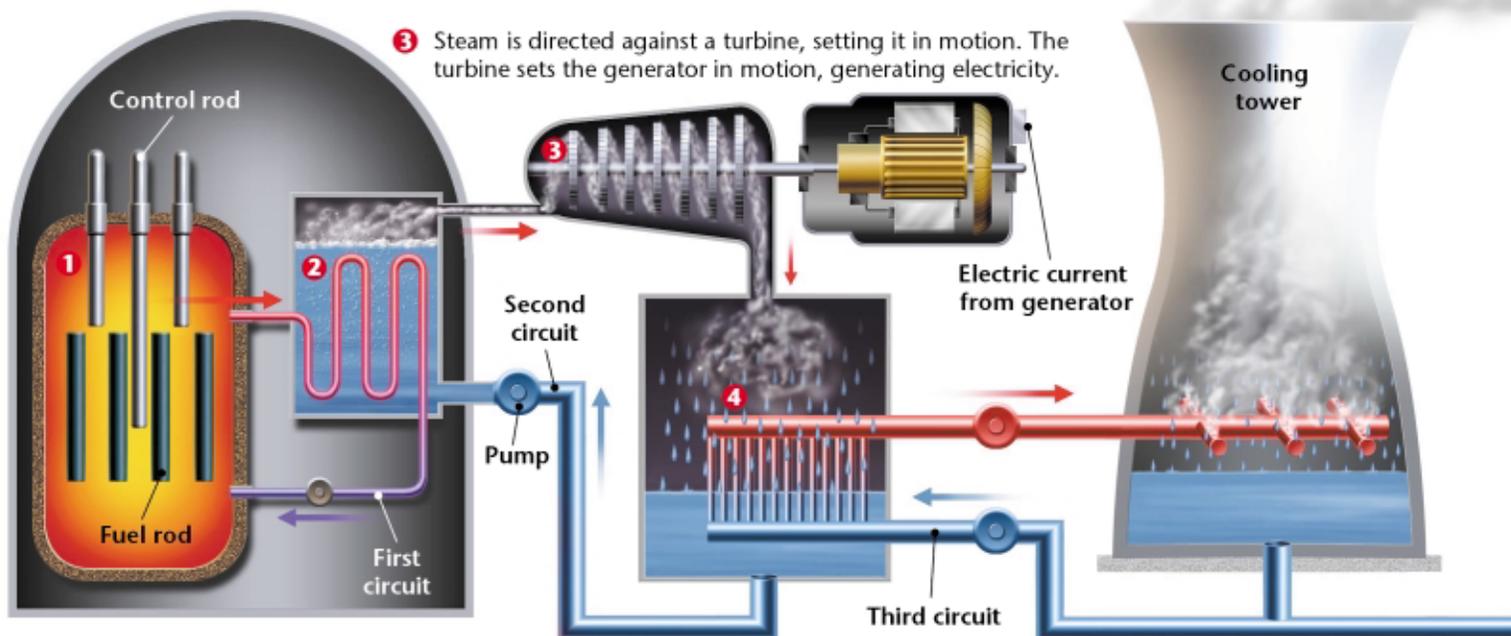


Figure 14 ▶ Every year, the Diablo Canyon nuclear plant generates enough energy for 2 million Californian households—the energy equivalent of burning 20 million barrels of oil.

Figure 15 ▶ How a Typical Nuclear Power Plant Works

2 The superheated water is pumped to a heat exchanger, which transfers the heat of the first circuit to the second circuit. Water in the second circuit flashes into high-pressure steam.

3 Steam is directed against a turbine, setting it in motion. The turbine sets the generator in motion, generating electricity.



1 Energy released by the nuclear reaction heats water in the pressurized first circuit to a very high temperature.

4 A third circuit cools the steam from the turbine and the waste heat is released from the cooling tower in the form of steam.



Figure 16 ▶ Uranium is a very compact fuel. The uranium pellets (above) can generate as much electricity as the trainload full of coal does.



Geofact

Radon Uranium occurs naturally in rock and soil. When uranium undergoes radioactive decay, it gives off a number of products, including an invisible and odorless radioactive gas called radon. Radon can seep into buildings from the surrounding rock and soil, and if buildings are not ventilated properly, dangerous levels of radon can build up. It is estimated that radon causes 5,000 to 20,000 people in the United States to die from lung cancer each year.

The Advantages of Nuclear Energy

Nuclear energy has many advantages. Nuclear fuel is a very concentrated energy source, as shown in **Figure 16**. Furthermore, nuclear power plants do not produce air-polluting gases. When operated properly, nuclear plants release less radioactivity than coal-fired power plants do. Many countries with limited fossil-fuel reserves rely heavily on nuclear plants to supply electricity. France, for example, generates about three-fourths of its electricity from nuclear power. France produces less than one-fifth of the air pollutants per person than does the United States, which relies on fossil fuels for almost 70 percent of its electricity needs.

Why Aren't We Using More Nuclear Energy?

Building and maintaining a safe reactor is very expensive. As a result, nuclear power is no longer competitive with other energy sources in many countries. The last 20 nuclear reactors built in the United States cost more than \$3,000 per kilowatt of electrical capacity. In contrast, wind power is being installed at less than \$1,000 per kilowatt, and newer natural gas power plants can cost less than \$600 per kilowatt. However, the actual cost of new nuclear power plants is uncertain, so it is difficult to predict whether investors will build new plants in the United States.

Storing Waste The difficulty of finding a safe place to store nuclear wastes is one of the greatest disadvantages of nuclear power. The fuel cycle of uranium produces fission products that can remain dangerously radioactive for thousands of years. Uranium mining and fuel development produce radioactive waste. In addition, the used fuel, liquids, and equipment from a reactor core are also considered hazardous wastes. Storage sites for nuclear wastes must be located in areas that are geologically stable for tens of thousands of years. The United States has spent over two decades studying a site called Yucca Mountain in southern Nevada as a place to store nuclear waste. Scientists are also researching a process called transmutation, that would recycle the radioactive elements in nuclear fuel.

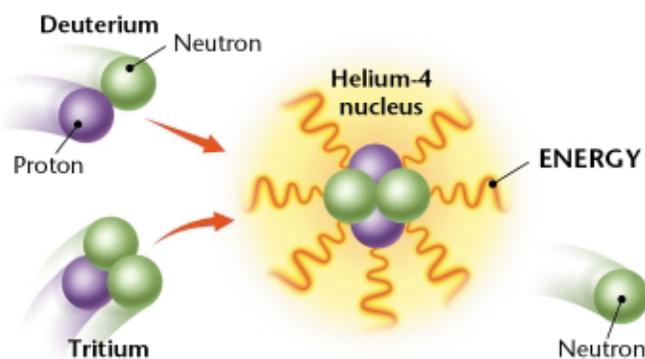
Safety Concerns In a poorly designed nuclear plant, the fission process can potentially get out of control. This is what happened during the world's worst nuclear reactor accident, which occurred at Chernobyl in the Ukraine in 1986. Engineers turned off most of the reactor's safety devices to conduct an unauthorized test. This test caused explosions that destroyed the reactor and blasted tons of radioactive materials into the air. Hundreds of firefighters, residents, and workers died from radiation exposure. Areas of northern Europe and the Ukraine are still contaminated from the disaster. The Chernobyl reactor was an old design that, for safety reasons, is not used in the United States. The nuclear reactor had no containment building. In addition, the engineers at Chernobyl violated basic safety guidelines.

In the United States, the most serious nuclear accident occurred in 1979 at the Three Mile Island nuclear power plant in Pennsylvania. Human error, along with blocked valves and broken pumps, was responsible for the accident at Three Mile Island. Fortunately, only a small amount of radioactive gas escaped. Since this accident, the U.S. Nuclear Regulatory Commission has required more than 300 safety improvements to nuclear power plants.

The Future of Nuclear Power

One possible future energy source is nuclear fusion. **Nuclear fusion** occurs when lightweight atomic nuclei combine to form a heavier nucleus and release tremendous amounts of energy. **Figure 17** illustrates the process of nuclear fusion. Nuclear fusion is the process that powers the stars, including our sun. It is potentially a safer energy source than nuclear fission is because it creates less dangerous radioactive byproducts.

Unfortunately, although the potential of fusion is great, so is the technical difficulty of achieving that potential. For fusion to occur, atomic nuclei must be heated to extremely high temperatures (about 100,000,000°C, or 180,000,000°F). The nuclei also must be maintained at very high concentrations and properly confined. Achieving all three of these conditions simultaneously is extremely difficult. The technical problems are so complex that building a nuclear fusion plant may take decades or may never happen.



Connection to History

Three Mile Island The Three Mile Island accident was a wake-up call for the nuclear industry. Many reforms and safety measures were instituted throughout the industry after the accident occurred. In 1989, 10 years after the accident, the nuclear plant received the best INPO rating in the world. The rating was based on a measure of reliability, efficiency, and safety. In 1999, the plant set a world record after running continuously for 688 days.

Figure 17 ▶ During nuclear fusion, the nuclei of two forms of hydrogen (deuterium and tritium in this case) join to form helium, which releases large amounts of energy.

SECTION 2 Review

1. **Compare** a power plant that burns fossil fuels with a nuclear power plant.
2. **Describe** two advantages and two disadvantages of nuclear power plants.
3. **Explain** the difference between nuclear fission and nuclear fusion.

CRITICAL THINKING

4. **Applying Ideas** Read about the advantages of nuclear energy. Explain why countries such as France and Japan rely heavily on nuclear power.

READING SKILLS

5. **Making Decisions** Which poses more of an environmental threat: transporting spent nuclear fuel or transporting toxic chemicals? Write your opinion in the form of a short essay. **WRITING SKILLS**

CHAPTER 17

Highlights

1 Energy Resources and Fossil Fuels



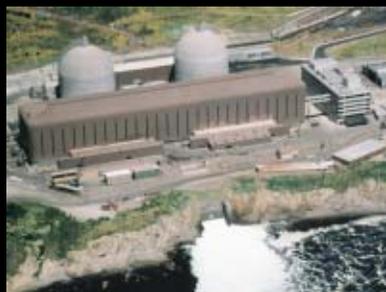
Key Terms

fossil fuels, 435
electric generator,
436
petroleum, 440
oil reserves, 442

Main Ideas

- ▶ Most of the world's energy needs are met by fossil fuels, which are nonrenewable resources.
- ▶ Coal is abundant in North America and Asia. In the United States, coal is used primarily to produce electricity.
- ▶ Petroleum can be refined into fuels to power vehicles and machines. Petroleum can also be used to manufacture many other products.
- ▶ Natural gas is often found above oil deposits. In general, burning natural gas releases fewer pollutants than burning coal or oil.
- ▶ The extraction, transportation, and use of fossil fuels cause many environmental problems, including air and water pollution and habitat destruction.
- ▶ Calculations of fossil-fuel reserves predict that oil production will peak and then decline in the early 21st century.

2 Nuclear Energy



nuclear energy, 444
nuclear fission, 444
nuclear fusion, 447

- ▶ Nuclear energy is energy that exists within the nucleus of an atom. When uranium nuclei are bombarded with neutrons, they undergo fission and release large amounts of energy.
- ▶ In a nuclear power station, the heat generated by fission is used to heat water to form steam. The steam drives turbines that generate electricity.
- ▶ The main advantages of nuclear power are that the fuel is compact and the power stations generally do not pollute. The main disadvantage is that nuclear power produces radioactive waste, which will be dangerous for centuries.

Using Key Terms

Use each of the following terms in a separate sentence.

1. *fossil fuels*
2. *petroleum*
3. *oil reserves*
4. *nuclear fission*
5. *nuclear fusion*

For each pair of terms, explain how the meanings of the terms differ.

6. *petroleum* and *oil reserve*
7. *turbine* and *electric generator*
8. *nuclear fission* and *nuclear fusion*



STUDY TIP

Get Organized Being organized can help make studying more efficient and less confusing. Start by reducing clutter and consolidating loose papers. Arrange your items by subject, and be sure to label your books, notebooks, and dividers. A planner, or agenda book, can help you balance schoolwork with other activities. It also can serve as a reminder of upcoming deadlines and help you to prioritize multiple tasks.

Understanding Key Ideas

9. Which of the following statements provides a reason for the widespread use of fossil fuels?
 - a. Fossil fuels are a renewable source of energy.
 - b. Fossil fuels are readily available and inexpensive.
 - c. Fossil fuels are not harmful to the environment.
 - d. all of the above
10. Which of the following pairs are design features that nuclear power plants and coal-fired power plants share?
 - a. fuel rods and containment buildings
 - b. turbines and generators
 - c. combustion chamber and reactor cores
 - d. none of the above
11. The main reason for the worldwide slow-down in the construction of nuclear power plants is that
 - a. we have run out of uranium fuel.
 - b. the electricity from nuclear power is generally more expensive to produce than electricity from other sources.
 - c. nuclear reactors are inherently unsafe.
 - d. nuclear reactors release large quantities of greenhouse gases.
12. Which is an example of the direct use of fossil fuels?
 - a. a nuclear reactor
 - b. an oil-fired furnace
 - c. a wood-burning stove
 - d. an electric generator
13. Which of the following statements describes the process by which modern nuclear power plants use nuclear energy?
 - a. Power plants use nuclear fusion to split uranium atoms and release nuclear energy.
 - b. Power plants use nuclear fusion to combine atomic nuclei and release nuclear energy.
 - c. Power plants use nuclear fission to split uranium atoms and release nuclear energy.
 - d. Power plants use nuclear fission to combine atomic nuclei and release nuclear energy.
14. If fossil fuels are still forming today, why are they considered nonrenewable resources?
 - a. Fossil fuels are broken down by natural processes faster than they form.
 - b. We are depleting fossil fuels much faster than they form.
 - c. The fossil fuels being formed today are deep under the ocean, where they cannot be reached.
 - d. The only fossil fuels being produced are methane hydrates, which we cannot use yet.
15. Which of the following is *not* a concern about nuclear energy?
 - a. the difficulty of safe storage of nuclear waste
 - b. the high levels of air pollution produced
 - c. the high costs of nuclear energy
 - d. the possibility that a nuclear chain reaction can get out of control

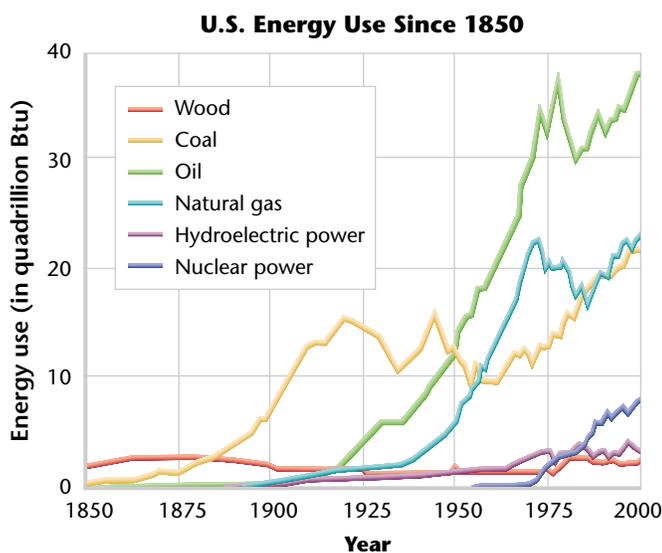
Short Answer

- Why have fossil fuels become our primary energy resource?
- How did the Three Mile Island accident affect nuclear safety in the United States?
- What factors make nuclear power expensive?
- What is the difference between oil reserves and oil deposits?

Interpreting Graphics

The graph below shows the different contributions of various fuels to the U.S. energy supply since 1850. Use the graph to answer questions 20–24.

- When did oil first become a more important energy source than coal?
- Why do you think the use of coal increased so rapidly between 1850 and 1920?
- The data for oil and natural gas are nearly parallel—they rise and fall together. Why do you think this pattern exists?
- Why do you think the use of coal is on the rise after having fallen in the 1950s?
- Why do you think that the use of wood as a fuel has not significantly increased or decreased since about 1850?



Concept Mapping



- Use the following terms to create a concept map: *oil well*, *petroleum*, *refinery*, *gasoline*, *natural gas*, *plastics*, and *oil reserve*.

Critical Thinking

- Demonstrating Reasoned Judgment** The invention of artificial plastics had a damaging effect on the environment because most plastics break down very slowly, so they remain in landfills and are dangerous to wildlife. However, the invention of plastics also affected the environment in many positive ways. List as many positive effects as you can.
- Analyzing Relationships** Read the description of how fossil-fuel deposits form. Explain why fossil fuels are a form of stored solar energy.
- Analyzing Relationships** The United States currently imports about half of all the crude oil it uses. Why might this be a problem? Write a paragraph that describes the recommendations that you would make to U.S. lawmakers, manufacturers, and consumers to reduce the country's dependence on foreign oil. **WRITING SKILLS**

Cross-Disciplinary Connection

- Economics** What incentives could encourage automobile manufacturers in the United States to produce more fuel-efficient cars? The U.S. government could increase the requirements for fuel efficiency. However, at least two other strong forces are likely to change the types of vehicles that manufacturers produce. What do you think these forces are?

Portfolio Project

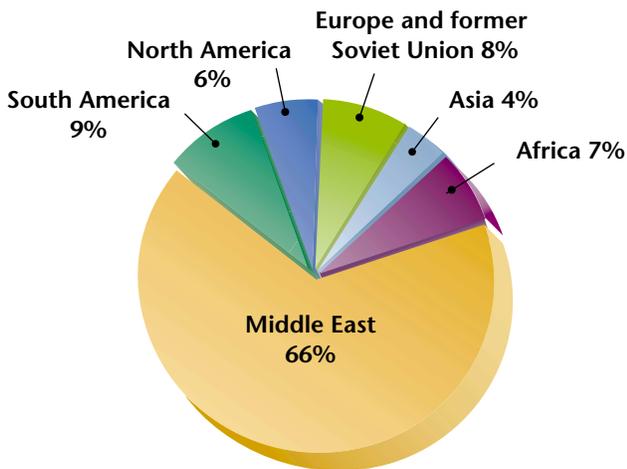
- Prepare a Display** Find out how petroleum, natural gas, coal, or uranium are extracted. For example, engineers have developed methods to drill sideways to reach oil deposits thousands of feet underground. Research one method and prepare a model or a posterboard display that communicates your findings. Be sure to include information about the environmental effects of the method you studied.



MATH SKILLS

The graph below compares the contribution of each world region to world oil production. Use the graph to answer question 31.

- 31. Analyzing Data** If the total sales of oil in 2002 were \$500 billion, what is the value of the oil produced by each region?



WRITING SKILLS

- 32. Communicating Main Ideas** How would our lives change if oil reserves became so depleted that gasoline is very expensive?
- 33. Recognizing Relationships** Outline the major forms of environmental change that have resulted from fossil-fuel use. Include your thoughts on subjects such as habitat loss, pollution, and our use of land. Remember to include positive environmental changes.



READING FOLLOW-UP

Now that you have read the chapter, take a moment to review your answers to the **Reading Warm-Up** questions in your **EcoLog**. If necessary, revise your answers.



Read the passage below, and then answer the questions that follow.

Paula Curtis became chief executive officer of Zaft Motors in 2002. She has a strong interest in the environment. Because she is chief executive of the country's second-largest auto manufacturer, she has an influence on the automobile industry. For instance, Zaft left the Global Climate Coalition, a group of companies that denied the scientific research proving global warming. Within four months, two other auto manufacturers also left. Zaft publishes a "corporate citizenship" report each year. In 2001, the report stated that Zaft's vehicles and factories emit 350 million metric tons of carbon dioxide annually and contribute to global warming. The report also stated that Zaft was committed to reducing this number.

However, Zaft has a long way to go to fulfill this goal. Zaft has failed to improve the fuel economy of its cars and trucks, so its new vehicles get fewer miles per gallon, on average, than the vehicles built in 1982. Modern technology for engines, transmissions, and aerodynamics could help Zaft achieve an average fuel economy of 40 mi/gal for its cars, pickups, and sport utility vehicles. As a result, the United States would save almost 1 million barrels of oil per day—over half as much as the country imports from Saudi Arabia.

- Which of the following statements best describes the thesis of the article?
 - Zaft Motors is jeopardizing its position as the country's second-largest automaker by enacting environmental controls.
 - Zaft left the Global Climate Coalition because it acknowledged the scientific evidence for global warming.
 - Although Zaft has taken some actions to be an environmentally responsible corporate citizen, the company still needs to improve the fuel efficiency of its vehicles.
 - none of the above