

Aligns to the 2019-2020 AP[®] Updates

TEACHER'S EDITION

Environmental Science for the AP[®] Course

THIRD EDITION

INSIDE: Preview of
**CHAPTER 13. ACHIEVING
ENERGY SUSTAINABILITY**

Andrew Friedland

Rick Relyea

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Elizabeth Jones

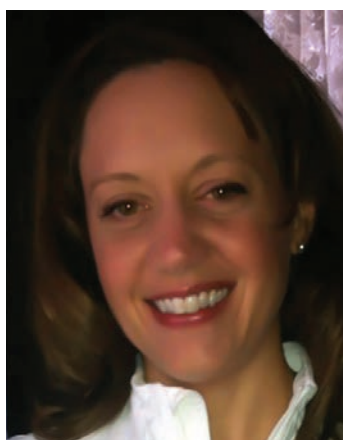
Elisa McCracken

About the Teacher's Edition Authors



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We would like to offer special thanks to the members of the third edition supplements team: Jabin Burnworth, Manchester Junior Senior High School; Suzanne Carmody, Widefield High School; Nathaniel F. Draper, James River Association; Chelsea Sexton, Cobb County School District; and Erika Yates, Rensselaer Polytechnic Institute.

About the Program

Annotated Teacher's Edition

Over the past few years, both seasoned AP[®] Environmental Science teachers and those new to the course have been overwhelmingly positive about the Teacher's Edition to accompany *Friedland and Relyea Environmental Science for the AP[®] Course*. For the third edition of the text we have continued to work with a team of experienced AP[®] Environmental Science teachers to bring the best possible support for you and your students. *The advent of the 2019–2020 Curriculum Framework has inspired us to add an additional layer of teaching aids that will enable you to adapt your lesson plans seamlessly to the Big Ideas, Enduring Understandings, Learning Objectives, and Science Practices now emphasized in the course.* We have included even more guidance for working with challenging material, and have added many new features to help you make the most of your preparation and class time. This Teacher's Edition has everything you need to make the course fun, engaging, and successful.

This Teacher's Edition includes:

- An **AP[®] Primer** that offers guidance on how to write, initiate, prepare, and teach an AP[®] Environmental Science course successfully.
- The **complete student text** with wraparound content including answers to all student edition questions, Activities, Labs, Math Skills Practice, Debate the Issue, Teaching Tips, Common Misconceptions, Teaching the AP[®] Tip, Exploring the Literature, Teaching with Figures, Practicing Science, and more.
- **Introduction pages** for each chapter that precede the wraparound student pages. These introductions provide an in-depth guide to the chapter content and support materials, including:
 - **Chapter and module overviews** These overviews include a discussion of the chapter topics students need to know for the AP[®] Exam, numerous suggestions for how to approach material that students find challenging, and recommendations for ways to make connections with previous chapter materials.
 - **Pacing guide** The pacing guide breaks down the chapter by module and learning goal, suggests the amount of class time to devote to each module, and lists key activities and labs to incorporate into your lesson.
 - **Additional chapter resources** A comprehensive reference list indicates all of the additional chapter resources available for download from the Teacher's Edition, Teacher's e-book, and Teacher's Resource Flash Drive (TRFD).
 - **List of relevant free-response questions available from College Board[®]** Most chapters contain a list of relevant free-response questions from previous AP[®] Environmental Science Exams with descriptions of the material they test.
 - **Correlation to the 2019–2020 Curriculum Framework** A full page in each chapter introduction is dedicated to information about how the chapter correlates with the curriculum framework. The description also shows you how the chapter incorporates science practices.

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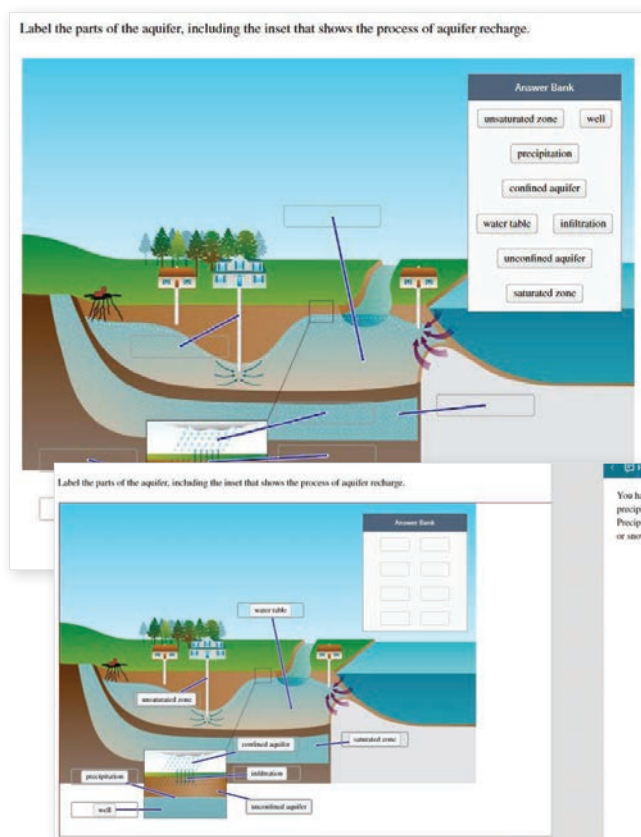
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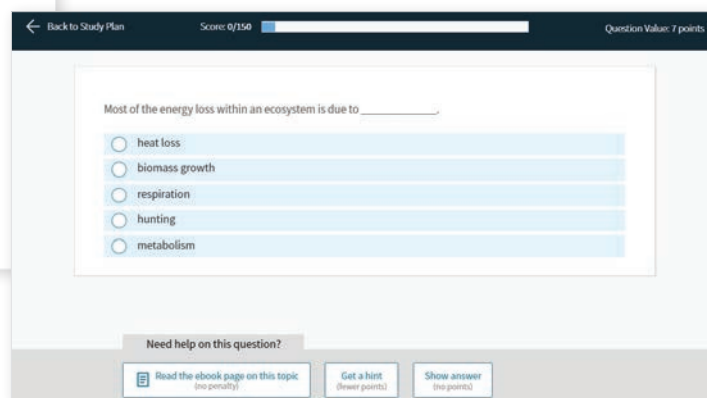
Resources for Students and Teachers



SaplingPlus

Environmental Science for the AP[®] Course provides students with the support they need to be successful on the AP[®] exam and in the classroom. Strong media offerings include our online homework system with built-in tutorials to provide just-in-time feedback along with the following:

- Interactive e-book
- AP[®] Environmental Science Practice Problems
- Sapling Learning problems with tutorials
- Self-test concept checks
- Videos
- LearningCurve adaptive quizzing and more!



Homework problems include hints, answer-specific feedback, and solutions.

Ask your rep for a demo of SaplingPlus today!

LearningCurve adapts to each student's correct and incorrect answers, with feedback linked to the e-book.

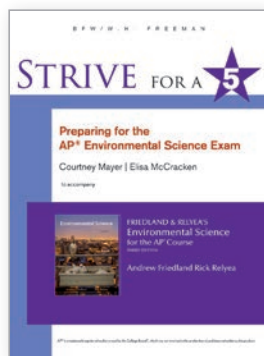
FOR INSTRUCTORS

Teacher's Resource Flash Drive

This resource contains supplementary material to the TE to help teachers maximize their effectiveness in class. It includes handouts to accompany math problems, labs, and activities in the Teacher's Edition—more than 200 items total for the text—plus complete answer keys, labs, additional FRQ questions, PD Videos, lecture presentation slides, web resources, and more!

ExamView[®] Test Bank

This resource includes over 1500 AP[®] practice multiple-choice questions of different levels, including questions that require analysis of graphs and other visuals.



FOR STUDENTS

Strive for a 5: Preparing for the AP[®] Environmental Science Exam

COURTNEY MAYER

Northside ISD, Texas

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Brandeis High School, Texas

SUZANNE CARMODY

Widefield High School, Colorado

Now with a Chapter Reading Guide—a detailed step-by-step set of 100–200 questions per chapter to help students with reading comprehension.

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13 Achieving Energy Sustainability

PD Overview

This chapter looks at a fundamental topic in the AP[®] Environmental Science course: renewable energy. The chapter also addresses the issue of energy conservation and efficiency. Major renewable energy sources considered include biomass, solar, hydroelectric, geothermal, wind, and fuel cell technology. As you go through the chapter, make sure students are confident that they understand the advantages and disadvantages of each renewable energy source.

Module 37 Conservation, Efficiency, and Renewable Energy

The discussion of renewable energy begins with a look at conservation and efficiency. The module then explores the range of renewable energy resources that are available. This module provides a good opportunity to review energy concepts from previous chapters and “Activity 13.3: Energy Sources Concept Map” on page 458 helps students differentiate among the various types of energy sources. Students can also learn about ways that they can improve their own conservation and efficiency with “Activity 13.1: Reducing My Energy Use” on page 453. One challenge for students is their ability to understand and relate to the units of energy use, namely kilowatt-hours. “Lab 13.1: Kilowatt Lab” on page 456 is a fun way to teach your class about energy consumption, while having students practice energy-use calculations. You can complete this module in one class period.

Module 38 Biomass and Water

This module presents two important renewable energy sources: biomass and water, which are currently major sources of renewable energy in both the developed and the developing worlds. Students often confuse the different types of biomass, so try “Activity 13.4: Biomass Concept Map” on page 461 to help them distinguish between solid biomass and biofuels. “Teaching the AP[®] Tip” on page 465 clarifies key concepts for students regarding emissions from biofuels, a topic frequently missed on the AP[®] Environmental Science Exam. It’s always important to facilitate student connection with the material, so give them the opportunity to voice their viewpoint about flex-fuel vehicles, while listening to those of others, with “Debate the Issue 13.1: Are Flex-Fuel Vehicles Good for the Environment?” on

page 464. “Teaching Tip: Video” on page 464 features a recent college graduate working with biofuels in India, and will also spark student interest. AP[®] Environmental Science students often have difficulty linking material across chapters, so use “Teaching with Figure 38.5” on page 466 to help your class understand the similarities and differences between the hydroelectric dams presented in this chapter and coal-fired power plants from Chapter 12. Finally, try “Activity: Find a Dam” on page 467 to engage your students and help them build connections to the world around them. This module should take you two class periods.

Module 39 Solar, Wind, Geothermal, and Hydrogen

This module explores energy from the Sun and wind, the world’s fastest growing forms of energy development, as well as geothermal energy and hydrogen fuel. AP[®] Environmental Science students are always fascinated by solar energy. Give them a chance to use their creative skills in “Activity 13.5: Solar Soil-Heating Contest” on page 470, which uses a fun competition to help students learn about passive solar heating. Solar energy also has many applications and associated technologies, which often confuses students. Help them clarify the various ways that we capture and use solar energy with “Activity 13.6: Solar Energy Concept Map” on page 470. You can further student engagement with solar energy with “Lab 13.2: Solar Energy” on page 474, which gives students hands-on experience with solar cells and allows them to compare various energy outputs.

Many students have never seen a wind farm or a geothermal power plant, so use “Teaching Tip: Video” on page 475 on wind power and “Teaching Tip: Video” on page 478 on geothermal energy to help them visualize and better understand these sources of electricity. Being able to read and analyze graphs is a key skill for all AP[®] Environmental Science students. “Teaching with Figure 39.7” on page 475 will help students practice their analytical skills, while learning about wind energy use in different countries. Students can find fuel cells challenging to understand, so try “Activity: Fuel Cell Song” on page 479 to help them connect to the material, followed by “Teaching Tip: Journal Prompt” on page 480 to improve their comprehension. Three class periods are needed to complete this module.

Module 40 Planning Our Energy Future

In this module, students learn that minimizing energy use through conservation and efficiency is the best approach to energy use, since all energy choices have environmental consequences. They also compare and contrast the various energy resources discussed in this chapter. By the end of this chapter, students may feel overwhelmed by the many types of renewable energy. “Activity 13.8: Renewable

Energy Quiz” on page 485 will help students distill and categorize the information, while providing them with a valuable study aid for future tests. “Activity: Name That Term” on page 488, will enliven the class and help students learn from each other. Finally, “Teaching the AP[®] Tip” on page 486 is a key exercise that helps students remember the different methods of producing electricity, while reviewing concepts from both Chapter 12 and Chapter 13. One class period is sufficient for this module.

Chapter 13 Pacing Guide

This pacing guide is based on a schedule with 120 sessions of 50 minutes each before the AP[®] Environmental Science Exam. If you have a different number of sessions before the exam, you can modify the pacing to suit your needs. If you have additional time, consider incorporating quizzes, released AP[®] Environmental Science free-response and multiple-choice questions, or additional activities. Note that it may not be possible to cover all activities and exams listed using class time alone. Some activities or practice exams may be assigned as homework.

| Standard schedule days | Block schedule days | Topic | Learning goals After reading this module you should be able to... | Key activities and labs (page) |
|------------------------|---------------------|---|---|---|
| 1 | ½ | <p>Module 37 Conservation, Efficiency, and Renewable Energy</p> <p>We can use less energy through conservation and increased efficiency</p> <p>Renewable energy is either potentially renewable or nondepletable</p> | <ul style="list-style-type: none"> describe strategies to conserve energy and increase energy efficiency. explain differences among the various renewable energy resources. | <p>Activity 13.1 Reducing My Energy Use (453)</p> <p>Lab 13.1 Kilowatt Lab (456)</p> <p>Activity 13.3 Energy Sources Concept Map (458)</p> |
| 2 | 1 | <p>Module 38 Biomass and Water</p> <p>Biomass is energy from the Sun</p> <p>The kinetic energy of water can generate electricity</p> | <ul style="list-style-type: none"> describe the various forms of biomass. explain how energy is harnessed from water. | <p>Activity 13.4 Biomass Concept Map (461)</p> <p>Debate the Issue 13.1 Are Flex-Fuel Vehicles Good for the Environment? (464)</p> <p>Teaching Tip Video (464)</p> <p>Teaching the AP[®] Tip (465)</p> <p>Teaching with Figure 38.5 (466)</p> <p>Activity Find a Dam (467)</p> |

| Standard schedule days | Block schedule days | Topic | Learning goals After reading this module you should be able to... | Key activities and labs (page) |
|------------------------|---------------------|---|---|---|
| 3 | 1 ½ | <p>Module 39 Solar, Wind, Geothermal, and Hydrogen</p> <p>The energy of the Sun can be captured directly</p> <p>Wind energy is the most rapidly growing source of electricity</p> <p>Earth's internal heat is a source of nondepletable energy</p> <p>Hydrogen fuel cells have many potential applications</p> | <ul style="list-style-type: none"> list the different forms of solar energy and their application. describe how wind energy is harnessed and its contemporary uses. discuss the methods of harnessing the internal energy from Earth. explain the advantages and disadvantages of energy from hydrogen. | <p>Activity 13.5 Solar Soil-Heating Contest (470)</p> <p>Activity 13.6 Solar Energy Concept Map (470)</p> <p>Lab 13.2 Solar Energy (474)</p> <p>Teaching Tip Video (475)</p> <p>Teaching with Figure 39.7 (475)</p> <p>Teaching Tip Video (478)</p> <p>Activity Fuel Cell Song (479)</p> <p>Teaching Tip Journal Prompt (480)</p> |
| 1 | ½ | <p>Module 40 Planning Our Energy Future</p> <p>Our energy future depends on efficiency, conservation, and the development of renewable and nonrenewable energy resources.</p> <p>A renewable energy strategy presents many challenges</p> | <ul style="list-style-type: none"> discuss the environmental and economic options we must assess in planning our energy future. consider the challenges of a renewable energy strategy. | <p>Activity 13.8 Renewable Energy Quiz (485)</p> <p>Activity Name That Term (488)</p> <p>Teaching the AP[®] Tip (486)</p> |
| 1 | ½ | Chapter 13 assessment | | Chapter 13 AP[®] Environmental Science Practice Exam (490) |

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- Do the Math Videos
- Chapter 13 Web Resources
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- Activity 13.3: Energy Sources Concept Map
- Activity 13.4: Biomass Concept Map
- Activity 13.5: Solar Soil Heating Contest
- Activity 13.6: Solar Energy Concept Map
- Activity 13.7: Renewable Energy Word Guessing Game
- Activity 13.8: Renewable Energy Quiz
- Activity 13.9: Electricity Bill
- Handout 13.1: Review of the First and Second Laws of Thermodynamics
- Handout 13.2: Modified Figure 37.2
- Handout 13.3: Green Building
- Handout 13.4: Questions on Figure 38.1
- Handout 13.5: Journal Prompt on Biomass
- Handout 13.6: Questions for *A Conversation with Sarah Alexander*
- Handout 13.7: Biodiesel Versus Fossil Fuel
- Handout 13.8: Tidal Energy Research Project
- Handout 13.9: Differentiating Types of Active Solar Energy
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- Math Skills Practice 13.2: Capacity Factor
- Debate the Issue 13.1: Are Flex-Fuel Vehicles Good for the Environment?
- Lab 13.1: Kilowatt Lab
- Lab 13.2: Solar Energy
- Measuring Your Impact 13: Choosing a Light Bulb
- Exploring the Literature 13
- Answers to Chapter 13 AP[®] Practice Exam
- Answer to Science Applied 6 Practice AP[®] Free-Response Question
- Answers to Unit 6 AP[®] Practice Exam
- Unit 6 Additional AP[®] Practice Free-Response Question

The teacher's resource materials listed throughout this chapter and referenced with the **TRM** icons are available for download on the Teacher's Resource Flash Drive (TRFD), in the Teacher's Resource Materials on the book's digital platform, and by clicking on the links in the Teacher's e-book.

Free-Response Questions from Previous AP[®] Environmental Science Exams

Free-response questions from prior AP[®] Environmental Science Exams are available on the AP[®] course website. Students should be able to answer all of the questions listed below with material learned in this and previous chapters. When a question requires students to understand material from multiple chapters, the question will be listed in the last chapter required to complete the entire question. Questions marked with an asterisk (*) are from exams with released multiple-choice questions. Questions marked with double asterisks (**) require math to calculate a problem. Look for references to these questions throughout the chapter.

| Year | Question | Content |
|------|----------|---|
| 1999 | 2 | <ul style="list-style-type: none"> • Renewable versus nonrenewable energy sources • Total resource use per capita in developed and developing countries • Sustainable resource use • Policies that help and hinder sustainable resource use |
| 2001 | 1** | <ul style="list-style-type: none"> • The amount and cost of natural gas needed to heat a house • Advantages and disadvantages of heating with wood |
| 2004 | 2** | <ul style="list-style-type: none"> • Costs and benefits of wind-generated electricity |
| 2006 | 1 | <ul style="list-style-type: none"> • Environmental benefit and cost of using photovoltaic system • Promotion of passive solar design |
| 2008 | 1* ** | <ul style="list-style-type: none"> • Biodiesel from microalgae and soybeans • Problems associated with producing fuel from corn |
| 2009 | 2** | <ul style="list-style-type: none"> • Use of methane to produce electricity |
| 2011 | 3 | <ul style="list-style-type: none"> • Geothermal energy • Per capita emissions of CO₂ versus total emissions • Production of fuel from either sugarcane or tar sands |
| 2012 | 2** | <ul style="list-style-type: none"> • Alternative energy sources to heat a school • Calculation of forest needed to offset CO₂ emissions |
| 2013 | 2** | <ul style="list-style-type: none"> • Battery electric vehicles versus internal combustion engine vehicles |
| 2017 | 4 | <ul style="list-style-type: none"> • Generation of hydroelectric electricity • Economic benefits of dams • Environmental consequences of dam removal • Keystone species, role of beavers as a keystone species |
| 2018 | 2 | <ul style="list-style-type: none"> • Environmental and economic benefits of offshore wind projects • Additional ways for oceans to provide renewable power for electricity |

Correlation to the 2019–2020 Curriculum Framework*

The Big Ideas of the AP® Environmental Science Course

Module 37 focuses on *Energy Transfer (ENG)* and *Sustainability (STB)*

Module 38 focuses on *Energy Transfer (ENG)*

Module 39 focuses on *Energy Transfer (ENG)*

Module 40 focuses on *Energy Transfer (ENG)*

Science Practices

All science practices are covered in this chapter. Key examples include:

- **Concept Application (SP1):** Teaching Tip, p. 452; Teaching Tip, p. 466
- **Visual Representations (SP2):** Teaching with Figures; Activity 13.3; Activity 13.4
- **Text Analysis (SP3):** Chapter Opening Case; Teaching Tip, p. 451; Exploring the Literature
- **Scientific Experiments (SP4):** Practicing Science, p. 458
- **Data Analysis (SP5):** Activity 13.2; Lab 13.1; Practice Math and Graphing
- **Mathematical Routines (SP6):** Do the Math; Math Skills Practice
- **Environmental Solutions (SP7):** Activity 13.1; Debate the Issue 13.1; Teaching Tip, p. 483; Working Toward Sustainability; Measuring Your Impact

Coverage of the AP® Environmental Science Learning Objectives and Essential Knowledge

| Module | Enduring Understanding/ Big Idea | AP® Learning Objective | AP® Essential Knowledge |
|--------|-------------------------------------|--|--|
| 37 | ENG-3 STB-1 | ENG-3.B ENG-3.T STB-1.A | ENG-3.B.1 ENG-3.T.1, ENG-3.T.2 STB-1.A.1 |
| 38 | ENG-3 | ENG-3.I ENG-3.L | ENG-3.I.1, ENG-3.I.2 ENG-3.L.1, ENG-3.L.2 |
| 39 | ENG-3 | ENG-3.J ENG-3.K ENG-3.R ENG-3.S ENG-3.N ENG-3.O ENG-3.P ENG-3.Q | ENG-3.J.1, ENG-3.J.2, ENG-3.J.3 ENG-3.K.1 ENG-3.R.1 ENG-3.S.1 ENG-3.N.1 ENG-3.O.1 ENG-3.P.1 ENG-3.Q.1 |
| 40 | ENG-3 | ENG-3.A ENG-3.T | ENG-3.A.2 ENG-3.T.1 |

*Consult <https://www.highschool.bfwpub.com/APES3e> for the full correlation to the most current curriculum framework.

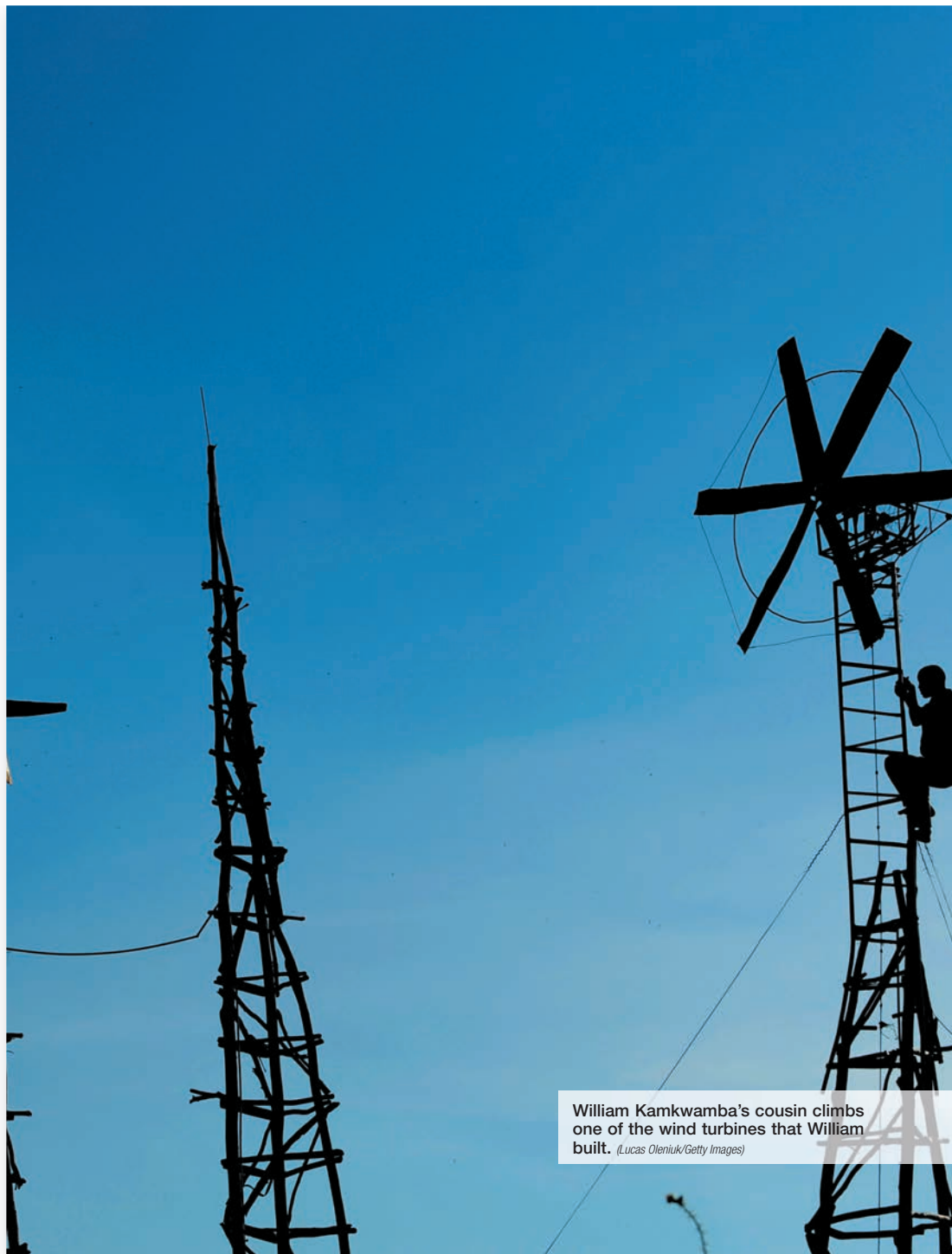
Notes

PD Chapter 13 Video Overview

A video overview of Chapter 13 for teachers is available in the Teacher's Resource Materials.

TRM Lecture Slide Presentation 13

A lecture slide presentation for Chapter 13 is available in the Teacher's Resource Materials.



William Kamkwamba's cousin climbs one of the wind turbines that William built. (Lucas Oleniuk/Getty Images)

Achieving Energy Sustainability

CHAPTER

13

MODULE 37 Conservation, Efficiency, and Renewable Energy

MODULE 39 Solar, Wind, Geothermal, and Hydrogen

MODULE 38 Biomass and Water

MODULE 40 Planning Our Energy Future

CASE STUDY

Energy from the Wind

In a small village in the African nation of Malawi, a 14-year-old boy named William Kamkwamba and his family did not have enough to eat because of a famine. His family could not afford the required school tax; in many parts of Africa a child whose parents cannot pay the school tax cannot attend school. So instead of attending school, he spent his days in a public library funded by the U.S. government, trying to teach himself. In the library, he studied one book over and over—a textbook titled *Using Energy*. The cover of the book featured a series of windmills. Although William had never seen a windmill, within months he was building his own from abandoned bicycles and old parts he found in scrap heaps. William used the fundamentals of physics he learned from the book and his inherent skills at tinkering and fixing things. He did not have any teachers or mentors but he did rely on assistance from some of his friends. He worked hard and made many attempts to construct something that in his world was seemingly impossible. At first his neighbors thought he was mentally disturbed or was practicing magic. But when he was able to

illuminate a small light bulb at the top of what they had called his “junk” tower, people rushed from great distances to see it, and he became a local hero. William had generated electricity without any conventional fuel and far from the nearest power

Although William had never seen a windmill, within months he was building his own from abandoned bicycles and old parts he found in scrap heaps.

plant. Because there were no visible inputs like fuel and no waste piles or pollution outputs, in many ways it did seem like magic. William used the electricity he generated from wind to light his house and charge cell phones, and eventually to irrigate his family's crops.

The use of windmills, also known as wind turbines, to generate electricity is

growing in both the developing and developed worlds. The mechanics of how to build a windmill are widely discussed in online sources including YouTube, Wikipedia, and “how to build it” instructional videos. However William had only one book and no access to the Internet. A few years after he built his first windmill, William exclaimed to Jon Stewart on *The Daily Show*, “Where was this Internet when I needed it?” William recently graduated from Dartmouth College, where he majored in environmental studies. He is coauthor of the book *The Boy Who Harnessed the Wind*, which has sold thousands of copies and has been adopted as summer reading in high schools and colleges around the United States and elsewhere in the world. The book was also the basis of a BBC feature film that was released in 2018. Today, William is a designer/coordinator at Widernet, a nonprofit organization in Chapel Hill, North Carolina, that strives to improve digital communications around the world, particularly in developing countries.

Sources: W. Kamkwamba and B. Mealer, *The Boy Who Harnessed the Wind* (Harper, 2009); R. Wolfson, *Energy, Environment and Climate*, 3rd ed. (Norton, 2017).

Teaching Tip: Chapter Opening Case

Text Analysis (SP3)

Have students read the chapter opening case, “Energy from the Wind,” which discusses how William Kamkwamba, a young man in Malawi, built a windmill out of local resources. Many people in his village thought he was either mentally unbalanced or practicing magic. However, when his windmill first generated enough electricity to light up a light bulb, they began to think differently.

Teaching Tip: Beyond the Classroom

Text Analysis (SP3)

As a summer assignment or during a school break, have students read the *New York Times* bestseller *The Boy Who Harnessed the Wind* by William Kamkwamba, the subject of the chapter-opening case. After reading this book, students can write a one-page reaction to the challenges Kamkwamba faced. Students can also discuss the effects of bringing electricity to the village. How did Kamkwamba's windmill change the lives of his family and other villagers?

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Teaching Tip: Beyond the Classroom

Concept Application (SP1)

(30 minutes)

Ask students to research wind farm projects in your state or region. Ask them to produce a table that includes information about the capacity in megawatts and the actual or expected number of gigawatt-hours each installation will produce per year. Then ask them to identify the largest capacity wind farm project in the United States and compare the local farms to that one.

Throughout this book we have discussed sustainability as the foundation of the environmental health of our planet. Sustainability is particularly important to consider with respect to energy because energy is a resource that humans cannot live without and energy use often has many consequences for the environment. Currently, only a very small fraction of the energy we use, particularly in the developed world, comes from renewable resources. While expanding renewable energy resources is an important step, achieving energy sustainability will require us to rely as much, or more, on reducing the amount of energy that we use.

In Chapter 12 we discussed the finite nature of traditional energy resources such as fossil fuels and the environmental consequences of their use. In this chapter we outline the components of a sustainable energy strategy, beginning with ways to reduce our use of energy through conservation and increased efficiency. We define renewable forms of energy and discuss an important carbon-based energy resource, biomass, as well as energy that is obtained from flowing water. We then describe innovations in obtaining energy from non-carbon-based resources such as the Sun, wind, internal heat from Earth, and hydrogen. We conclude the chapter with a discussion of our energy future.

TRM Teaching Tip: Review

Concept Application (SP1)

Chapter 13 provides a good opportunity to review the first and second laws of thermodynamics. Students should write a simple definition of each law and give two examples. (Sample answers are provided in italics.) **Handout 13.1: Review of the First and Second Laws of Thermodynamics** includes a reproducible version of the chart without the answers.

| | First law of thermodynamics | Second law of thermodynamics |
|------------|---|--|
| Definition | <i>Energy is neither created nor destroyed, but can change from one form to another.</i> | <i>Whenever energy is converted from one form into another, some energy is lost.</i> |
| Example | <i>The potential energy contained in firewood never goes away, but it is transformed into heat energy permeating a room when the wood is burned in a fireplace.</i> | <i>When using an incandescent light bulb, 5 percent of the energy entering the light bulb is converted to useful light energy and the remaining 95 percent is lost to the environment as heat.</i> |

Conservation, Efficiency, and Renewable Energy

In any discussion of energy use—whether renewable or nonrenewable—energy conservation and increased energy efficiency rank among the most crucial factors to consider. We begin our discussion of renewable energy with a look at conservation and efficiency. We will then explore the range of renewable energy resources that are available.

We can use less energy through conservation and increased efficiency

A truly sustainable approach to energy use must incorporate both *energy conservation* and energy efficiency. Conservation and efficiency efforts save energy that can then be used later, just as you might save money in a bank account to use later when the need arises. In this sense, conservation and efficiency are sustainable energy “sources.”

Energy conservation and energy efficiency are the least expensive and most environmentally sound options for maximizing our energy resources. In many cases, they are also the easiest approaches to implement because they often require fairly simple changes to existing systems rather than a switch to a completely new technology. In this section we will examine ways to achieve both objectives.

Energy Conservation and Efficiency

Energy conservation means finding and implementing ways to use less energy. As we saw in Chapters 2 and 12, increasing energy efficiency means obtaining the same

Learning Goals

After reading this module, you should be able to

- describe strategies to conserve energy and increase energy efficiency.
- explain differences among the various renewable energy resources.

work from a smaller amount of energy. Energy conservation and energy efficiency are closely linked. One can conserve energy by not using an electrical appliance; doing so results in less energy consumption. But one can also conserve energy by using a more efficient appliance—one that does the same work but uses less energy.

Conservation

TABLE 37.1 on page 454 lists some of the ways that an individual might conserve energy, including lowering the household thermostat during cold months, consolidating errands in order to drive fewer miles, or turning off a computer when it is not being used. On a larger scale, a government might implement energy conservation measures that encourage or even require individuals to adopt strategies or habits that use less energy. One such top-down approach is to improve the availability of public transportation (**FIGURE 37.1** on page 454). Governments can also facilitate energy conservation by taxing electricity, oil, and natural gas, since higher taxes discourage use. Alternatively, governments might offer rebates or tax credits for retrofitting a

Energy conservation Finding and implementing ways to use less energy.

Bell Ringer

Ask students to work with a partner and list five renewable energy sources. When students are done, have them volunteer their answers, and write them on the board. Keep asking for answers until all the energy sources from this chapter are listed: *solar, wind, hydroelectric, geothermal, biomass, and fuel cell technology.*

Teaching Tip: Journal Prompt

Environmental Solutions (SP7)

(30 minutes)

Ask students to take the role of a mayor or congressional representative with a mandate to reduce energy consumption. They should describe ways in which government policy can encourage people to reduce energy consumption. Examples might include improving public transportation, instituting a tax, or providing a subsidy. For example, the city might build a subway system or institute a carpooling initiative. Students should describe the feasibility of the initiative and be ready to read their journal entry to the class. At the end of the readings, have the class vote on the top three most viable strategies, based on feasibility and practicality.

TRM ACTIVITY 13.1

Reducing My Energy Use

Environmental Solutions (SP7)

(10 minutes)

Ask students to create and fill in a chart like the one shown. **Activity 13.1: Reducing My Energy Use** contains a reproducible version of the chart without answers. Ask students to consider ways of reducing energy use in each of the three categories. (Suggested answers are provided in italics.)

| Home | Transportation | Electronic devices |
|---|---------------------------------------|--|
| <i>Replace single-pane windows with double- or triple-pane windows.</i> | <i>Ride a bike to school or work.</i> | <i>Reduce phantom drain.</i> |
| <i>Turn down thermostat.</i> | <i>Carpool with others.</i> | <i>Use electronic devices less.</i> |
| <i>Weatherize anywhere cold air or hot air is entering home.</i> | <i>Take mass transit.</i> | <i>Buy Energy Star or the most efficient model when replacing devices.</i> |

Teaching Tip: Concept Check

Environmental Solutions (SP7)

Ask students: What are some ways that the government can facilitate energy conservation? *Governments can encourage energy conservation by improving the availability of public transportation, taxing fossil fuels, and offering rebates or tax credits for those who retrofit buildings to operate on less energy. Electric companies can also use a tiered rate system to encourage people to use less energy.*

TRM ACTIVITY 13.2

Graphing Energy Demands

Data Analysis (SP5)

(25 minutes)

In this activity students research state energy demands, create a graph with the data they find or provided data below, and answer some questions.

Activity 13.2: Graphing Energy Demands contains a reproducible version of the data table and questions.

- Have students research the grid energy demands for your state. If you can't find the daily energy demand of your state use the data in the table provided.
- Have students create a line graph depicting energy demands for a 24-hour period. Place hours on the x axis starting at midnight and finishing at midnight 24 hours later. Place amount of energy in gigawatts (GW) on the y axis. (See sample graph below.)
- After the graph is complete, ask students the following questions. (Answers are provided in italics for the sample data and graph.)
 - What is the 4-hour range where peak usage occurs? *Peak usage occurs between 2 and 6 PM.*
 - When is energy use at its lowest? *The energy demand is 11 GW at 4 AM. It is the lowest power demanded in a 24-hour period.*
 - What happens if the power company doesn't meet the peak power demands? *If the power company doesn't meet peak power demands, there could be a brownout or a blackout.*

TABLE 37.1 Reducing energy use

| Home | Transportation | Electrical and electronic devices |
|--|---|--|
| <ul style="list-style-type: none"> Weatherize; insulate, seal gaps Turn thermostat down in winter, up in summer Reduce use of hot water; do laundry in cold water; take shorter showers | <ul style="list-style-type: none"> Walk or ride a bike Take public transportation Carpool Consolidate trips | <ul style="list-style-type: none"> Buy Energy Star devices and appliances Unplug when possible or use a power strip Use a laptop rather than a desktop computer |

home or business so it will operate on less energy. Some electric companies bill customers with a **tiered rate system** in which customers pay a low rate for the first increment of electricity they use and pay higher rates as use goes up. All of these practices encourage people to reduce the amount of electricity they use.

As we saw in Chapter 12, the demand for energy varies with time of day, season, and weather. When electricity-generating plants are unable to handle the demand during high-use periods, brownouts or blackouts may occur. To avoid this problem, electric companies must be able to provide enough energy to satisfy **peak demand**, the greatest quantity of energy used at any one time. Peak demand may be several times the overall average demand, which means that substantially more energy must be available than is needed under average conditions. To meet peak demand for electricity, electric companies often keep backup generators of electricity available—typically fossil fuel-fired generators, and in some cases, batteries.

Therefore, an important aspect of energy conservation is the reduction of peak demand, which would make it less likely that electric companies will have to build excess generating capacity that is used only sporadically. One way of reducing peak demand is to establish a variable price structure under which customers pay less to use electricity when demand is lowest (typically in the middle of the night and on weekends) and more when demand is highest. This approach helps even out the use of electricity, which both reduces the burden on the generating capacity of the utility and rewards the electric consumer at the same time.

The second law of thermodynamics tells us that whenever energy is converted from one form into another, some energy is lost as unusable heat. In a typical thermal fossil fuel or nuclear power plant, only about one-third of the energy consumed goes to its intended purpose; the rest is lost during energy conversions. We need to consider these losses in order to fully account for

all energy conservation savings. So, the amount of energy we save is the sum of both the energy we did not use together with the energy that would have been lost in converting that energy into the form in which we would have used it. For example, if we can reduce our electricity use by 100 kWh, we may actually be conserving 300 kWh of an energy resource such as coal, since we save both the 100 kWh that we decide not to use and the 200 kWh that would have been lost during the conversion process to make the 100 kWh available to us.

Efficiency

Modern changes in electric lighting are a good example of how steadily increasing energy efficiency results in overall energy conservation. Compact fluorescent light bulbs use one-fourth as much energy to provide the same amount of light as incandescent bulbs. LED (light-emitting diode) light bulbs are even more efficient; they use one-sixth as much energy as incandescent bulbs. Over time, the widespread adoption of these efficient bulbs has resulted in substantially less energy used to provide the same amount of lighting.

Another way in which consumers can increase energy efficiency is by switching to products that meet the efficiency standards of the Energy Star program set by the



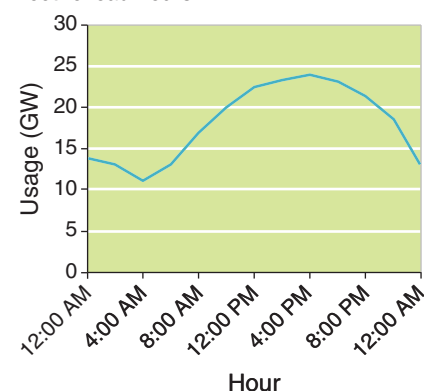
FIGURE 37.1 Reducing energy use. There are many ways individuals can reduce their energy use in and outside the home. Taking public transportation rather than traveling by personal vehicle is one method of energy conservation. These students are taking the Washington, D.C., Metro. (Chicago Tribune/Tribune News Service/Getty Images)

Tiered rate system A billing system used by some electric companies in which customers pay higher rates as their use goes up.

Peak demand The greatest quantity of energy used at any one time.

| Time | 12 AM | 2 AM | 4 AM | 6 AM | 8 AM | 10 AM | 12 PM | 2 PM | 4 PM | 6 PM | 8 PM | 10 PM | 12 AM |
|------------|-------|------|------|------|------|-------|-------|------|------|------|------|-------|-------|
| Usage (GW) | 14 | 13 | 11 | 13 | 17 | 20 | 22.8 | 23.5 | 24 | 23 | 21.5 | 19 | 13.5 |

Electric load hours



Thinking clearly about energy efficiency and energy conservation can save you a lot of money in some surprising ways. If you are saving money on your electric bill, you are also saving energy and reducing the emission of pollutants. Consider the purchase of an air conditioner. Suppose you have a choice: an Energy Star unit for \$300 or a standard unit for \$200. The two units have the same cooling capacity but the Energy Star unit costs 5 cents per hour less to run. If you buy the Energy Star unit and run it 12 hours per day for 6 months of the year, how long does it take to recover the \$100 extra cost?

You would save

$$\$0.05/\text{hour} \times 12 \text{ hours}/\text{day} = \$0.60/\text{day}$$

Six months is about 180 days, so in the first year you would save

$$\$0.60/\text{day} \times 180 \text{ days} = \$108$$

Spending the extra \$100 for the Energy Star unit actually saves you \$8 in just 1 year of use. In 3 years of use, the savings will more than pay for the entire initial cost of the unit ($3 \times \$108 = \324), and after that you pay only for the operating costs.

YOUR TURN You are about to invest in a 66-inch flat screen TV. These TVs come in both Energy Star and non-Energy Star models. The cost of electricity is \$0.15 per kilowatt-hour, and you expect to watch TV an average of 4 hours per day.

1. The non-Energy Star model uses 0.5 kW (half a kilowatt). How much will it cost you per year for electricity to run this model?
2. If the Energy Star model uses only 40 percent of the amount of electricity used by the non-Energy Star model, how much money would you save on your electric bill over 5 years by buying the efficient model?

U.S. Environmental Protection Agency. For example, an Energy Star air conditioner may use 0.2 kWh (200 watt-hours) less electricity per hour than a non-Energy Star unit. In terms of cost, a single consumer may save only 2 to 5 cents per hour by switching to an Energy Star unit. However, if 100,000 households in a city switched to Energy Star air conditioners, the city would reduce its energy use by 20 MW, or 4 percent of the output of a typical power plant. “Do the Math: Energy Star” shows you how to calculate Energy Star savings.

Sustainable Design

Sustainable design can improve the efficiency of the buildings and communities in which we live and work. **FIGURE 37.2** on page 456 shows some key features of sustainable design applied to a single-family dwelling. Insulating foundation walls and basement floors, orienting a house properly in relation to the Sun, and planting shade trees in warm climates are all appropriate design features. As we saw in Chapter 10, good community planning also conserves energy. Building houses close to where residents work reduces reliance on fossil fuels used for transportation, which in turn reduces the amount of pollution and carbon dioxide released into the atmosphere.

Buildings consume a great deal of energy for cooling, heating, and lighting. Many sustainable building

strategies rely on **passive solar design**, a construction technique designed to take advantage of solar radiation without the use of active technology. **FIGURE 37.3** on page 456 illustrates key features of passive solar design. Passive solar design stabilizes indoor temperatures without the need for pumps or other mechanical devices. For example, in the Northern Hemisphere, constructing a house with windows along a south-facing wall allows the Sun’s rays to penetrate and warm the house, especially in winter when the Sun is more prominent in the southern sky. Double-paned windows insulate while still allowing incoming solar radiation to warm the house. Carefully placed windows also allow the maximum amount of light into a building and reduce the need for artificial lighting. Dark materials on the roof or exterior walls of a building absorb more solar energy than light-colored materials, further warming the structure. Conversely, using light-colored materials on a roof reflects heat away from the building, which keeps it cooler. In summer, when the Sun is high in the sky for much of the day, an overhanging roof helps block out sunlight during the hottest period, which makes the indoor temperature cooler and reduces the need for ventilation fans or air conditioning.

Passive solar design Construction designed to take advantage of solar radiation without active technology.

compare energy usage of Energy Star and non-Energy Star compliant appliances. “Your Turn” provides an opportunity for students to do a similar problem.

ANSWER TO YOUR TURN

The cost of electricity is \$0.15 per kWh and we wish to run the TV for 4 hours per day. Calculate the cost to run the non-Energy Star compliant TV first.

1. Non-Energy Star TV

This TV uses 0.5 kW. Therefore:

$$0.5 \text{ kW} \times 4 \text{ hours}/\text{day} \times 365 \text{ days}/\text{year} \\ \times \$0.15/\text{kWh} = \$109.50/\text{year}$$

2. Energy Star TV

This TV uses 40 percent of the energy used by the first TV, meaning we save 60 percent of the energy. If we save 60 percent of the energy, we save 60 percent of the cost. Therefore, in one year:

$$0.60 \times \$109.50/\text{year} = \$65.70/\text{year}$$

So over 5 years we would save:

$$5 \text{ years} \times \$65.70/\text{year} = \$328.50 \text{ savings}$$

TRM MATH SKILLS Practice 13.1

Energy Cost for Light Bulbs

Mathematical Routines (SP6)

Ask students to use the information in the table to complete the table by calculating the yearly energy cost for each of the three light bulbs. Assume that the cost of electricity is \$0.15 per kWh and each bulb is used for 3 hours per day. **Math Skills Practice 13.1: Energy Cost for Light Bulbs** contains a reproducible version of this problem and the table without the answers.

| Type of bulb | Incandescent | Compact fluorescent | LED |
|------------------------------|--------------|---------------------|------------|
| Wattage | 60 watts | 17 watts | 9.5 watts |
| Estimated life expectancy | 0.9 years | 9.1 years | 22.8 years |
| Estimated yearly energy cost | \$9.86 | \$2.79 | \$1.56 |

Incandescent: $0.06 \text{ kW} \times 3 \text{ hours}/\text{day} \times 365 \text{ days}/\text{year} \times \$0.15/\text{kWh} = \$9.86/\text{year}$

Compact fluorescent: $0.017 \text{ kW} \times 3 \text{ hours}/\text{day} \times 365 \text{ days}/\text{year} \times \$0.15/\text{kWh} = \$2.79/\text{year}$

LED: $0.0095 \text{ kW} \times 3 \text{ hours}/\text{day} \times 365 \text{ days}/\text{year} \times \$0.15/\text{kWh} = \$1.56/\text{year}$

Note: The row “estimated life expectancy” is not needed in the calculation.

TRM **TEACHING with**
FIGURE 37.2

Visual Representations (SP2)

Show your students Figure 37.2 without the labels and ask them to identify the various features that contribute to the home's energy efficiency. **Handout 13.2: Modified Figure 37.2** contains a reproducible version of the figure without labels. *The sustainable features of this house include: insulated foundation walls and basement floors, proper orientation in relation to the Sun, high-efficiency windows, skylight, shade tree for warm climates, and high-efficiency heating and cooling systems.*

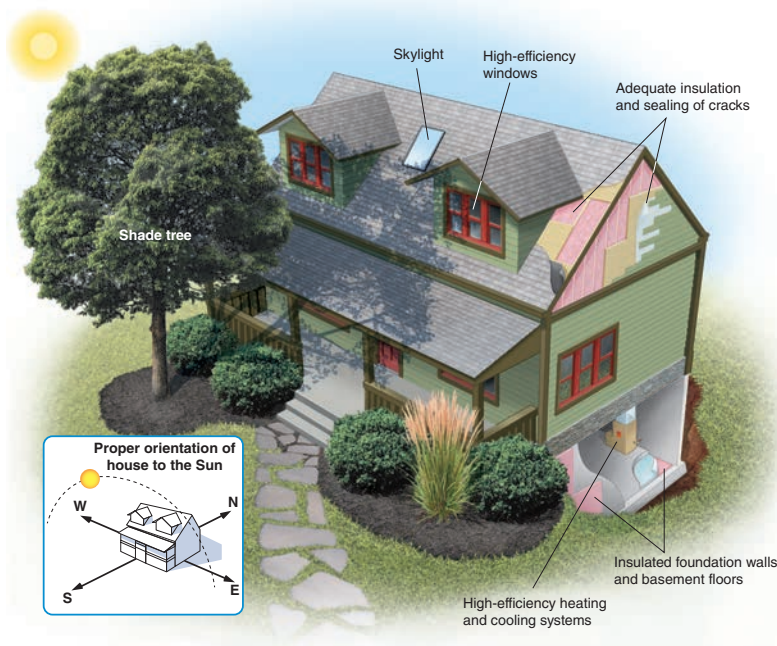


FIGURE 37.2 An energy-efficient home. A sustainable building design incorporates proper solar orientation and landscaping as well as insulated windows, walls, and floors. In the Northern Hemisphere, a southern exposure allows the house to receive more direct rays from the Sun in winter when the path of the Sun is in the southern sky.

TRM **LAB 13.1**
Kilowatt Lab

(45 minutes)

Lab 13.1: Kilowatt Lab allows students compare the energy use of different electrical appliances and devices. They also practice calculating the carbon emissions generated by the electronics we use.

Addresses SP5

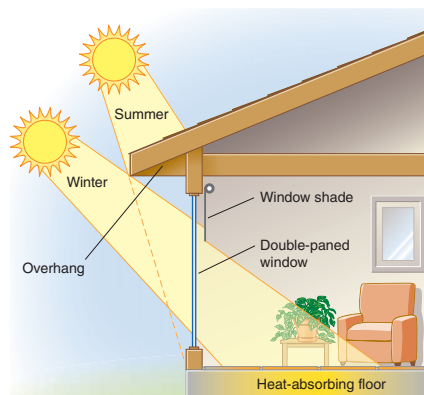


FIGURE 37.3 Passive solar design. Passive solar design uses solar radiation to maintain indoor temperature. Roof overhangs make use of seasonal changes in the Sun's position to reduce energy demand for heating and cooling. In winter, when the Sun is low in the sky, it shines directly into the window and heats the house. In summer, when the Sun is higher in the sky, the overhang blocks incoming sunlight and the room stays cool. High-efficiency windows and building materials with high thermal inertia are also components of passive solar design.



FIGURE 37.4 The California Academy of Sciences. The sustainable design of this San Francisco research institution maximizes the use of natural light and ventilation. The building generates much of its own electricity with solar panels on its roof and captures water in its rooftop garden. (Nancy Hoyt Belcher/Alamy)

Window shades can also reduce solar energy entering the house.

To reduce demand for heating at night and for cooling during the day, builders can use construction materials that have high *thermal mass*. **Thermal mass** is a property of a building material that allows it to retain heat or cold. Materials with high thermal mass stay hot once they have been heated and cool once they have been cooled. Stone and concrete have high thermal mass, whereas wood and glass do not; think of how a cement sidewalk stays warm longer than a wooden boardwalk after a hot day. A south-facing room with stone walls and a stone floor will heat up on sunny winter days and retain that heat long after the Sun has set.

Although building a house into the side of a hill or roofing a building with soil and plants are less-common approaches, these measures also provide insulation and reduce the need for both heating and cooling. While “green roofs”—roofs with soil and growing plants—are somewhat unusual in the United States, many European cities, such as Berlin, have them on new or rebuilt structures. They are especially common on high-rise buildings in downtown areas that have little natural plant cover. These green roofs cool and shade

the buildings and the surrounding environment. And the addition of plants to an urban environment also improves overall air quality.

The use of recycled building materials is another method of energy conservation. Recycling reduces the need for new construction materials, which reduces the amount of energy required to produce the components of the building. For example, many buildings now use recycled denim insulation in the walls and ceilings, and fly ash (a byproduct recovered from coal-fired power plants) in the foundation.

Homes constructed today may incorporate some or all of these sustainable design strategies, but it is possible to achieve energy efficiency even in very large buildings. The building that houses the California Academy of Sciences in Golden Gate Park in San Francisco is a showcase for several of these sustainable design techniques (FIGURE 37.4). This structure, which incorporates a combination of passive solar design, radiant heating, solar panels, and skylights, actually uses 30 percent

Thermal mass A property of a building material that allows it to maintain heat or cold.

Teaching Tip: Engage

Ask students: What kind of structures might be built with materials that have a high thermal mass, and what kind of structures might be built with materials that have a low thermal mass? *Homes and other buildings can be built with materials that have a high thermal mass, such as stone or concrete. This reduces the demand for heating at night and cooling during the day since materials with high thermal mass retain heat and cold. A boardwalk in a warm climate can be built with materials that have a low thermal mass, such as wood. This prevents the walkway from becoming too hot, and allows people to walk on it.*

ACTIVITY

Rooftop Gardens Search

(10 minutes)

Divide your class into pairs and have students do an image search on the internet for “rooftop gardens.” Ask students to find their favorite rooftop garden, and then have pairs share their choice with the class.

TRM Teaching Tip: Beyond the Classroom

Environmental Solutions (SP7)

(20 minutes)

Encourage your class to learn more about the California Academy of Sciences’ Green Building. Have students use the link found in **Chapter 13 Web Resources** to fill out the table to the right. They should be able to find three ways that each building feature contributes to its sustainable design. **Handout 13.3: Green Building** contains a reproducible version of the table without answers.

| Living roof | Natural light | Heating and cooling | Renewable energy |
|--|--|--|--|
| Soil acts as natural insulation. | Large windows reduce lighting needs. | Fresh air is circulated throughout the building to reduce cooling needs. | 60,000 photovoltaic cells surround the living roof. |
| Soil prevents pollutants from entering the ecosystem through runoff. | Glass has low heat absorption and minimizes energy used for cooling. | Skylights open to release hot air. | Bathroom faucets use flowing water to generate power. |
| Plants are habitat for wildlife. | Windows open to regulate inside air temperature naturally. | Heated floors warm spaces efficiently. | Heat recovery systems capture and use heat produced from HVAC. |

Practicing Science:
Scientific Experiments (SP4)

(10 minutes)

In this demonstration, students compare the heat retention of two materials that differ in thermal mass. Thermal mass is a property that allows a building material to retain heat or cold. Materials with high thermal mass stay hot once they have been heated and cool once they have been cooled.

Choose a material with high thermal mass, such as stone or concrete, and one with low thermal mass, such as wood or glass. At the beginning of class, place both materials in constant sunlight or under a heat lamp. After 30 minutes, place a thermometer on the materials and record the temperatures. Then remove the materials from the heat sources and wait 10 minutes before recording the temperatures again. Ask students to predict which material retained more heat and then calculate the change as a class. Discuss how their prediction compares to the data you collected. *You should find that the stone or concrete retained more heat than the wood or glass, and therefore had a smaller temperature change when removed from the heat source.*

less energy than the amount permitted under national building energy requirements. Natural light fills 90 percent of the office space and many of the public areas. Windows, blinds, and skylights open as needed to allow air to circulate, capturing the ocean breezes and ventilating the building. Recycled denim insulation in the walls and a soil-covered rooftop garden provide insulation that reduces heating and cooling costs. As an added benefit, the living green roof grows native plants and captures 13.6 million liters (3.6 million gallons) of rainwater per year, which is then used to recharge groundwater stores.

In addition to these passive techniques, the designers of this building incorporated active technologies that further reduce its use of energy. An efficient radiant heating system carries warm water through tubes embedded in the concrete floor, using a fraction of the energy required by a standard forced-air heating system. To produce some of the electricity used in the building directly, the designers added 60,000 photovoltaic solar cells to the roof. These solar panels convert energy from the Sun into 213,000 kWh of electricity per year and reduce greenhouse gas emissions by about 200 metric tons per year.

The California Academy of Sciences took an innovative approach to meeting its energy needs through a combination of energy efficiency and use of renewable energy resources. However, many, if not all, of these approaches will have to become commonplace if we are going to use energy in a sustainable way.

Renewable energy is either potentially renewable or nondepletable

As fossil fuels become less available and more expensive, what will take their place? Probably it will be a mix of energy efficiency strategies, energy conservation, and new energy sources. In the rest of this chapter we will explore our renewable energy options.

In Chapter 12 we learned that conventional energy resources, such as petroleum, natural gas, coal, and uranium ore, are nonrenewable. From a systems analysis perspective, fossil fuels constitute an energy reservoir we

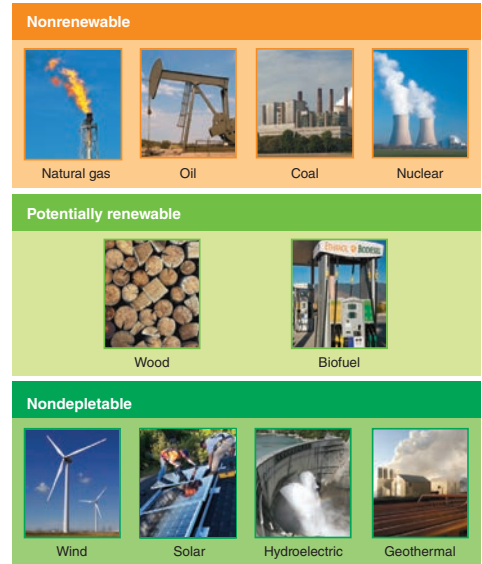


FIGURE 37.5 Renewable and nonrenewable energy resources. Fossil fuels and nuclear fuels are nonrenewable energy resources. Renewable energy resources include potentially renewable energy sources such as biomass, which is renewable as long as humans do not use it faster than it can be replenished, and nondepletable energy sources, such as solar radiation and wind. (Ian Hamilton/Stockphoto.com, babyblueut/Getty Images, MichaelUtecht/Getty Images, RelaxFoto.de/Getty Images, BerndLang/Getty Images, IngaSpence/ScienceSource, acilo/Getty Images, BlendImages-DonMason/Getty Images, Kyodo News/Getty Images, Rhoberazzi/Getty Images)

are depleting much faster than it can ever be replenished. Similarly, we have a finite amount of uranium ore available to use as fuel in nuclear reactors.

In contrast, some other sources of energy can be regenerated rapidly. Biomass energy resources are **potentially renewable** because those resources can be regenerated indefinitely as long as we do not consume them more quickly than they can be replenished. There are still other energy resources that cannot be depleted no matter how much we use them. Solar, wind, geothermal, hydroelectric, and tidal energy are essentially **nondepletable** in the span of human time; no matter how much we use there will always be more. The amount of a nondepletable resource available tomorrow does not depend on how much we use today. In this book we refer to potentially renewable and nondepletable energy resources together as **renewable** energy resources. **FIGURE 37.5** illustrates the categories of energy resources.

Potentially renewable An energy source that can be regenerated indefinitely as long as it is not overharvested.
Nondepletable An energy source that cannot be used up.
Renewable In energy management, an energy source that is either potentially renewable or nondepletable.

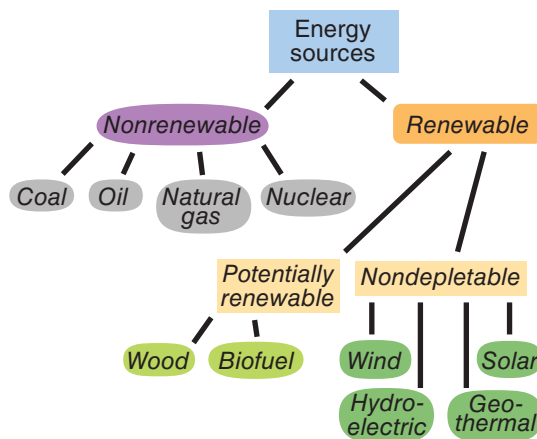
ACTIVITY 13.3

Energy Sources Concept Map

Visual Representations (SP2)

(10 minutes)

Students often confuse potentially renewable and nondepletable energy sources. Have students fill in the concept map to help them differentiate among the various types of energy sources. **Activity 13.3: Energy Sources Concept Map** contains a reproducible version of the concept map without answers.



Many renewable energy resources have been used by humans for thousands of years. In fact, before humans began using fossil fuels, the only available energy sources were wood and plants, animal manure, and fish or animal oils. Today, in parts of the developing world where there is little access to fossil fuels, people still rely on local biomass energy sources such as manure and wood for cooking and heating—sometimes to such an extent that they overuse the resource. For example, according to the International Energy Agency, biomass is currently the source of 65 percent of the energy consumed in sub-Saharan Africa (excluding South Africa) and much of it is not harvested sustainably.

As **FIGURE 37.6** shows, renewable energy resources account for approximately 14 percent of the energy used worldwide, most of which is in the form of biomass. In the United States, which depends heavily on fossil fuels, renewable energy resources provide only about 10 percent of the energy used. That 10 percent, shown in detail in **FIGURE 37.7**, comes primarily from biomass, hydroelectricity, and wind.

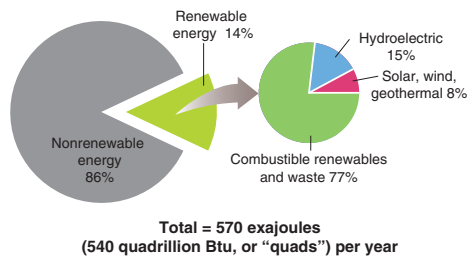


FIGURE 37.6 Global energy use. Renewable energy resources provide about 14 percent of energy worldwide. (Data from International Energy Agency for the 2015 year, *Key World Energy Statistics*, 2017.)

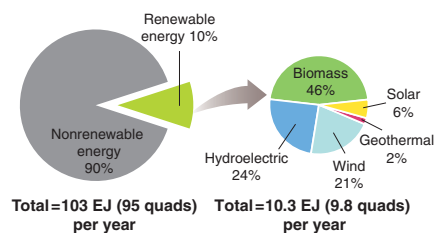


FIGURE 37.7 Energy use in the United States. Roughly 10 percent of the energy used in the United States comes from renewable energy resources. Note that the sum of components does not equal 100 percent due to rounding. (Data from www.eia.doe.gov)

TEACHING with FIGURES 37.6 and 37.7

Visual Representations (SP2)

Have students compare Figure 37.6 and Figure 37.7. Then ask the following questions:

- Who uses a higher percentage of renewable energy, the United States or the rest of the world? *Global renewable energy use is 14 percent of its total, whereas United States renewable energy use is 10 percent of its total. The rest of the world uses a higher percentage of renewable energy than the United States.*
- When you compare the renewable energy use of the United States to that of the rest of the world, what are three differences that you see?
 1. *As a fraction of total renewable energy use, the United States uses a lower percentage of biomass (46 percent vs. 77 percent).*
 2. *The United States uses a higher percentage of hydroelectric (24 percent vs. 15 percent).*
 3. *The United States uses a higher total percentage of wind, solar, and geothermal (29 percent vs. 8 percent).*

MODULE

37 AP[®] Review

Preparing for the AP[®] Exam

In this module, we have seen that to achieve energy sustainability we should begin with conserving energy and increasing energy efficiency. Energy conservation refers to finding ways to use less energy. Increasing energy efficiency means achieving the same amount of work from a smaller quantity of energy. Sustainable design of buildings and communities can decrease energy use. We also looked at different categories of

renewable energy resources. Potentially renewable energy sources can regenerate if we do not consume them more quickly than they can be replaced. Nondepletable energy resources such as the wind cannot be depleted no matter how much we use. In the next module, we examine two important renewable resources, biomass and water that is used for generating electricity.

Answers to Module 37

AP[®] Practice Questions

- d
- d
- c
- c
- b

Bell Ringer

Explain to students that part of this module explores biomass as an energy source. Then ask: How is biomass actually just another form of solar energy? *Biomass energy resources include various types of plant material, manure, and even municipal solid waste. The energy in plants is made using the Sun's energy, and the energy in animals is derived from plant energy. So, ultimately, all the energy in plants and animals originates from the Sun.*

AP[®] Practice Questions

Choose the best answer for the following.

- Which is an energy efficiency improvement?
 - adjusting the thermostat in a building
 - using a power strip
 - using cold water instead of hot water
 - replacing incandescent bulbs with LEDs
- Peak demand
 - decreases electricity-generating capacity.
 - is caused by higher electricity prices.
 - occurs equally in all seasons.
 - can be managed using a variable price structure.
- If an Energy Star refrigerator costs 2 cents less per hour to run, and if it runs for 16 hours a day, how much will it save in a year?
 - \$44
 - \$82
 - \$117
 - \$174
- Which is LEAST likely to be used in sustainable design in North America?
 - recycled building materials
 - an overhanging roof
 - windows on the northern wall
 - building materials with high thermal mass
- Which energy source is NOT nondepletable?
 - wind
 - biomass
 - tidal
 - solar

MODULE

38

Biomass and Water

As we discussed in Chapter 12, the Sun is the ultimate source of fossil fuels. Fossil fuels are created from dead plants and animals that are buried deep in sediments and that are slowly transformed into petroleum or coal. Most types of renewable energy are also derived from the Sun and cycles driven by the Sun, including solar, wind, and hydroelectric energy as well as plant biomass such as wood. In this module, we present two important renewable energy sources: biomass and water.

Learning Goals

After reading this module, you should be able to

- describe the various forms of biomass.
- explain how energy is harnessed from water.

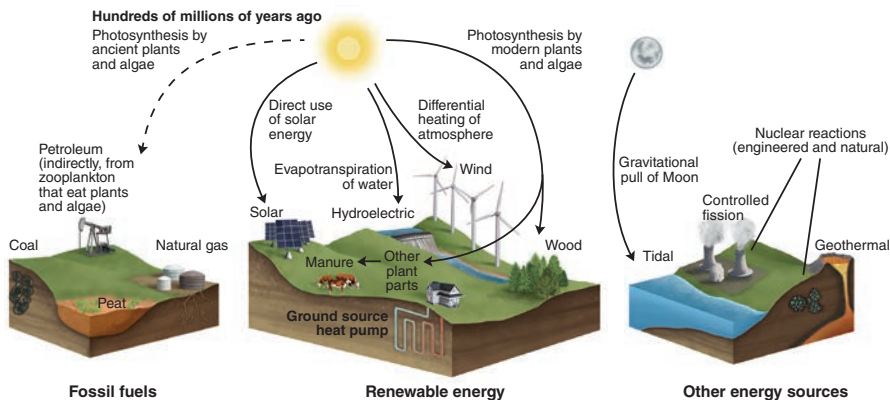


FIGURE 38.1 Energy from the Sun. The Sun is the ultimate source of almost all types of energy.

Biomass is energy from the Sun

As **FIGURE 38.1** shows, all fossil fuel and most renewable energy sources ultimately come from the Sun. Biomass energy resources encompass a large class of fuel types that include wood and charcoal, animal products and manure, plant remains, and municipal solid waste (MSW), as well as liquid fuels such as ethanol and biodiesel. Many forms of biomass used directly as fuel, such as wood and manure, are readily available all over the world. Because these materials are inexpensive and abundant, they account for more than 10 percent of world energy consumption (see Figure 37.6 on page 459), with a much higher percentage in many developing countries. Biomass can also be processed or refined into liquid fuels such as ethanol and biodiesel, known collectively as **biofuels**. These fuels are used in more limited quantities due to the technological demands associated with their use. For example, it is easier to burn a log in a fire than it is to develop the technology to produce a compound such as ethanol.

Biomass—including ethanol and biodiesel—accounts for roughly one-half of the renewable energy and approximately 4.5 percent of all the energy consumed in the United States today (see Figure 37.7 on page 459). However, the mix of biomass used in the United States differs from that found in the developing world. A little less than half of the biomass energy used in the United States comes from wood, and a similar amount comes from biofuels. Only a small amount (less than 5 percent)

comes from MSW, while in the developing world, a larger percentage of biomass energy comes from wood and animal manure.

Modern Carbon versus Fossil Carbon

Like fossil fuels, biomass contains a great deal of carbon, and burning it releases that carbon into the atmosphere. Given the fact that both fossil fuels and biomass raise atmospheric carbon concentrations, is it really better for the environment to replace fossil fuels with biomass? The answer depends on how the material is harvested and processed and on how the land is treated during and after harvest. It also depends on how long the carbon has been stored. The carbon found in plants growing today was in the atmosphere in the form of carbon dioxide until recently when it was incorporated into the bodies of the plants through photosynthesis. Depending on the type of plant it comes from, the carbon in biomass fuels may have been captured through photosynthesis as recently as a few months ago, as in the case of a corn plant, or perhaps up to several hundred years ago, as in the case of wood from a large tree. We call the carbon in biomass **modern carbon**, in contrast to the carbon in fossil fuels, which we call **fossil carbon**.

Biofuel Liquid fuel created from processed or refined biomass.

Modern carbon Carbon in biomass that was recently in the atmosphere.

Fossil carbon Carbon in fossil fuels.

TRM TEACHING with FIGURE 38.1

Visual Representations (SP2)

Ask students to work in groups of two and answer the following questions. **Handout 13.4: Questions on Figure 38.1** contains a reproducible version of the questions without the answers.

- How are fossil fuels related to the Sun? *All fossil fuels are created by decomposition of ancient plants and animals. Plants require sunlight to grow and animals require plants for food, either directly or indirectly. Therefore, energy from the Sun is the source of the energy in fossil fuels.*
- How are wind, hydroelectric, and solar energy related to the Sun? *Wind is the result of the unequal heating of Earth and the atmosphere. The heating comes from the Sun. Hydroelectric energy is indirectly related to the Sun through the water cycle in which the Sun evaporates water. Finally solar energy is energy harnessed from sunlight.*
- What are the sources of tidal, nuclear, and geothermal energy? *The gravitational pull of the moon creates tides. Nuclear energy is produced by uranium, which is a radioactive element mined from Earth's crust. Geothermal energy uses the heat from radioactive elements, including uranium from Earth's interior.*

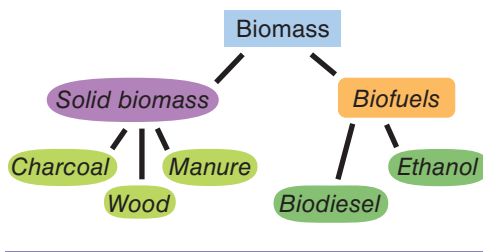
TRM ACTIVITY 13.4

Biomass Concept Map

Visual Representations (SP2)

(10 minutes)

Students often confuse the different types of biomass. Have them fill in the concept map shown to help them distinguish between solid biomass and biofuels. **Activity 13.4: Biomass Concept Map** contains a reproducible version of the concept map without answers.



TRM Teaching Tip: Journal Prompt

(15 minutes)

Ask students to compare solid biomass and liquid biomass with the following questions. **Handout 13.5: Journal Prompt on Biomass** contains a reproducible version of these questions without answers.

- What are the different types of solid biomass and liquid biomass? *Solid biomass includes wood, charcoal, and manure. Liquid biomass includes ethanol and biodiesel.*
- How are the different types of biomass used? *Solid biomass is used primarily for heating homes and cooking food. Liquid biomass is used as a substitute for petroleum. It is often mixed with gasoline or diesel.*
- Where are the different types of biomass used? *Solid biomass is mostly used in developing countries because wood and manure are less expensive than other fuels. Liquid biomass is used more in developed countries where people can afford it.*
- How are liquid biomass and solid biomass similar? *Both solid and liquid biomass are derived from the Sun. Both are considered modern carbon inputs.*
- Describe the environmental effects of using solid biomass and the effects of using liquid biomass. *Solid biomass such as wood and manure produce large amounts of particulate matter, carbon dioxide, and nitrous oxides. Liquid biomass burns cleaner than gasoline.*

Unlike modern carbon, fossil carbon has been buried for millions of years. Fossil carbon is carbon that was out of circulation until humans discovered it and began to use it. The burning of fossil fuels results in a rapid increase in atmospheric CO₂ concentrations because we are unlocking or releasing stored carbon that was last in the atmosphere millions of years ago. In theory, the burning of biomass (modern carbon) should not result in a net increase in atmospheric CO₂ concentrations because we are returning the carbon to the atmosphere, where it had been until recently. And, if we allow vegetation to grow back in areas where biomass was recently harvested, that new vegetation will take up an amount of CO₂ more or less equal to the amount we released earlier by burning the biomass. Over a long period of time, the net change in atmospheric CO₂ concentrations should be zero. An activity that does not change atmospheric CO₂ concentrations is referred to as **carbon neutral**.

Whether using biomass is truly carbon neutral, however, is an important question that is currently being discussed by scientists and policy makers. Sometimes the use of modern carbon ends up releasing CO₂ into the atmosphere that would otherwise have remained in the soil.

Solid Biomass: Wood, Charcoal, and Manure

Throughout the world, 2 billion to 3 billion people rely on wood for heating or cooking. In the United States, approximately 3 million homes use wood as the primary heating fuel, and more than 20 million homes use wood for energy at least some of the time. In addition, the pulp and paper industries, power plants, and other industries use wood waste and by-products for energy. In theory, cutting trees for fuel is sustainable if forest growth keeps up with forest removal. Unfortunately, many forests, like those in Indonesia and parts of Africa and South America, are cut intensively, allowing little chance for regrowth.

Removing more timber than is replaced by growth, or **net removal** of forest, is an unsustainable practice that will eventually lead to deforestation. This net removal of forest together with the burning of wood results in a net increase in atmospheric CO₂: The CO₂ released from the burned wood is not balanced

Carbon neutral An activity that does not change atmospheric CO₂ concentrations.

Net removal The process of removing more than is replaced by growth, typically used when referring to carbon.

Ethanol Alcohol made by converting starches and sugars from plant material into alcohol and CO₂.

by photosynthetic carbon fixation that would occur in new tree growth. Harvesting the forest may also release carbon from the soil that would otherwise have remained buried in the A and B horizons. Although the mechanism is not entirely clear, it appears that some of this carbon release may occur because logging equipment disturbs the soil.

Tree removal can be sustainable if we allow time for forests to regrow. In addition, in some heavily forested areas, extracting individual trees of abundant species and opening up spaces in the canopy will allow other plants to grow and increase habitat diversity, which may even increase total photosynthesis. More often, however, tree removal has the potential to cause soil erosion, to increase water temperatures in nearby rivers and streams, and to fragment forest habitats when logging roads divide them. Tree removal may also harm species that are dependent on old-growth forest habitat.

Many people in the developing world use wood to make charcoal, which is a superior fuel for many reasons. Charcoal is lighter than wood and contains approximately twice as much energy per unit of weight. A charcoal fire produces much less smoke than wood and does not need to be tended constantly, as does a wood fire. Although it is more expensive than wood, charcoal is a fuel of choice in urban areas of the developing world and for families who can afford it. However, harvesters who clear an area of land for charcoal production often leave it almost completely devoid of trees (**FIGURE 38.2**).

In regions where wood is scarce, such as parts of Africa and India, people often use dried animal manure as a fuel for indoor heating and cooking. Burning manure can be beneficial because it removes harmful microorganisms from surrounding areas, which reduces the risk of disease transmission. However, burning manure also releases particulate matter and other pollutants that cause a variety of respiratory illnesses, from emphysema to cancer. The problem is exacerbated when the manure is burned indoors in poorly ventilated rooms, a common situation in many developing countries. The World Health Organization estimates that indoor air pollution is responsible for 3 million deaths annually. Chapters 15 and 17 cover indoor air pollution and human health in more detail.

Whether indoors or out, burning biomass fuels produces a variety of air pollutants, including particulate matter, carbon monoxide (CO), and nitrogen oxides (NO_x), which are important components of air pollution (**FIGURE 38.3**).

Biofuels: Ethanol and Biodiesel

The liquid biofuels—ethanol and biodiesel—can be used as substitutes for gasoline and diesel, respectively. **Ethanol** is an alcohol made by converting starches and sugars from plant material into alcohol and carbon

AP® FRQ Practice

The use of wood as an energy source and nonrenewable energy sources are covered in the 2001 AP® Environmental Science Exam, Question 1. To answer this question, students must

- calculate the number of cubic feet of natural gas used to heat a house over the course of a winter, and the cost, using data provided.
- describe actions residents can take to conserve energy and lower heating costs.
- discuss the environmental advantages and disadvantages of using wood as an energy source for home heating.

AP® FRQ Practice

The use of wood as an energy source and forest conservation are covered on the 2012 AP® Environmental Science Exam, Question 2. To answer this question, students must

- describe a way to reduce a school's carbon footprint, including environmental benefits and environmental drawbacks.
- explain the ecological benefits of an intact forest system.
- using provided data, calculate the mass of carbon accumulated in a forest in 1 year, the mass of carbon emitted by a school from fuel consumption in 1 year, the amount of forest reserve needed to offset the carbon emissions of the school, and how much money the school would need to raise to preserve the amount of forest it needs to reduce its carbon footprint.

AP® FRQ Practice

The use of animal manure as a fuel is covered in the 2009 AP® Environmental Science Exam, Question 2. To answer this question, students must

- summarize an article that outlines the steps by which methane is used to produce electricity in a methane digester.
- discuss environmental benefits of a methane digester.
- calculate the amount of electricity a farmer can generate through cow manure.
- calculate how much the farmer would save by producing electricity in a methane digester and the number of years it would take to recover the installation costs.
- calculate the minimum number of cows the farmer would need to produce 800,000 kWh of electricity from methane in a year.



(a)



(b)

FIGURE 38.2 Charcoal as fuel in the developing world. (a) Many people in developing countries rely on charcoal for cooking and heating. This photo shows a charcoal market in the Philippines. (b) Charcoal production can strip the land of all trees (a: JAY DIRECTO/Getty Images, b: Eduardo Martino/Panos Pictures)



FIGURE 38.3 Particulate emissions from burning biomass fuels. Burning biomass fuels contributes to air pollution. This photo shows smog and decreased visibility in Montreal, Canada, caused by emissions of particulate matter due to the extensive use of woodstoves. (alank/Getty Images)

dioxide. More than 90 percent of the ethanol produced in the United States comes from corn and corn by-products, although ethanol can also be produced from sugarcane, wood chips, crop waste, or switchgrass. **Biodiesel**, a diesel substitute produced by extracting and chemically altering oil from plants, is a substitute for regular petroleum diesel. It is usually produced by extracting oil from algae and plants such as soybean and palm. In the United States, many policy makers are encouraging the production of ethanol and biodiesel as a way to reduce the need to import foreign oil while also supporting U.S. farmers and declining rural economies.

Ethanol

The United States is the world leader in ethanol production, manufacturing roughly 59 billion liters (15.5 billion gallons) in 2017. Brazil, the world's second largest ethanol producer, is making biofuels a major part of its sustainable energy strategy. Brazil manufactures ethanol from sugarcane, which is easily grown in its tropical climate. Unlike corn, which must be replanted

Biodiesel A diesel substitute produced by extracting and chemically altering oil from plants.

Teaching Tip: Engage

Ask students: Have you ever used a barbecue with charcoal briquettes? What do you remember about how it looks, feels, or smells? *Answers will vary.*

Teaching Tip: Journal Prompt

Many students don't understand the difference between biofuel and biodiesel. Ask students to describe the difference between gasohol, E-85, and B-20. *Gasohol is 10 percent ethanol and 90 percent gasoline. Gasohol is currently used in the United States for cars and light trucks. E-85 is 85 percent ethanol and 15 percent gasoline. E-85 is available in the United States but is typically only found in Midwestern states. B-20 is a mixture of 80 percent petroleum diesel and 20 percent biodiesel. B-20 is available at some gas stations scattered around the United States and can be used in any diesel engine without modifications to that engine.*

AP® FRQ Practice

Biodiesel is covered on the 2008 AP® Environmental Science Exam, Question 1. To answer this question, students must

- use provided data to calculate the amount of microalgae or soybeans needed to produce 1,000 gallons of oil in a year.
- explain the advantage of microalgae as a source for biodiesel over other crops.
- compare the effect on atmospheric CO₂ concentrations from burning biodiesel and fossil fuels.
- describe two benefits not related to the atmosphere of increasing biodiesel use over the next 50 years.
- discuss two economic or social problems of using corn for fuel.

ACTIVITY

Science Applied 6: Should Corn Become Fuel?

Concept Application (SP1)

(20 minutes)

For a closer look at the issues involved in using food crops for fuel, have students read "Science Applied 6: Should Corn Become Fuel?" on page 493. Use the questions on page 496 for class discussion, or use the practice free-response question as a class exercise.

TRM Debate the Issue 13.1:
**Are Flex-Fuel Vehicles Good
for the Environment?**

Environmental Solutions (SP7)

(45 minutes)

Have students research flex-fuel vehicles in preparation for a debate. Students should be prepared to discuss the following questions in their debate.

Debate the Issue 13.1: Are Flex-Fuel Vehicles Good for the Environment? contains a reproducible version of these questions.

- What is a flex-fuel car and how is it different from a regular vehicle?
- What are the environmental pros or cons to using flex-fuel vehicles?
- What is E-85 and how might it help the United States become energy independent?
- Would using more corn for ethanol result in a net environmental benefit?

In class, select groups to debate the issue. Allow each side 2 minutes to prepare, 3 minutes to present, and 1 minute for rebuttal. Have the remainder of the class take notes, ask questions, and decide which side has the most persuasive argument.

Teaching Tip: Discussion Starter

Ask students: Why is biodiesel a better option for the environment than conventional diesel fuel? What are some of the concerns about biodiesel? *Emissions of carbon monoxide from combustion of biodiesel are lower than those from conventional petroleum diesel. Since it contains modern carbon rather than fossil carbon, biodiesel should be closer to carbon neutral, although, as with ethanol, some critics question whether biodiesel is truly carbon neutral. For example, producing biodiesel from soybeans requires less fossil fuel input per liter of fuel than producing ethanol from corn, but because soybeans require more cropland, the conversion of other lands to cropland may actually transfer more carbon from the soil to the atmosphere. In contrast, producing biodiesel from wood waste or algae may require very little or no cropland and a minimal amount of other land.*

every year, sugarcane is replanted every 6 years and is sometimes harvested by hand, factors that reduce the amount of fossil fuel energy needed to grow it.

Ethanol is usually mixed with gasoline, most commonly at a ratio of one part ethanol to nine parts gasoline. The result is gasohol, a fuel that is 10 percent ethanol. Gasohol has a higher oxygen content than gasoline alone and produces less of some air pollutants when combusted. In certain parts of the midwestern United States, especially in corn-growing states, a fuel called E-85 (85 percent ethanol, 15 percent gasoline) is available. **Flex-fuel vehicles** can run on either gasoline or E-85. However, a study by General Motors several years ago revealed that most of the owners of the 7 million flex-fuel vehicles in use at that time did not know that their cars could run on E-85.

Proponents of ethanol claim that it is a more environmentally friendly fuel than gasoline, although opponents dispute that claim. Ethanol does have disadvantages. The carbon bonds in alcohol have a lower energy content than those in gasoline, which means that a 90 percent gasoline/10 percent ethanol mix reduces gas mileage by 2 to 3 percent when compared with 100 percent gasoline fuel. As a result, a vehicle needs more gasohol to go the same distance it could go on gasoline alone. Furthermore, growing corn to produce ethanol uses a significant amount of fossil fuel energy, as well as land that can otherwise be devoted to growing food. Ethanol production has led to concern among economic analysts that this production periodically contributes to short-term food shortages. Furthermore, some scientists argue that using ethanol actually creates a net increase in atmospheric CO₂ concentrations. The benefits and drawbacks of using ethanol as a fuel are discussed in more detail in “Science Applied 6: Should Corn Become Fuel?” that follows this chapter.

Research is under way to find viable alternatives to corn as sources for U.S. ethanol production. Switchgrass is one possibility. It is a perennial crop, which means that farmers can harvest it without replanting, minimizing soil disturbance and erosion. Furthermore, switchgrass does not require as much fossil fuel input as corn to produce. However, crops such as corn and sugarcane produce ethanol more readily due to their high sugar content because sugars are readily and rapidly converted into ethanol. In contrast, switchgrass and other alternative materials, such as wood chips, are composed primarily of cellulose—the material that constitutes plant cell walls—which must be broken down into sugars before it can be used in ethanol production. Scientists have not yet developed an efficient breakdown process for large-scale ethanol production from switchgrass, although such a process would increase the energy and carbon advantages of ethanol.

Flex-fuel vehicle A vehicle that runs on either gasoline or a gasoline/ethanol mixture.

Biodiesel

Biodiesel is a direct substitute for petroleum-based diesel fuel. It is usually more expensive than petroleum diesel, although the difference varies depending on market conditions and the price of petroleum. Biodiesel is typically diluted to “B-20,” a mixture of 80 percent petroleum diesel and 20 percent biodiesel, and is available at some gas stations scattered around the United States. It can be used in any diesel engine without modification.

Because biodiesel tends to solidify into a gel at low temperatures, higher concentrations of biodiesel work effectively only in modified engines. However, with a kit sold commercially, a skilled individual or automobile mechanic can modify any diesel vehicle to run on 100 percent straight vegetable oil (SVO), typically obtained as a waste product from restaurants and filtered for use as fuel. Groups of students in the United States have driven buses around the country almost exclusively on SVO, and some municipalities have community-based SVO recycling facilities (FIGURE 38.4). Although there is unlikely to be enough waste vegetable oil to significantly reduce fossil fuel consumption, SVO is nevertheless a potential transition fuel that may temporarily reduce our use of petroleum.

In the United States, most biodiesel comes from soybean oil or processed vegetable oil. However, scientists are working on ways to produce large quantities of biodiesel directly from wood or other forms of cellulose—especially waste wood from logging and sawmills. In addition, some species of algae appear to have great potential for producing biodiesel. Algae are photosynthetic microorganisms that can be grown almost anywhere and, of all biodiesel options, produce the greatest yield of fuel per hectare of land area per year and utilize the least amount of energy and fertilizer per quantity of



FIGURE 38.4 A cooking oil recycling program. Used cooking oil collected from restaurants in San Francisco, California, is transferred to dumpsters where it will be recycled into biodiesel, reducing demand for fossil fuels and keeping the oil from entering the sewer system. (Justin Sullivan/Getty Images)

TRM Teaching Tip: Video

A Conversation with Sarah Alexander (10 minutes)

This short video describes how waste vegetable oil can be made into biodiesel fuel. It focuses on a recent college graduate who is working with street food vendors in India. **Chapter 13 Web Resources** contains a link to this video. After watching the video, ask your students the following questions.

Handout 13.6: Questions for A Conversation with Sarah Alexander contains a reproducible version of the questions.

- What are two environmental benefits of using waste vegetable oil to make biodiesel? *When biodiesel fuel replaces conventional diesel fuel, a modern carbon*

is used instead of a fossil carbon. This reduces air pollution by lowering the release of soot, carbon monoxide, and sulfates. Additionally, using waste vegetable oil diverts it from the landfill or drainage system.

- How does a diesel car need to be altered to run on biodiesel? *It doesn't. A diesel car can use up to 20 percent biodiesel fuel (B-20) without a retrofit.*
- What are two social benefits of using waste vegetable oil from street food vendors? *Vendors are paid for oil that they would normally throw away, and biodiesel fuel is less expensive than conventional diesel fuel.*

fuel. One study reported that algae produce 15 to 300 times more fuel per area used than did conventional crops. Algae can be grown on marginal lands, in brackish water, on rooftops, and in other places that are not traditionally thought of as agricultural space.

Emissions of carbon monoxide from combustion of biodiesel are lower than those from petroleum diesel. Since it contains modern carbon rather than fossil carbon, biodiesel should be carbon neutral, although, as with ethanol, some critics question whether biodiesel is truly carbon neutral. For instance, producing biodiesel from soybeans requires less fossil fuel input per liter of fuel than producing ethanol from corn, but soybeans require more cropland, and so they may actually transfer more carbon from the soil to the atmosphere. In contrast, producing biodiesel from wood waste or algae may require very little or no cropland and a minimal amount of other land.

AP® Exam Tip

Make sure that you can differentiate between the impact of biodiesel fuel and fossil fuels on atmospheric CO₂ concentrations.

The kinetic energy of water can generate electricity

Hydroelectricity is electricity generated by the kinetic energy of moving water. It is the second most commonly used form of renewable energy in the United States and in the world, and it is the form most widely used for electricity generation. As we saw in Chapter 12 (Figure 34.8 on page 425), hydroelectricity accounts for approximately 6.5 percent of the electricity generated in the United States. More than one-half of that hydroelectricity is generated in five states: Washington, California, New York, Oregon, and Alabama. Worldwide, 17 percent of all electricity comes from hydroelectric power plants, with China the leading producer, followed by Brazil, Canada, the United States, India, and Russia. In this section we will look at ways in which hydroelectricity is generated, and we will consider whether hydroelectricity is sustainable.

Methods of Generating Hydroelectricity

Moving water, either falling over a vertical distance or flowing with a river or tide, contains kinetic energy. A hydroelectric power plant captures this kinetic energy and uses it to turn a turbine in the same way that the kinetic energy of steam turns a turbine in a coal-fired

power plant. The turbine, in turn, transforms the kinetic energy of water or steam into electricity, which is then exported to the electrical grid via transmission lines.

The amount of electricity that can be generated at any particular hydroelectric power plant depends on the flow rate, the vertical distance the water falls, or both. Where falling water is the source of the energy, the amount of electricity that can be generated depends on the vertical distance the water falls; the greater the distance, the more potential energy the water has, and the more electricity it can generate (see Figure 5.2 on page 48). The amount of electricity a hydroelectric power plant can generate also depends on the flow rate: the amount of water that flows past a certain point per unit of time. The higher the flow rate, the more kinetic energy is present, and the more electricity can be generated.

Run-of-the-River Systems

In **run-of-the-river** hydroelectricity generation, water is retained behind a low dam and runs through a channel before returning to the river. Run-of-the-river systems do not store water in a reservoir. These systems have several advantages that reduce their environmental impact: Relatively little flooding occurs upstream, and seasonal changes in river flow are not disrupted. However, run-of-the-river systems are generally small and, because they rely on natural water flows, electricity generation can be intermittent. Heavy spring runoff from rains or snowmelt cannot be stored, and the system cannot generate any electricity in hot, dry periods when the flow of water is low.

Water Impoundment Systems

Storing water in a reservoir behind a dam is known as **water impoundment**. **FIGURE 38.5** on page 466 illustrates the various features of a water impoundment system. By managing the opening and closing of the gates, the dam operators control the flow rate of the water that turns the turbine—and in turn the generator—and thereby influence the amount of electricity produced.

Water impoundment is the most common method of hydroelectricity generation because it usually allows for the generation of electricity on demand. The largest hydroelectric water impoundment dam in the United States is the Grand Coulee Dam in Washington State, which generates 6,800 MW at peak capacity. The Three Gorges Dam on the Yangtze River in China (see Figure 27.2 on page 315) is the largest dam in the world. It has a capacity of 22,500 MW and can generate almost

Hydroelectricity Electricity generated by the kinetic energy of moving water.

Run-of-the-river Hydroelectricity generation in which water is retained behind a low dam or no dam.

Water impoundment The storage of water in a reservoir behind a dam.

TRM Teaching the AP® Tip

(10 minutes)

To help students differentiate between the impact of biodiesel fuel and fossil fuels on atmospheric CO₂ concentrations, ask students

to complete a chart comparing the two.

Handout 13.7: Biodiesel Versus Fossil Fuel contains a reproducible version of this chart without the answers.

| | Biodiesel fuel | Fossil fuel |
|--|--|--|
| Does it release CO ₂ when burned? | Yes | Yes |
| Where did the CO ₂ come from? | Sequestered (absorbed) from the atmosphere when the plants grew | Sequestered (absorbed) from the atmosphere when phytoplankton or plants grew |
| How long ago was the CO ₂ captured from the atmosphere? | Within the last few months, years, or decades, depending on the plant material | 50 to 150 million years ago |
| Based on time of release, what kind of carbon is released into the atmosphere? | Modern (recently in the atmosphere) | Fossil (out of circulation for millions of years) |
| Does burning this fuel result in a net increase of atmospheric CO ₂ concentrations? | Potentially not (carbon neutral), if there are no land use changes during or after biomass removal | Yes |

Teaching Tip: Review

(10 minutes)

Ask students to answer the following questions as you review biomass:

- What are the major forms of biomass energy? *Biomass energy resources encompass a large class of fuel types that include wood and charcoal, animal products and manure, and plant remains and municipal solid waste (MSW), as well as liquid fuels such as ethanol and biodiesel.*
- Why is energy from modern carbon potentially carbon neutral? *The carbon in biomass fuels may have been captured through photosynthesis as recently as a few months ago, in the case of a corn plant, or up to several hundred years ago, in the case of wood from a large tree. In theory, the burning of biomass should not result in a net increase in atmospheric CO₂ concentrations because the carbon it releases has recently been in the atmosphere and presumably will be taken up by the plants that have replaced the corn or trees that were removed.*
- Why is it important to find abundant sources of biomass energy? What are the advantages and disadvantages of different forms of biomass energy? *Biodiesel combustion emits less carbon monoxide and sulfur oxides than petroleum diesel combustion. Also, because biofuels contain modern carbon, biodiesel should be carbon neutral. Advantages: Plants can be grown in many different climates on Earth, and biomass is potentially renewable, can reduce dependence on fossil fuels, and is possibly more environmentally friendly than fossil fuels. Disadvantages: The production of biomass can potentially lead to the loss of agricultural land and higher food costs. Biomass contains less energy per liter of fuel and thus will yield fewer miles per gallon, and may cause a net increase in greenhouse gas emissions.*

TEACHING with FIGURE 38.5

Visual Representations (SP2)

Show students Figure 38.5 and compare it to Figure 34.7 on page 424 in Chapter 12. Ask them the following questions:

1. How is this hydroelectric dam similar to the coal-fired electricity generation plant from Chapter 12? Both figures show a turbine that is connected to a generator, which leads to electric transmission lines. Both systems generate electricity by turning a turbine.
2. How do the electricity generation plants differ? The coal-fired electricity generation plant uses steam to turn the turbine. The steam is produced when energy from burning coal heats water. The hydroelectric dam uses flowing water to turn the turbine.

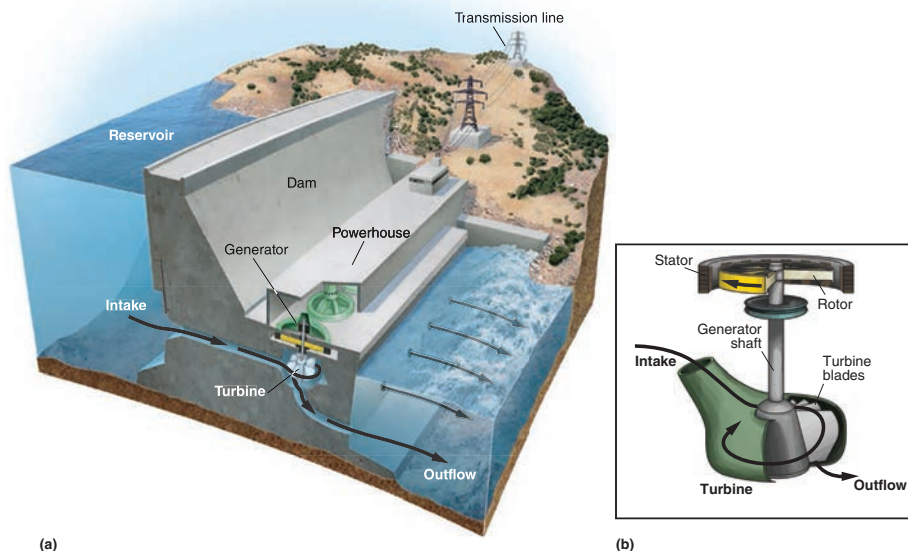


FIGURE 38.5 A water impoundment hydroelectric dam. (a) Water impoundment, a common method of hydroelectricity generation, allows for electricity generation on demand. Dam operators control the rate of water flow by opening and closing the gates. Increased water flow results in increased rotation of the turbines (b) resulting in a greater amount of electricity generated. The arrows indicate the path of water flow.

TRM Teaching Tip: Beyond the Classroom

Concept Application (SP1)

(60 minutes)

Ask students to research a tidal energy power plant. There are several locations around the world, including Roosevelt Island Tidal Energy Project (RITE) in New York City, La Rance Tidal Power Plant in France, Sihwa Lake Tidal Power Station in South Korea, and the Tidal Lagoon Project in Swansea, Wales. Some questions for students to consider in their reports include the following.

Handout 13.8: Tidal Energy Research Project contains a reproducible version of these questions.

- Where is the plant located?
- When was the plant constructed?
- How much energy does it provide?
- What are the environmental benefits and environmental costs of the project?

85 billion kilowatt-hours per year, approximately 11 percent of China's total electricity demand.

Tidal Systems

Tidal energy also comes from the movement of water, although the movement in this case is driven by the gravitational pull of the Moon. Tidal energy systems use gates and turbines similar to those used in run-of-the-river and water impoundment systems to capture the kinetic energy of water flowing through estuaries, rivers, and bays and convert this energy into electricity.

Although tidal power plants are operating in many parts of the world, including France, Korea, and Canada, tidal energy does not have the potential to become a major energy source. In many locations around the world, the difference in water level between high and low tides is not great enough to provide sufficient kinetic energy to generate a large amount of electricity. In addition, to

transfer the energy generated, transmission lines must be constructed on or near a coastline or estuary. This infrastructure may have a disruptive effect on coastal, shoreline, and marine ecology as well as on tourism that relies on the aesthetics of a coastal region.

Hydroelectricity and Sustainability

Major hydroelectric dam projects have brought renewable energy to large numbers of rural residents in many countries, including the United States, Canada, India, China, Brazil, and Egypt. Although hydroelectric dams are expensive to build, once built, they require a minimal amount of fossil fuel for operation. In general, the benefits of water impoundment hydroelectric systems are great: They generate large quantities of electricity without creating air pollution, waste products, or CO₂ emissions. Electricity from hydroelectric power plants is usually less expensive for the consumer than electricity generated using nuclear fuels or natural gas. In the United States, the price of hydroelectricity ranges from 5 cents to 11 cents per kilowatt-hour.

Tidal energy Energy that comes from the movement of water driven by the gravitational pull of the Moon.

Teaching Tip: Concept Check

Ask students: What are three methods of generating hydroelectricity?

Hydroelectricity can be generated by run-of-the-river systems, water impoundment systems, and tidal systems.

In addition, the reservoir behind a hydroelectric dam can provide recreational and economic opportunities as well as downstream flood control for flood-prone areas. For example, Lake Powell, the reservoir impounded by the hydroelectric Glen Canyon Dam, draws more than 3 million visitors to the Glen Canyon National Recreation Area each year and generates more than \$400 million annually for the local and regional economies in Arizona and Utah (FIGURE 38.6). In China, the Three Gorges Dam provides flood control and protection to many millions of people.

Water impoundment, however, does have negative environmental consequences. In order to form an impoundment, a free-flowing river must be held back. The resulting reservoir may flood hundreds or thousands of hectares of prime agricultural land or canyons with great aesthetic or archeological value. It may also force people to relocate. As we saw in Chapter 9, the construction of the Three Gorges Dam displaced more than 1.3 million people and submerged ancient cultural and archaeological sites as well as large areas of farmland. Impounding a river in this way may also make it unsuitable for organisms or recreational activities that depend on a free-flowing river. Large reservoirs of standing water hold more heat and contain less oxygen than do free-flowing rivers, thereby affecting which species can survive in the waters. Certain human parasites also become more abundant in impounded waters in tropical regions.

By regulating water flow and flooding, dams also alter the dynamics of the river ecosystem downstream. Some rivers, for example, have sandbars created during periods of low flow that follow periods

of flooding. Some plant species, such as cottonwood trees, cannot reproduce in the absence of these sandbars. The life cycles of certain aquatic species, such as salmon, certain trout species, and freshwater clams and mussels, also depend on seasonal variations in water flow. Impoundment systems disrupt these life cycles by controlling the flow of water so it is consistently plentiful for hydroelectricity generation.

It is possible to address some of these problems. For example, as we saw in Chapter 9, the installation of a fish ladder (see Figure 27.3 on page 315) may allow fish to travel upstream around a dam. Such solutions are not always optimal, however; some fish species fail to utilize them and some predators learn to monitor the fish ladders for their prey.

Other environmental consequences of water impoundment systems include the release of greenhouse gases to the atmosphere, both during dam construction and after filling the reservoir. Production of cement—a major component of dams—is responsible for approximately 5 percent of global anthropogenic CO₂ emissions to the atmosphere. Once the dam is completed, the impounded water usually covers forests or grasslands. The dead plants and organic materials in the flooded soils decompose anaerobically and release methane, a potent greenhouse gas. Some researchers assert that in tropical regions, the methane released from a hydroelectric water impoundment contributes more to climate warming than a coal-fired power plant with about the same electricity generation output.

The accumulation of sediments in reservoirs has negative consequences not only for the environment but also for the electricity-generating capacity of hydroelectric dams. A fast-moving river carries sediments



FIGURE 38.6 A recreation area created by water impoundment. Lake Powell at the Glen Canyon National Recreation Area was created by water impoundment at the hydroelectric Glen Canyon Dam in northern Arizona. (Sal Maimone/Sal Maimone/Superstock)

AP® FRQ Practice

Dams and keystone species are covered in the 2017 AP® Environmental Science Exam, Question 4. To answer this question, students must

- explain how a dam generates hydroelectric energy.
- identify additional economic benefits of dams.
- describe a negative environmental consequence of removing a dam from a river.
- define keystone species.
- describe how beavers are keystone species in some ecosystems because of the dams they build.

ACTIVITY

Find a Dam

(20 minutes)

Divide your class into six groups and assign each group a question from the list below. Each group will then have to find the name and a picture of their dam. Once groups have finished, ask them to share their findings with the class.

1. What is the tallest dam in the United States? *Oroville Dam (CA): 235 m (770 ft.)*
2. What is the tallest dam in the world? *Jinping-I Dam (China): 305 m (1,001 ft.)*
3. What dam has the highest generating capacity in the United States? *Grand Coulee Dam (WA): 6809 MW*
4. What is the dam with the highest generating capacity in the world? *Three Gorges Dam (China): 22,500 MW*
5. Is there a dam in your home state? *Answers will vary*
6. Name ONE dam in another country. *Answers will vary*

ACTIVITY

Should We Build a Dam?

Environmental Solutions (SP7)

(20 minutes)

Have your class help you list the pros and cons of dams on the board (see Table 40.1 on pages 482–483). Then divide students into groups of three or four and pose the hypothetical question: Suppose you live in a small town that is beside a beautiful river. Your town is in need of an additional source of electricity and the town council is considering building a dam. Should your town build the dam?

Have groups discuss whether or not they would want to build the dam and encourage them to refer to the pro and con list. When groups have decided, take a class poll, and see how many groups voted in favor of the dam, and how many voted against the dam. Be certain to remind the students that there are other possibilities: They can conserve, increase efficiency, and perhaps shift electrical demand to different times of the day and night and eliminate the need for the additional source of electricity.

TRM ACTIVITY

Dam Removal Investigation

(20 minutes)

The website noted in **Chapter 13 Web Resources** shows a map of the U.S. dams removed since 1916. Have students work in pairs to find the dam removal project closest to your school. Have them click on the icon to find out more information about the project, such as the name of the dam, when it was removed, dam height, length, and the name of the river or basin. You can also suggest that students do an image search on the internet for the dam so they can see pictures of it.

Teaching the AP[®] Tip

To help students understand the processes by which alternative forms of energy are converted to useable forms of energy, ask them the following questions:

- How can water be used as a renewable energy resource? *Moving water, either falling over a vertical distance or flowing with a river or tide, contains kinetic energy. A hydroelectric power plant captures this kinetic energy and uses it to turn a turbine, just as the kinetic energy of steam turns a turbine in a coal-fired power plant. It harnesses the flowing water by forcing it past turbine blades where it is converted into electrical energy. Moving water is of limited value to people, but electrical energy can be widely used.*
- What renewable energy source is similar to water in the way that it generates electricity? *Wind is similar to water, in that both are natural currents are used to move a turbine.*



(a)



(b)

FIGURE 38.7 Dam removal and environmental restoration. In recent years, a number of dams have been dismantled due to environmental concerns or heavy siltation. (a) This photo shows Oregon's Marmot Dam, on the Sandy River, before removal. (b) The same stretch of the Sandy River after dam removal in 2007 shows how the natural landscape has been restored.

(a and b: Portland General Electric)

that settle out when the river feeds into the reservoir. The accumulation of these sediments on the bottom of the reservoir is known as **siltation**. Over time, as the reservoir fills up with sediments, the amount of water that can be impounded, and thus the generating capacity and life span of the dam, is reduced. This process may take hundreds of years or only decades, depending on the geology of the area. The only way to reverse the siltation process is by dredging, removal of the sediment, usually with machinery that runs on fossil fuels.

Because of either environmental concerns or heavy siltation, a number of hydroelectric dams are being

dismantled, as we saw at the beginning of Chapter 9. In 1999, the Edwards Dam was removed from the Kennebec River in Maine. More than a decade later, native fishes such as bass and alewives have returned to the waters and are flourishing. In 2007, the Marmot Dam on Oregon's Sandy River was removed using explosives. The restored river now hosts migrating salmon and steelhead trout (*Oncorhynchus mykiss*) for the first time since 1912 (**FIGURE 38.7**).

Siltation The accumulation of sediments, primarily silt, on the bottom of a reservoir.

AP[®] Exam Tip

You should be able to explain the processes by which alternative sources of energy are converted to useable forms of energy.

MODULE

38

AP[®] Review

Preparing for the AP[®] Exam

In this module, we have seen that biomass and water are two important renewable energy sources. Biomass is a modern source of carbon, which was formed between a few years ago and hundreds of years ago, as opposed to fossil fuels, which contain carbon formed millions of years ago. Solid biomass includes wood, charcoal, and animal manure, all of which are relatively low-quality sources of energy and release a fair amount of particulates and other pollutants when burned. Liquid fuels include ethanol, an alcohol derived from plant material such as corn, and biodiesel, produced from vegetable oils such

as soybean. Algae is another source of oil for biodiesel. Hydroelectricity is generated from the energy in water. The largest hydroelectric projects come from impounding water behind a large dam and releasing it periodically when electricity is needed. The impounded water behind a dam can promote recreational and economic opportunities but can also have numerous impacts on the environment. Water availability in a region may be somewhat variable. In the next module we will examine two continuous, nondepletable sources of renewable energy: the Sun and wind.

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Teaching Tip: Journal Prompt

(10 minutes)

Ask students to review the definition of siltation and answer the following questions:

- What are the negative consequences of the accumulation of sediment in reservoirs? *As a reservoir fills up with sediment, less water can be impounded. This reduces the generating capacity and the lifespan of a dam. A dam prevents nutrient-rich sediment from overflowing the river and fertilizing the low-lying agricultural areas adjacent to the river.*
- How can siltation be remediated or fixed? Describe some of the environmental disadvantages of these techniques.

Removal is the only way to reverse excess siltation. This is done by dredging silt from behind the dam or using large equipment to dig it out. Both are labor intensive, use fossil fuels, and are expensive.

AP® Practice Questions

Choose the best answer for the following.

- Which is NOT a form of biomass?
 - coal
 - charcoal
 - municipal solid waste
 - ethanol
- A hydroelectric power plant's rate of electricity generation depends on
 - the flow rate of the water.
 - the vertical distance the water falls.
 - the amount of water behind the dam.
 - I only
 - I and II
 - II only
 - II and III
- Which is true of solid biofuels?
 - Charcoal is the primary replacement when wood is scarce.
 - Indoor air pollution from them results in millions of deaths annually.
 - Switchgrass is a newly developed replacement for wood.
 - They are carbon neutral due to the net removal of forests.
- Cellulosic ethanol is produced from
 - corn.
 - beets.
 - sugarcane.
 - switchgrass.
- The most common method of hydroelectric generation is
 - run-of-the-river.
 - tidal.
 - water impoundment.
 - gorge dams.

Answers to Module 38 AP® Practice Questions

- a
- b
- b
- d
- c

MODULE

39

Solar, Wind, Geothermal, and Hydrogen

After biomass and water, the most important forms of renewable energy come from the Sun and wind. These nondepletable sources of renewable energy represent the fastest growing forms of energy development throughout the world.

The energy of the Sun can be captured directly

In addition to driving the natural cycles of water and air movement that we can tap as energy resources, the Sun also provides energy directly. Every day, Earth is

Learning Goals

After reading this module, you should be able to

- list the different forms of solar energy and their application.
- describe how wind energy is harnessed and its contemporary uses.
- discuss the methods of harnessing the internal energy from Earth.
- explain the advantages and disadvantages of energy from hydrogen.

Bell Ringer

Tell students that this module covers four different energy sources: solar, wind, geothermal, and hydrogen. Then ask: Which of these four energy sources do you think accounts for the largest percentage of renewable energy use in the United States? *Wind, at 21 percent of U.S. renewable energy use, accounts for the largest percentage of renewable energy use in the United States.*

TEACHING with FIGURE 39.1

Visual Representations (SP2)

Show students Figure 39.1 and ask the following questions:

- What do the colors on the map indicate? *The colors indicate the amount of solar energy available to a flat photovoltaic solar panel in kilowatt-hours per square meter per day, averaged over a year.*
- What is the kilowatt hours per square meter per day at each of the following locations?

Houston, TX:

5.0 – 5.5 kWh/m²/day

New York City:

4.5 – 5.0 kWh/m²/day

Phoenix, AZ:

6.0 – 6.5 kWh/m²/day

Cleveland, OH:

4.0 – 4.5 kWh/m²/day

- What is the kilowatt hours per square meter per day at your location? (*Answers will vary.*)
- If you were the governor of the state of Arizona, what type of incentive would you recommend to increase the number of photovoltaic arrays used in residential homes? *Answers will vary. For example, the state could offer a tax deduction for those who install a photovoltaic system of 2 kW or more in their homes. The state could also offer a subsidy for those who purchase a photovoltaic system.*

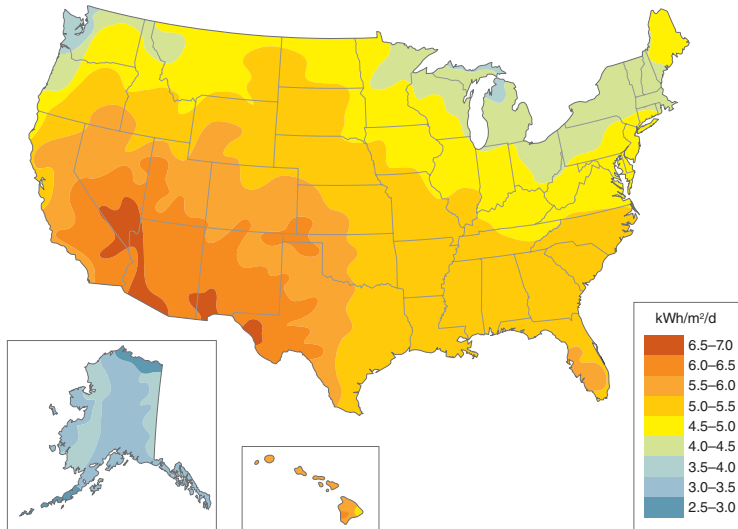


FIGURE 39.1 Geographic variation in solar radiation in the United States. This map shows the amount of solar energy available to a flat photovoltaic solar panel in kilowatt-hours per square meter per day, averaged over a year. (Data from National Renewable Energy Laboratory, U.S. Department of Energy.)

bathed in solar radiation, an almost limitless source of energy. The amount of solar energy available in a particular place varies with amount of cloudiness, time of day, and season. The average amount of solar energy available varies geographically. As **FIGURE 39.1** shows, average daily solar radiation in the continental United States ranges from 3 kWh of energy per square meter in the Pacific Northwest to almost 7 kWh per square meter in parts of the Southwest.

Passive Solar Heating

We have already seen several applications of passive solar heating, including positioning windows on south-facing walls to admit solar radiation in winter, covering buildings with dark roofing material in order to absorb the maximum amount of heat, and building homes into the side of a hill. None of these strategies relies on intermediate pumps or technology to supply heat. Solar ovens are another practical application of passive solar heating. For instance, a simple “box cooker” concentrates sunlight as it strikes a reflector on the top of the

oven. Inside the box, the solar energy is absorbed by a dark base and a cooking pot and is converted into heat energy. The heat is distributed throughout the box by reflective material lining the interior walls and is kept from escaping by a glass top. On sunny days, such box cookers can maintain temperatures of 175°C (350°F), heat several liters of water to boiling in under an hour, or cook traditional dishes of rice, beans, or chicken in 2 to 5 hours.

Solar ovens have both environmental and social benefits. The use of solar ovens in place of firewood reduces deforestation and, in areas unsafe for travel, having a solar oven means not having to leave the relative safety of home to seek firewood. For example, over 10,000 solar ovens have been distributed in refugee camps in the Darfur region of western Sudan in Africa, where leaving the camps to find cooking fuel would put women at risk of attack (**FIGURE 39.2**).

Active Solar Energy Technologies

In contrast to passive solar design, **active solar energy** technologies capture the energy of sunlight with the use of technologies that include small-scale solar water heating systems, photovoltaic solar cells, and large-scale concentrating solar thermal systems for electricity generation.

TRM ACTIVITY 13.5

Solar Soil-Heating Contest

(60 minutes)

In this activity, students design a passive solar heater to warm up a bit of soil. They also compete with their classmates to see which group can heat their petri dish of soil the most.

Activity 13.5: Solar Soil-Heating Contest contains a step-by-step guide for running this activity with your class.

Active solar energy Energy captured from sunlight with advanced technologies.

TRM ACTIVITY 13.6

Solar Energy Concept Map

Visual Representations (SP2)

(10 minutes)

There are many types of solar energy systems and students often need help differentiating among them. Have students fill in the concept map shown to clarify the various ways that we capture and use solar energy.

Activity 13.6: Solar Energy Concept Map contains a reproducible version of the concept map without answers.

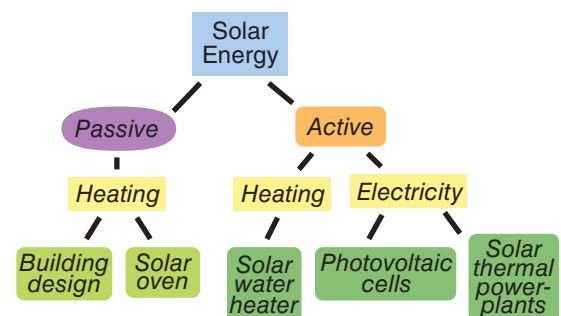




FIGURE 39.2 Solar cookers. This woman in a Mali village in West Africa is preparing food with a solar cooker. (Joerg Boethling/Alamy)

Solar Water Heating Systems

Solar water heating applications range from providing domestic hot water and heating swimming pools to a variety of heating purposes for business and home. In the United States, heating swimming pools is the most common application of solar water heating, and it is also the one that pays for itself the most quickly.

A household solar water heating system, like the domestic hot water system shown in **FIGURE 39.3**, allows heat energy from the Sun to be transferred directly to water or another liquid, which is then circulated to a hot water heating system. The circulation of the liquid is driven either by a pump (in active systems) or by natural convection (in passive systems). In both cases, cold liquid is heated as it moves through a solar collector mounted on the roof or wall of a building or situated on the ground.

The simplest solar water heating systems pump cold water directly to the collector to be heated; the heated water then flows back to an insulated storage tank. In areas that are sunny but experience temperatures below freezing, the water is kept in the storage

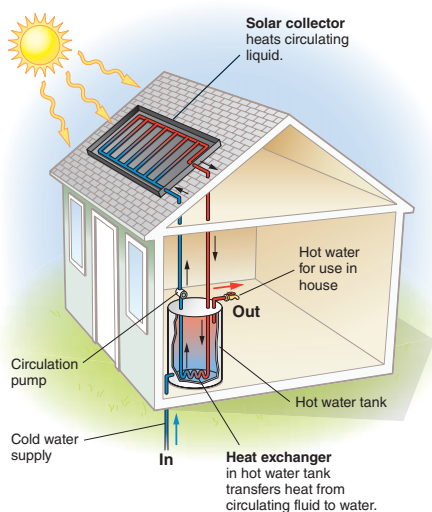


FIGURE 39.3 A solar domestic hot water system. When a solar hot water system is used to heat a house, a non-freezing liquid is circulated by an electric pump through a closed loop of pipes. This circulating liquid moves from a water storage tank to a solar collector on the roof, where it is heated, and then sent back to the tank, where a heat exchanger transfers the heat to water.

tank and a “working” liquid containing nontoxic antifreeze circulates in pipes between the storage tank and the solar collector. The nonfreezing circulating liquid is heated by the Sun in the solar collector, then returned to the storage tank where it flows through a heat exchanger that transfers its heat to the water. The energy needed to run the pump is usually much less than the energy gained from using the system, especially if the pump runs on electricity from the Sun. Solar water heating systems typically include a backup energy source, such as an electric heating element or a connection to a fossil fuel-based central heating system, so that hot water is available even when it is cloudy or very cold.

Photovoltaic Systems

In contrast to solar water heating systems, **photovoltaic solar cells** capture energy from the Sun as light, not heat, and convert it directly into electricity.

Photovoltaic solar cell A system of capturing energy from sunlight and converting it directly into electricity.

Teaching Tip: Discussion Starter

(10 minutes)

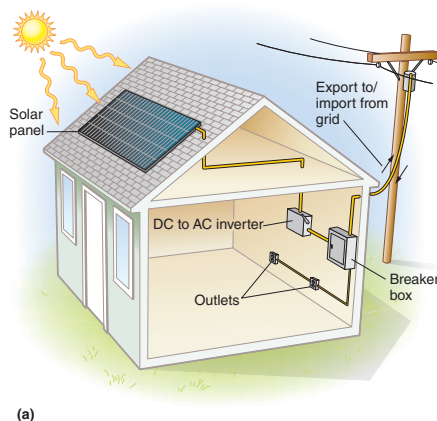
Ask students the following questions to compare and contrast passive solar heating and active solar water heating system:

- What equipment do passive solar heating and active solar water heating systems use? *Passive systems need no extra equipment. Passive systems include positioning windows on south-facing walls to admit solar radiation in winter and covering buildings with dark roofing material in order to absorb the maximum amount of heat. Active systems for heating water in homes typically involve a nonfreezing liquid that moves from a water storage tank to a solar collector on the roof, where it is heated and then returns to the tank, where a heat exchanger transfers the heat to water.*
- What is the primary use of a passive solar heating system? What is the primary use of an active solar heating system? *A passive solar heating system is primarily used to heat homes or as solar cookers. An active solar heating system is used for heating homes and can be used for heating water.*
- What is the relative cost of passive and active solar heating systems? *The cost of a passive system can be relatively low. The house would need to add double- or triple-pane windows, with the windows facing south, and solar cookers require few materials. The cost of an active system is higher because of the piping, heat exchanger, and solar collector.*

AP® FRQ Practice

Photovoltaic systems are covered on the 2006 AP® Environmental Science Exam, Question 1. To answer this question, students must

- describe environmental costs and benefits of photovoltaic systems.
- write an argument in favor of a solar-power system described in an accompanying article, including an analysis of the pros and cons of that system.
- create and describe two possible ways that government or industry could promote photovoltaic systems for homeowners.
- discuss two methods homeowners could use to incorporate passive solar design or systems into the energy plan for their homes and how these methods would reduce their energy costs.



(a)



(b)

FIGURE 39.4 Photovoltaic solar energy. (a) In this domestic photovoltaic system, photovoltaic solar panels convert sunlight into direct current (DC). An inverter converts DC into alternating current (AC), which supplies electricity to the house. Any electricity not used in the house is exported to the electrical grid. (b) Photovoltaic panels on the roof of this house provide nearly all of the electricity this family uses. (altrendo images/Getty Images)

you how to calculate electricity production and dollar savings from a home photovoltaic solar system.

Electricity produced by photovoltaic systems can be used in several ways. Solar panels—arrays of photovoltaic solar cells—on a roof can be used to supply electricity to appliances or lights directly, or they can be used to charge batteries. The vast majority of photovoltaic systems are tied to the electrical grid, meaning that any extra electricity generated and not needed is sent to the electric utility, which buys it or gives the customer credit toward the cost of future electricity use. Homes that are “off the grid” may rely on photovoltaic solar cells as their only source of electricity, using batteries to store the electricity until it is needed. Photovoltaic solar cells have other uses in locations far from the grid where a small amount of electricity is needed on a regular basis. For example, small photovoltaic solar cells charge the batteries that keep highway emergency telephones working. In several U.S. cities, photovoltaic solar cells provide electricity for streetside trash compactors and for new “smart” parking meter systems that have replaced aging coin-operated parking meters.

Concentrating Solar Thermal Electricity Generation

Concentrating solar thermal (CST) systems are a large-scale application of solar energy to electricity generation. CST systems use lenses or mirrors and tracking systems to focus the sunlight falling on a large area into a small beam, in the same way you might use a magnifying glass to focus energy from the Sun and perhaps burn a hole in a piece of paper. In this case, however, the heat of the concentrated beam is used to evaporate water and produce steam that turns a turbine to generate electricity. CST power plants operate much like conventional thermal power plants; the only difference is that the energy to produce the steam comes directly from the Sun, rather than from fossil fuels. The arrays of lenses and mirrors required are large, so CST power plants are best constructed in desert areas where there is consistent sunshine and plenty of open space (FIGURE 39.5).

Although CST systems have existed for 10 years or more, they are now becoming more common. In the United States, several plants are under development in California and in the Southwest. For example, the Ivanpah plant in California contains over 250 MW of capacity on 3,500 acres (1,420 ha). These plants, though, have drawbacks that include the large amount of land required and their inability to generate electricity at night.

AP® Exam Tip

Be sure that you understand the different types of solar energy systems, their respective benefits and costs, and their use and design.

TRM Teaching the AP® Tip

Many students have a hard time differentiating among the types of active solar energy technologies. Ask students to work with a partner to fill in the chart shown below. (Answers are provided in italics.) **Handout 13.9: Differentiating Types of Active Solar Energy Technologies** contains a reproducible version of this chart without answers.

FIGURE 39.4a shows how a photovoltaic system, also referred to as PV, delivers electricity to a house. A photovoltaic solar cell makes use of the fact that certain semiconductors—very thin, ultraclean layers of material—generate a low-voltage electric current when they are exposed to direct sunlight (Figure 39.4b). The low-voltage direct current is usually converted into higher-voltage alternating current for use in homes or businesses. Typically, photovoltaic solar cells are 12 to 20 percent efficient in converting the energy of sunlight into electricity. “Do the Math: Calculating Home PV Generation and Capacity Factor” shows

| | Description | Advantages | Disadvantages |
|----------------------------------|---|--|--|
| Solar water heating systems | <i>Typically involves a nonfreezing liquid circulated by an electric pump through a closed loop of pipes from a water storage tank to a solar collector on the roof, where it is heated and sent back to the tank, where a heat exchanger transfers the heat to water</i> | <ul style="list-style-type: none"> • <i>Relatively inexpensive to install</i> • <i>After initial investment, no cost to harvest energy</i> • <i>Reduces costs for home heating and hot water</i> | <ul style="list-style-type: none"> • <i>Manufacturing materials require high input of metals and water</i> • <i>Geographically limited</i> • <i>High initial cost</i> |
| Photovoltaic cells | <i>Capture energy from the Sun as light, not heat, and convert it directly into electricity</i> | <ul style="list-style-type: none"> • <i>Nondepletable resource</i> • <i>After initial investment, no cost to harvest energy</i> • <i>Can connect to main grid so owner can sell excess energy</i> | <ul style="list-style-type: none"> • <i>Manufacturing materials require high input of metals and water</i> • <i>No plan in place to recycle solar panels</i> • <i>Geographically limited</i> • <i>High initial cost</i> • <i>Storage batteries required for off-grid system</i> |
| Solar thermal power plants (CST) | <i>Large-scale application of solar energy to electricity generation; use lenses or mirrors and tracking systems to focus the sunlight falling on a large area into a small beam</i> | <ul style="list-style-type: none"> • <i>Can produce energy with no fossil fuels</i> • <i>After initial investment, no cost to harvest energy</i> | <ul style="list-style-type: none"> • <i>Requires a large amount of land</i> • <i>Unable to generate electricity at night</i> |

DO THE MATH

Calculating Home PV Generation and Capacity Factor

Preparing for the AP[®] Exam

One of this book's authors, Andy Friedland, has a 4,000 watt photovoltaic solar array along the side of the driveway to his house in Vermont. It consists of 16 250-watt solar panels. In 2017, this array generated 5,300 kWh of electricity. Electricity in Vermont costs \$0.15/kWh. What is the capacity factor of this system and how much did Professor Friedland offset in electricity costs?

If 4,000 watts were generating continuously, it would generate this much electricity in a year:

$$4,000 \text{ watts} \times 1 \text{ kW}/1,000 \text{ watts} = 4 \text{ kW}$$

$4 \text{ kW} \times 24 \text{ hours per day} \times 365 \text{ days per year} = 35,000 \text{ kWh per year}$ (after rounding to two significant figures) if the solar panels were generating 24 hours per day.

In actuality, if the system generated 5,300 kWh of electricity, the capacity factor is:

$$5,300 \text{ kWh/year} \div 35,000 \text{ kWh/year} = 0.15 \times 100\% = 15\% \text{ capacity factor}$$

The capacity factor or percentage of time that the photovoltaic cells were generating electricity at full capacity was 15 percent.

To determine the dollar amount of the offset with this system, multiply the amount generated by the cost of electricity:

$5,300 \text{ kWh} \times \$0.15/\text{kWh} = \$795$. Professor Friedland offset, or avoided paying, \$795 to the electrical utility in 2017.

YOUR TURN A 3 MW wind turbine was installed in an on-land location where the capacity factor was measured to be 22 percent.

1. How much electricity will this wind turbine generate in a year?
2. How much revenue would a utility receive if they were paid \$0.05/kWh for this electricity?



FIGURE 39.5 A concentrating solar thermal power plant. Mirrors and reflectors concentrate the energy of the Sun onto a “power tower,” which uses the sunlight to heat water and make steam for electricity generation. (Lowell Georgia/Science Source)

Benefits and Drawbacks of Active Solar Energy Systems

Active solar energy systems offer many benefits such as generating hot water or electricity without producing CO₂ or polluting the air or water during operation. In addition, photovoltaic solar cells and CST power plants can produce electricity when it is needed most: on hot, sunny days when demand for electricity is high, primarily for air conditioning. By producing electricity during peak demand hours, these systems can help reduce the need to build new fossil fuel–power plants.

In many areas, small-scale solar energy systems are economically feasible. For a new home located miles away from the grid, installing a photovoltaic system may be much less expensive than running electrical transmission lines to the home site. When a house is near the grid, the initial cost of a photovoltaic system may take 5 to 20 years for payback; once the initial cost is paid back, however, the electricity it generates is almost free.

Despite these advantages, a number of drawbacks have inhibited the growth of solar energy use in the United States. Photovoltaic solar panels are expensive

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TRM Teaching Tip: Video

How Do Solar Panels Work?

(10 minutes)

Use this short video from TED-Ed to help students understand how solar panels work.

Chapter 13 Web Resources contains a link to this video. Then ask the questions below.

Handout 13.10: Questions for How Do Solar Panels Work? contains a reproducible version of these questions.

- Why can solar cells last for decades? *The moving electrons return to their position in the crystalline silicon and are therefore reused, rather than depleted.*

- What are some physical and logistical challenges to producing more electricity from solar energy? *Solar energy is unevenly distributed across Earth, its availability in a given place varies from day to day, and most commercial systems are only 15 to 20 percent efficient.*

DO THE MATH

“Do the Math: Calculating Home PV Generation and Capacity Factor” works with the concept of capacity factor to show students how to calculate how much in electricity costs can be offset by using a photovoltaic solar array. “Your Turn” provides a similar problem using a wind turbine.

ANSWER TO YOUR TURN

1. $3 \text{ MW} = 3 \times 10^6 \text{ watts}$
 $3 \times 10^6 \text{ watts} \times 1 \text{ kW}/1,000 \text{ watts} \times 24 \text{ hours/day} \times 365 \text{ days/year} \times 0.22 = 5,800,000 \text{ kWh/year}$ (with rounding)
2. $5,800,000 \text{ kWh} \times \$0.05/\text{kWh} = \$290,000$ (after rounding)

TRM MATH SKILLS Practice 13.2 Capacity Factor

Mathematical Routines (SP6)

The problem below uses information from “Do the Math.” **Math Skills Practice 13.2: Capacity Factor** contains a reproducible version of this problem without the answer.

Suppose Professor Friedland wanted to increase his \$795 offset electricity costs by an additional \$500. How much electricity (in kWh) would his solar panel array have to generate for him to save this much in a year? What is the corresponding capacity factor of this system? Recall that electricity costs \$0.15/kWh and that if the system were working continuously it would generate 35,000 kWh per year.

Increased offsets:

$$\$795 + \$500 = \$1,295$$

Electricity generated:

$$\$1,295 \div \$0.15/\text{kWh} = 8,633.3 \text{ kWh.}$$

Professor Friedland needs to generate 8,634 kWh of electricity to save an additional \$500.

Capacity factor:

$$8,634 \text{ kWh/year} \div 35,000 \text{ kWh/year} = 0.25 \times 100\% = 25\%$$

The capacity factor, or percentage of time that the photovoltaic cells were generating electricity at full capacity, would be 25 percent.

TRM LAB 13.2 Solar Energy

(60 minutes)

Lab 13.2: Solar Energy allows students to experiment with solar cells and to compare energy output with different variables in order to learn how passive solar systems work.

Addresses SP4

Teaching Tip: Concept Check

Ask students: Why are active solar energy systems not feasible everywhere? *The average amount of solar energy available varies geographically. In the continental United States, average daily solar radiation ranges from 3 kWh of energy per square meter in the Pacific Northwest to almost 7 kWh per square meter in parts of the Southwest.*

Teaching Tip: Engage

Ask students: What parts of the United States do you think produce the most wind energy? What parts of the world produce the most electricity from wind? *California and Texas produce the most wind electricity in the United States. China has the largest wind energy generating capacity in the world, followed by the United States, Germany, India, and Spain.*

to manufacture and install. Although the technology is changing rapidly as industrial engineers and scientists seek better, cheaper photovoltaic materials and systems, the initial cost to install a photovoltaic system can be daunting and the payback period is a long one. In parts of the country where the average daily solar radiation is low, the payback period can be even longer. Some countries, such as Germany, have made solar energy a part of their sustainable energy agenda by subsidizing their solar industry. In the United States, recent tax breaks, rebates, and funding packages instituted by various states and the federal government have made solar electricity and water heating more affordable for consumers and businesses.

The use of photovoltaic solar cells has environmental as well as financial costs. Manufacturing photovoltaic solar cells requires a great deal of energy and water and involves a variety of toxic metals and industrial chemicals that can be released into the environment during the manufacturing process, although newer types of these solar cells may reduce reliance on toxic materials. For systems that use batteries for energy storage, there are environmental costs associated with manufacturing, disposing of, or recycling the batteries, as well as energy losses during charging, storage, and recovery of electricity in batteries. The end-of-life reclamation and recycling of photovoltaic solar cells is another potential source of environmental contamination, particularly if the cells are not recycled properly. However, solar energy advocates, and even most critics, agree that the energy expended to manufacture photovoltaic solar cells is usually recovered within a few years of their operation, and that if the life span of photovoltaic solar cells can be increased to between 30 and 50 years, they will be a very promising source of renewable energy.

Wind energy is the most rapidly growing source of electricity

The wind is another important source of nondepletable, renewable energy. **Wind energy** is energy generated from the kinetic energy of moving air. As discussed in Chapter 4, winds are the result of the unequal heating of the surface of Earth by the Sun. Warmer air rises and

Wind energy Energy generated from the kinetic energy of moving air.

Wind turbine A turbine that converts wind energy into electricity.

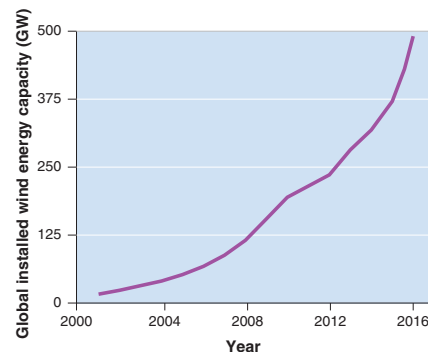


FIGURE 39.6 Global growth of installed wind energy capacity. Worldwide, installed wind energy capacity is now almost 500 gigawatts (GW). (Data from Global Wind Energy Council.)

cooler, denser air sinks, creating circulation patterns similar to those in a pot of boiling water. Ultimately, the Sun is the source of all winds—it is solar radiation and ground surface heating that drive air circulation.

Before the electrical grid reached rural areas of the United States in the 1920s, windmills dotted the landscape. Today, wind energy is the fastest-growing major source of electricity in the world. As **FIGURE 39.6** shows, global installed wind energy capacity has risen from less than 24 gigawatts in 2001 to almost 500 gigawatts today. **FIGURE 39.7** shows installed wind energy generating capacity and the percentage of electricity generated by wind for a number of countries. China has the largest wind energy generating capacity in the world, followed by the United States, Germany, India, and Spain.

Despite its large generating capacity, the United States obtains less than 6 percent of its electricity from wind. The largest amounts are generated in Texas, Oklahoma, Iowa, California, and Kansas, although more than 40 U.S. states produce at least some wind-generated electricity. Denmark, a country of 5.8 million people, generates about 37 percent of its electricity from wind and hopes to increase this figure to 50 percent soon. Although the United States currently obtains only a small percent of its electricity from wind, it is the fastest growing source of electricity in the country.

Generating Electricity from Wind

A **wind turbine** converts the kinetic energy of moving air into electricity in much the same way that a hydroelectric turbine harnesses the kinetic energy of moving water. As you can see in **FIGURE 39.8**, wind

AP® FRQ Practice

The subject of converting from coal-generated electricity to wind-generated electricity is covered in the 2004 AP® Environmental Science Exam, Question 2. To answer this question, students must

- calculate the kWh produced by a coal-burning power plant based on data provided.
- determine the amount of kWh a community needs per year based on usage data provided.
- explain why the amount of kWh generated by the coal-burning plant and the amount used are not the same.

- calculate the cost of the wind power the community would need to meet its current needs over a number of years based on data provided.
- describe two environmental benefits and two environmental costs of switching to wind-generated electricity.

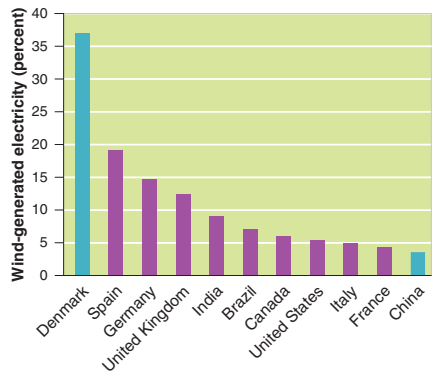
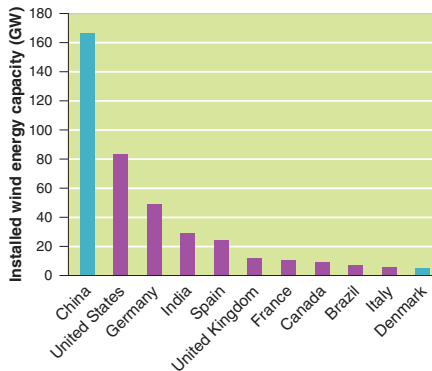


FIGURE 39.7 Installed wind energy capacity by country. (a) China generates more electricity from wind energy than any other country. (b) However, some relatively small countries, such as Denmark, generate a much higher percentage of their electricity from wind. (Data from Global Wind Energy Council.)

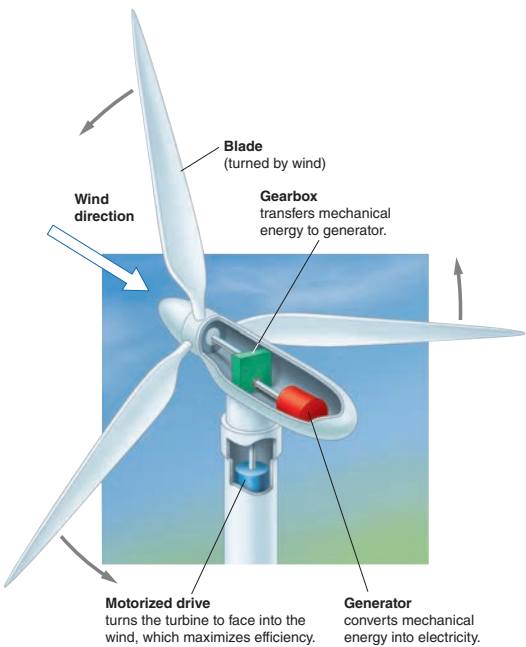


FIGURE 39.8 Generating electricity with a wind turbine. The wind turns the blade, which is connected to the generator, which generates electricity.

turns the blades of the wind turbine and the blades transfer energy to the gear box that in turn transfers energy to the generator that generates electricity. A modern wind turbine, like the one shown, may sit on a tower as tall as 100 m (330 feet) and have blades 40 to 75 m (130–250 feet) long. Under average wind conditions, a wind turbine on land might have a capacity factor of 25 percent. While it is spinning, it might generate between 2,000 and 3,000 kW (2–3 MW), and in a year it might produce more than 4.4 million kilowatt-hours of electricity, enough to supply more than 400 homes. Offshore wind conditions are even more desirable for electricity generation with capacity factors of 35 percent to 50 percent, and turbines can be made even larger in an offshore environment.

Wind turbines on land are typically installed in rural locations, away from buildings and population centers. However, they must also be close to electrical transmission lines with enough capacity to transport the electricity they generate to users. For these reasons, as well as for political and regulatory reasons and to facilitate servicing the equipment, the usual practice is to group wind turbines into wind farms or wind parks.

The number of wind farms is increasing in the United States and around the world. Wind farms are often placed on land in locations where the capacity factor can be as high as 25 percent. However, near-offshore coastal locations are even more desirable because the capacity factor can be up to 50 percent. Offshore wind parks, which are clusters of wind turbines, are often located in the ocean within a few miles of the coastline (FIGURE 39.9 on page 476). Such parks are operating in Denmark, the Netherlands, the United Kingdom, Sweden, and elsewhere.

TEACHING with FIGURE 39.7

Visual Representations (SP2)

Show students Figure 39.7. Ask them to explain why China has a high wind energy capacity (GW) but a low percentage of electricity generation by wind. *China produces about 170 gigawatts of wind power per year, which is the largest amount in the world. However, since China has such a large population it uses a large quantity of electricity. Approximately 4 percent of the energy it uses comes from wind and 96 percent comes from other sources, primarily fossil fuels and hydroelectric.*

Teaching Tip: Engage

Ask students: Have you ever seen a wind farm? Where? How many turbines did you see? *Answers will vary. Although California and Texas produce the most wind power, more than half of U.S. states produce at least some wind-generated electricity.*

TRM Teaching Tip: Video

Wind Power
(10 minutes)

This brief video from Nova, PBS describes how wind turbines work and discusses their advantages and disadvantages. **Chapter 13 Web Resources** contains a link to this video. Have students make a chart of pros and cons that they can complete as they watch the video. (Suggested answers are provided in italics.) **Handout 13.11: Wind Energy Pros and Cons** contains a reproducible version of this chart without the answers.

| Wind energy pros | Wind energy cons |
|--|--|
| <i>Wind is a renewable resource.</i> | <i>Wind is intermittent, and storing electricity is expensive.</i> |
| <i>Wind energy produces no greenhouse gas emissions.</i> | <i>Wind energy is highest in rural areas that are far from city centers.</i> |
| <i>Wind farms are inexpensive to operate.</i> | <i>Wind farms are expensive to build.</i> |

TRM Teaching Tip: Beyond the Classroom

Environmental Solutions (SP7)

(60 minutes)

Ask students to research a proposed wind-farm project and write a two-page report. The following questions can guide their research. **Handout 13.12: Wind Project Research Report** contains a reproducible version of these questions.

- Where is the proposed wind farm going to be built? Is it on land or offshore?
- What will be the capacity of this wind farm in MW when the project is complete?
- How many turbines will the farm include and what will they cost?
- Are any local groups against the construction of the wind farm? Describe their objections.

TRM Teaching Tip: Review

(10 minutes)

Ask students the following questions to review wind energy. **Handout 13.13: Wind Energy Review** contains a reproducible version of these questions.

- Where are wind farms typically located and why? *Wind farms on land are typically installed in rural locations, away from buildings and population centers. However, they must also be close to electrical transmission lines that have enough capacity to transport the electricity the wind farms generate to users.*
- How is wind used to generate electricity? *A wind turbine converts the kinetic energy of moving air into electricity. A modern wind turbine sits on a tower as tall as 100 m, where the blades are positioned. While the blades are spinning, a gearbox transfers mechanical energy to the generator, which then produces electricity.*
- What are the similarities and differences between near-offshore and land-based wind farms? *Offshore wind conditions are more desirable for the generation of electricity, and larger turbines can be used in an offshore environment. Land-based wind turbines are often installed in rural locations, away from buildings and population centers. Both need to be near electrical transmission lines to move the electricity from where it is produced to where it is used by the consumer.*



FIGURE 39.9 Offshore wind parks. Capacity factors at near-offshore locations like this one in Denmark are generally higher than on land. (Max Muelie/Alamy)

The United States lags behind many other countries in the development of near-offshore wind. A proposed project located off Cape Cod, Massachusetts, in Nantucket Sound languished for almost 2 decades and was never built. Called Cape Wind, it was to become the first offshore wind farm in the United States and would have featured 130 wind turbines with the potential to produce up to 420 MW of electricity, or up to 75 percent of the electricity used by Cape Cod and the nearby islands. In late 2016, its developer declared the project officially canceled. It failed for a variety of reasons. There was a lack of clarity about which U.S. agencies regulate off-shore wind development. In addition, the project was close to sensitive and scenic waterways near Cape Cod. Finally, some local landowners and legislators did not want to see a wind farm close to Nantucket Sound.

In 2016, the Block Island Wind Farm project went online in the near-offshore environment of Rhode Island. Officially the first near-offshore wind project to be completed in the United States, it contains five turbines, each 6 MW, for a total capacity

of 30 MW. Although near off-shore wind capacity factors are often around 35 percent, the developers of this project believe that the capacity factor may be higher, which means that the project may provide electricity to around 4,000 homes. There are other near off-shore wind projects under construction or approved in New Jersey, Oregon, New York, Massachusetts, and Virginia.

A Nondepletable Resource

Wind energy offers many advantages over other energy resources. Like sunlight, wind is a nondepletable, clean, and free energy resource; the amount available tomorrow does not depend on how much we use today. Furthermore, once a wind turbine has been manufactured and installed, the only significant energy input comes from the wind. The only substantial fossil fuel input required, once the turbines are installed, is the fuel workers need to travel to the wind farm to maintain the equipment. Thus, wind-generated electricity produces no pollution and no greenhouse gases. Finally, unlike hydroelectric, CST, and conventional thermal power plants, wind farms can share the land with other uses. For example, wind turbines on land may share the area with grazing cattle.

Wind-generated electricity does have some disadvantages, however. Currently, most off-grid residential wind energy systems rely on batteries to store electricity. As we have discussed, batteries are expensive to produce and hard to dispose of or recycle. In addition, birds and bats are killed by collisions with wind turbine blades. According to the National Academy of Sciences, as many as 40,000 birds may be killed by wind turbine blades in the United States each year—approximately four deaths per turbine. Bat deaths are not as well quantified. New turbine designs and location of wind farms away from migration paths have reduced these deaths to some extent, along with mitigating some of the noise and aesthetic disadvantages. There are a small but vocal minority of people in certain regions of the country who find a wind farm visually objectionable. Some people also find the sound of a wind turbine bothersome or intrusive, especially when it can be heard in their homes. Some people feel that the background noise of a wind turbine causes anxiety or irritability. For these and other reasons, there has been resistance to wind farms in some regions of the United States. For example, the Cape Wind project that we described earlier experienced numerous hearings, protests, and court decisions that slowed development and eventually led to its failure. In Vermont, a state often considered to be very environmentally friendly, more and more towns and individuals have argued against the installation of commercial wind projects on or

AP® FRQ Practice

Offshore wind turbines are covered on the 2018 AP® Environmental Science Exam, Question 2. To answer this question, students must

- Describe an environmental benefit of offshore wind projects.
- Describe an economic benefit of offshore wind projects.
- Describe an additional way that oceans can provide renewable power for electricity generation.
- Use provided data to calculate the following:
 - how much electricity a project needs to generate in a year to provide a percentage of the electoral demand in a service area

- the revenue produced in generating the electricity
- the hours needed for the wind turbines to operate to produce the electricity needed

near ridgelines, citing habitat fragmentation and alteration, noise, and aesthetics, among other reasons. Other states have slowed wind development by resisting the construction of above-ground electrical transmission lines, which also fragment habitat but are needed to move renewable electricity through forested areas to large numbers of users, who are usually in or close to metropolitan areas.

Earth's internal heat is a source of nondepletable energy

Unlike most forms of renewable energy, *geothermal energy* does not come from the Sun. **Geothermal energy** is heat that comes from the natural radioactive decay of elements deep within Earth. As we saw in Chapter 8, convection currents in Earth's mantle bring hot magma toward the surface of Earth. Wherever magma comes close enough to groundwater, that groundwater is heated. The pressure of the hot groundwater sometimes drives it to the surface, where it visibly manifests itself as geysers and hot springs, like those in Yellowstone National Park. Where hot groundwater does not naturally rise to the surface, humans may be able to reach it by drilling.

Many countries obtain clean, renewable energy from geothermal resources. The United States, China, and Iceland, all of which have substantial geothermal resources, are the largest geothermal energy producers.

Harvesting Geothermal Energy

Geothermal energy can be used directly as a source of heat. Hot groundwater can be piped directly into household radiators to heat a home. In other cases, heat exchangers can collect heat by circulating cool liquid underground, where heat from the ground flows to the cool circulating liquid, and then returns to the surface. Iceland, a small nation with vast geothermal resources, heats 85 percent of its homes this way.

Geothermal energy can also be used to generate electricity. The electricity-generating process is much the same as that in a conventional thermal power plant although, in this case, the steam to run the turbine comes from water evaporated by Earth's internal heat instead of by burning fossil fuels.

The heat released by decaying radioactive elements deep within Earth is essentially nondepletable in the span of human time. However, the groundwater that so often carries that heat to Earth's surface can be depleted. As we learned in Chapter 9, groundwater, if used sustainably, is a renewable resource. Unfortunately, long periods of harvesting groundwater from a site may deplete it to the point at which the site is no longer

a viable source of geothermal energy. Returning the water to the ground to be reheated is one way to use geothermal energy sustainably.

Iceland currently produces about 25 percent of its electricity using geothermal energy. In the United States, geothermal energy accounts for less than 1 percent of the renewable energy used. Geothermal power plants are currently in operation in many states including California, Nevada, New Mexico, Oregon, Hawaii, and Utah. Geothermal energy has less growth potential than wind or solar energy because it is not easily accessible everywhere. Hazardous gases and steam may also escape from geothermal power plants, another drawback of geothermal energy.

Ground Source Heat Pumps

Another approach to tapping Earth's thermal resources is the use of **ground source heat pumps**, a technology that transfers heat from the ground to a building. Ground source heat pumps take advantage of the high thermal mass of the ground. Earth's temperature about 3 m (10 feet) underground remains fairly constant year-round, at 10°C to 15°C (50°F–60°F), because the ground retains the Sun's heat more effectively than does the ambient air. We can take advantage of this fact to heat and cool residential and commercial buildings. Although the heat tapped by ground source heat pumps is often referred to informally as “geothermal,” it comes not from geothermal energy but from solar energy.

FIGURE 39.10 on page 478 shows how a ground source heat pump transfers heat from the ground to a house. In contrast to the geothermal systems just described, ground source heat pumps do not remove steam or hot water from the ground. In much the same way that a solar water heating system works, a ground source heat pump cycles fluid through pipes buried underground. In winter, this fluid absorbs heat from underground. The slightly warmed fluid is compressed in the heat pump to increase its temperature even more, and the heat is distributed throughout the house. The fluid is then allowed to expand, which causes it to cool and run through the cycle again, picking up more heat from the ground. In summer, when the underground temperature is lower than the ambient air temperature, the fluid is cooled underground and then pulls heat from the house as it circulates, resulting in a cooler house as heat is transferred underground.

Ground source heat pumps can be installed anywhere in the world, regardless of whether there is geothermal

Geothermal energy Heat energy that comes from the natural radioactive decay of elements deep within Earth.
Ground source heat pump A technology that transfers heat from the ground to a building.

AP® FRQ Practice

Geothermal energy as well as other renewable and nonrenewable sources of energy are covered on the 2011 AP® Environmental Science Exam, Question 3. To answer this question, students must

- explain how energy is generated from a geothermal source.
- describe the difference between per capita emissions of CO₂ and total emissions of CO₂.
- name at least one problem in addition to CO₂ emissions that China faces with the energy sources it uses.
- explain the advantages and disadvantages of using either sugarcane or tar sands as an energy source, and consider the sustainability of that source.

Teaching Tip: Concept Check

Ask students: Why does geothermal energy have less growth potential than other energy sources? *Geothermal energy has less growth potential than wind or solar energy because it is not easily accessible everywhere. Geothermal energy can only be harnessed where magma comes close to groundwater and heats it.*

TRM Teaching Tip: Video

Energy 101: Geothermal Energy

(10 minutes)

This animated video produced by the Department of Energy describes how geothermal energy works. It reviews three different types of geothermal energy and shows students how each is different.

Chapter 13 Web Resources contains a link to this video. After watching the video, ask your class the following questions. **Handout 13.14: Questions for Energy 101: Geothermal Energy** contains a reproducible version of these questions.

- What is a “dry steam geothermal power plant”? *The underground steam flows directly to a turbine and turns it. This drives the generator and produces electricity. It's the most common type of geothermal technology.*
- What are other types of geothermal technology? *A flash steam power plant and a binary cycle plant.*
- What are the environmental benefits of geothermal technology? *It is nondepletable, it has low greenhouse gas emissions and a small physical footprint, and it can help recycle wastewater.*

TRM Teaching Tip: Video

Energy 101: Geothermal Heat Pumps (10 minutes)

This animated video produced by the Department of Energy describes how ground source heat pumps or geothermal heat pumps work. It reviews how homeowners can reduce their heating and cooling bills by installing such a system. **Chapter 13 Web Resources** contains a link to this video. After watching the video, ask your class the following questions. **Handout 13.15: Questions for Energy 101: Geothermal Heat Pumps** contains a reproducible version of these questions.

- What is the temperature 10 feet below Earth's surface? How much does it vary? *The temperature is 54°F, and is nearly constant.*
- How does the heat pump work in the summer? *The system works in reverse. Below-surface temperatures are cooler than the summer air, so the fluid in the heat exchanger absorbs the heat in the building and circulates it underground. The ground cools the warm fluid and recirculates it back to the building.*
- What can you do if you don't have the space to spread out heat pumps horizontally? *A vertical loop system can be built by going straight into the ground.*

Teaching Tip: Engage

Ask students: Would you want a geothermal heat pump in your house? Why or why not? *Answers will vary.*

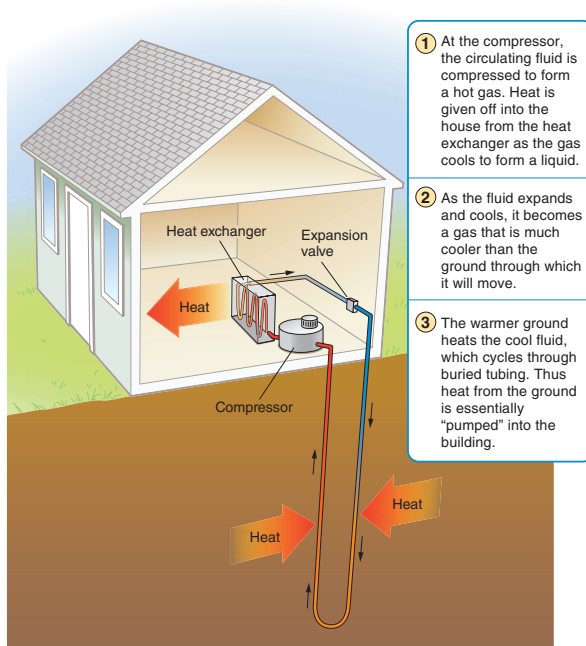


FIGURE 39.10 Heating and cooling with a ground source heat pump. By exchanging heat with the ground, a ground source heat pump can heat and cool a building using 30 to 70 percent less energy than traditional furnaces and air conditioners.

energy accessible in the vicinity. The operation of the pump requires some energy, but in most cases the system uses 30 to 70 percent less energy to heat and cool a building than a standard furnace or air conditioner.

Hot Water Heat Pumps

The hot water heat pump, a variation of the ground source heat pump, extracts heat from the air in a garage or basement and transfers it to water in a domestic hot water tank. This water is then used for household activities such as washing dishes and taking showers. Hot water heat pump systems are similar to those found in air conditioners and refrigerators as well as the ground source heat pump we just described. A refrigerator extracts heat from the inside of an insulated box—the refrigerator—thereby lowering the temperature of the food and air inside, while discharging heat to the outside—the kitchen. A hot water heat pump works in reverse: It extracts heat from the surrounding air in the basement or garage and pumps it into a tank filled with water destined for the kitchen sink or bathroom shower. We have said that a resistance coil water heater is 99 percent efficient, meaning that 99 percent of the energy in the electricity is transferred to the water. In a

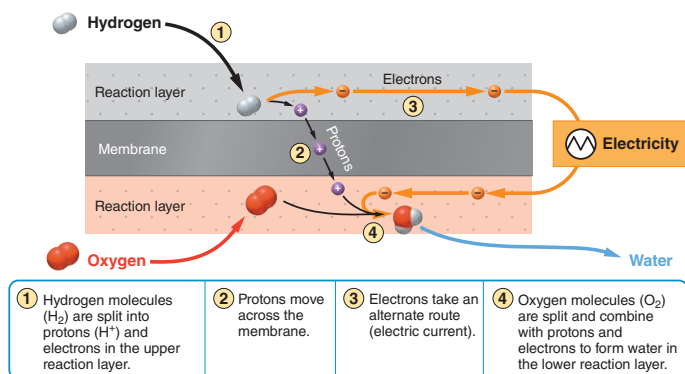
hot water heat pump, between 200 and 250 percent of the amount of energy in the electricity used to run the hot water heat pump is transferred to the water in the tank. You might be wondering if this violates the first law of thermodynamics. How can we obtain more energy from the system than the amount of energy put into the system? Remember our efficiency equation introduced in Chapter 2: Energy efficiency is the ratio of the amount of energy obtained in the desired form to the total amount of energy introduced into the system. The heat pump technology utilizes the energy in the electricity and also extracts heat energy from the surrounding air. The amount of electrical energy required to run the heat pump plus the energy extracted from the air in the room, is greater than the electrical energy used to run the heat pump. So this yields a number greater than 100 percent of the electricity used to run the pump. In the case of a home hot water heat pump, the overall energy gain in the hot water tank can be as much as 200 to 250 percent of the electrical energy put into the system. For this reason, hot water heat pumps are becoming more and more popular in homes and rental properties in the United States and can be found in all plumbing supply and big box home improvement stores.

ACTIVITY

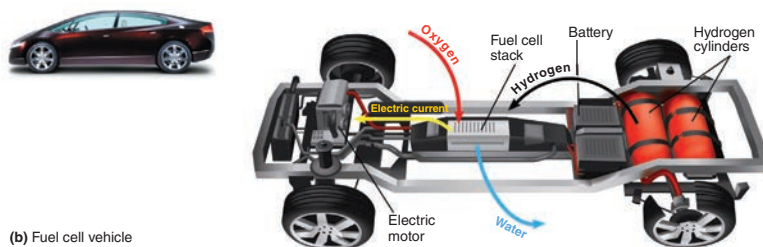
Make a Test Question

(20 minutes)

Divide your class into groups of two or three. Then ask each group to write a free-response question for the upcoming test on Chapter 13. Encourage them to follow the style of the AP[®] Environmental Science Exam, where one question has multiple parts. Then instruct each group to write the answer to their own question. You may also want to tell students that you will use the best question on the test, and the students who wrote it will get one extra credit point. But only questions with correct answers are eligible.



(a) One common fuel cell design



(b) Fuel cell vehicle

FIGURE 39.11 Power from a hydrogen fuel cell. (a) Hydrogen gas enters the cell from an external source. Protons from the hydrogen molecules pass through a membrane, while electrons flow around it, producing an electric current. Water is the only waste product of the reaction. (b) In a fuel cell vehicle, hydrogen is the fuel that reacts with oxygen to provide electricity to run the motor.

Hydrogen fuel cells have many potential applications

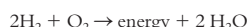
We end our coverage of sustainable energy types with one additional energy technology that has received a great deal of attention for many years: hydrogen fuel cells.

The Basic Process in a Fuel Cell

A **fuel cell** is an electrical-chemical device that converts fuel, such as hydrogen, into an electrical current. A fuel cell operates much like a common battery, but with one key difference. In a battery, electricity is generated by a reaction between two chemical reactants, such as nickel and cadmium. This reaction happens in a closed container to which no additional materials can be added; eventually the reactants are used up and the

battery goes dead. In a fuel cell, however, the reactants are added continuously to the cell, so the cell produces electricity for as long as it continues to receive fuel.

FIGURE 39.11 shows how hydrogen functions as one of the reactants in a hydrogen fuel cell. Electricity is generated by the reaction of hydrogen with oxygen, which forms water:



Although there are many types of hydrogen fuel cells, the basic process forces protons from hydrogen gas through a membrane, while the electrons take a different pathway. The movement of protons in one direction and electrons in another direction generates an electric current.

Fuel cell An electrical-chemical device that converts fuel, such as hydrogen, into an electrical current.

TRM Teaching Tip: Beyond the Classroom

(10 minutes)

Ask students to investigate hydrogen fuel cell vehicles that are on the market.

Chapter 13 Web Resources provides a link that outlines the few vehicles available in the United States. Ask students which car they might want to get and why. *Answers will vary. Models include a Honda, Hyundai, and Toyota, with varying fuel economies, sizes, and costs.*

Teaching Tip: Concept Check

Ask students: Before hydrogen fuel cells can become a viable source of energy for transportation, three problems must be investigated. What are they?

- How can we obtain hydrogen without expending more fossil fuel energy than we would save by using it?
- How can hydrogen suppliers safely deliver hydrogen to consumers?
- How can hydrogen be stored?

TEACHING with FIGURE 39.11

Visual Representations (SP2)

Show students Figure 39.11a and ask the following questions:

- What creates the electrical current? *Electricity is created by a flow of electrons that occurs when hydrogen molecules are split.*
- How does water form? *Water forms when oxygen molecules split and combine with the protons and electrons from hydrogen.*
- What are the inputs and outputs of the fuel cell process? *Hydrogen fuel and oxygen are the two inputs, and water is the only waste product after electricity is produced.*

ACTIVITY

Fuel Cell Song

(25 minutes)

After teaching students about fuel cells, divide your class into groups and ask them to write a jingle or a rap to describe the process. Explain that their composition should explain the four steps of the basic process in a fuel cell, as shown in Figure 39.11a, as well as the following terms: hydrogen, oxygen, water, protons, electrons, membrane, and electricity. When complete, ask groups to perform their composition for the class.

Teaching the AP[®] Tip

Environmental Solutions (SP7)

To help your class understand the hurdles of using alternative technologies for transportation, ask students: *Why is it so difficult to use renewable energy to power a car? The challenge in using alternative energy for transportation is that the energy must be converted first to electricity and then used in an electric vehicle. It would be very difficult to store and utilize energy from the sun, water, or wind if the energy were not first converted to electricity.*

Teaching Tip: Review

As class is ending, ask students to take out a sheet of paper and write down the following:

- Three things that interested them about today's class
- Two things about today's class that they would like to know more about
- One question that they still have about today's class

Collect the papers and review them after class to better understand students' grasp of the material.

Using a hydrogen fuel cell to generate electricity requires a supply of hydrogen. Supplying hydrogen is a challenge, however, because free hydrogen gas is relatively rare in nature and because the gas is explosive. Hydrogen tends to bond with other molecules, forming compounds such as water (H₂O) or natural gas (CH₄). Producing hydrogen gas requires separating it from these compounds using either heat or electricity. Currently, most commercially available hydrogen is produced by an energy-intensive process of burning natural gas in order to extract its hydrogen; carbon dioxide is a waste product of this combustion. In an alternative process, known as **electrolysis**, an electric current is applied to water to "split" it into hydrogen and oxygen. Energy scientists are looking for other ways to obtain hydrogen; for example, under certain conditions, some photosynthetic algae and bacteria, using sunlight as their energy source, can give off hydrogen gas.

Although it may seem counterintuitive to use electricity to create electricity, the advantage of hydrogen is that it can act as an energy carrier. Renewable energy sources such as wind and the Sun cannot produce electricity constantly, but the electricity they produce can be used to generate hydrogen, which can be stored until it is needed. Thus, if we could generate electricity for electrolysis using a clean, nondepletable energy resource such as wind or solar energy, hydrogen could potentially be a sustainable energy carrier.

AP[®] Exam Tip

Be prepared to describe hurdles to the use of alternative technologies for transportation.

The Viability of Hydrogen

Some policy makers consider hydrogen fuel cells to be the future of energy and the solution to many of the world's energy problems. Hydrogen fuel cells are 80 percent efficient in converting the potential energy of hydrogen and oxygen into electricity, with water as their only by-product. In contrast, thermal fossil fuel power

Electrolysis The application of an electric current to water molecules to split them into hydrogen and oxygen.

plants are only 35 to 50 percent efficient, and they produce a wide range of pollutants as by-products. However, there are many who believe that hydrogen fuel cells will not provide a solution to our energy problems.

Despite the many advantages of hydrogen as a fuel, it also has a number of disadvantages. First, scientists must learn how to obtain hydrogen without expending more fossil fuel energy than its use would save. This means that the energy for the hydrogen generation process must come from a renewable resource such as wind or solar energy rather than fossil fuels. Second, suppliers will need a distribution network to safely deliver hydrogen to consumers—something similar to our current system of gasoline delivery trucks and gasoline stations. Hydrogen can be stored as a liquid or as a gas, although each storage medium has its limitations. In a fuel cell vehicle, hydrogen would probably be stored in the form of a gas in a large tank under very high pressure. Vehicles would have to be redesigned with fuel tanks much larger than current gasoline tanks to achieve an equivalent travel distance per tank. There is also the risk of a tank rupture, in which case the hydrogen might catch fire or explode.

Given these obstacles, why is hydrogen even considered a viable energy alternative? Ultimately, hydrogen-fueled vehicles could be a sustainable means of transportation because a hydrogen-fueled car would use an electric motor. Electric motors are more efficient than internal combustion engines: While an internal combustion engine converts about 20 percent of the fuel's energy into the motion of the drive train, an electric motor can convert 60 percent of its energy into motion. So if we generated electricity from hydrogen at 80 percent efficiency, and used an electric motor to convert that electricity into vehicular motion at 60 percent efficiency, we would have a vehicle that is much more efficient than one with an internal combustion engine. Thus, even if we obtained hydrogen by burning natural gas, the total amount of energy used to move an electric vehicle using hydrogen might still be substantially less than the total amount needed to move a car fueled by gasoline. Using solar or wind energy to produce the hydrogen would lower the environmental cost even more, and the energy supply would be renewable. In those circumstances, an automobile could be fueled by a truly renewable source of energy that is both carbon neutral and pollution free.

MODULE

39

AP[®] Review

Preparing for the AP[®] Exam

In this module, we have seen that the Sun and wind provide viable sources of renewable energy in many locations. Solar energy can be used both passively, such as locating a building in a particular direction, as well as

actively, such as using photovoltaic cells. Wind energy is harnessed through the use of a wind turbine, which converts the energy of moving air into electricity. Wind is the fastest growing form of new electricity generation

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TRM Teaching Tip: Journal Prompt

(10 minutes)

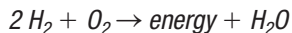
Ask students the following questions.

Handout 13.16: Journal Prompt on Hydrogen Fuel Cells contains a reproducible version of these questions.

- How do we obtain hydrogen for use in fuel cells? *Supplying hydrogen is a challenge because free hydrogen gas is relatively rare in nature and because it is explosive. Hydrogen tends to bond with other molecules, forming compounds such as water (H₂O) or natural gas (CH₄). Producing hydrogen gas requires separating*

it from these compounds with heat or electricity. Currently, most commercially available hydrogen is produced by an energy-intensive process of burning natural gas in order to extract its hydrogen. Another process known as electrolysis uses electrical current to split water and separate hydrogen from oxygen.

- How does a fuel cell work? *Electricity is generated by the reaction of hydrogen with oxygen, which forms water:*



The basic process forces protons from hydrogen gas through a membrane, while the electrons take a different pathway. The

movement of protons in one direction and electrons in another direction generates an electric current.

- Why is hydrogen useful as an alternative to fossil fuels? *The advantage of hydrogen is that it can act as an energy carrier. Renewable energy sources such as wind and the Sun cannot produce electricity constantly, but the electricity they produce can be used to generate hydrogen, which can be stored until it is needed. Thus if we could generate electricity for electrolysis using a clean nondepletable energy resource such as wind or solar energy, hydrogen could potentially be a sustainable energy carrier.*

in the world. Harnessing geothermal energy also is a good source of energy in certain locations. Hydrogen has great potential that has not yet been realized. We

can use all of these energy forms in appropriate locations under the proper circumstances, which is the focus of the next module.

AP[®] Practice Questions

Choose the best answer for the following.

- Which is an application of passive solar technology?
 - concentrating solar thermal
 - photovoltaic cells
 - solar water heating
 - solar ovens
- On average, what percentage of time does a land-based wind turbine generate electricity?
 - 60 percent
 - 45 percent
 - 30 percent
 - 25 percent
- Which is NOT true about geothermal energy?
 - It is only available in limited areas.
 - It cannot be used for cooling.
 - It can be locally depleted due to heavy use.
 - Ground source heat pumps require an additional source of energy.
- A hydrogen fuel cell is most similar to
 - an engine.
 - a photovoltaic cell.
 - a source of coal.
 - a battery.
- Which is NOT a benefit of solar energy systems?
 - They typically produce electricity during peak demand.
 - They require very little maintenance.
 - They produce electricity continuously.
 - They do not produce pollution while generating electricity.

Answers to Module 39 AP[®] Practice Questions

- d
- d
- b
- d
- c

MODULE

40

Planning Our Energy Future

Although renewable energy is a more sustainable energy choice than nonrenewable energy, using any form of energy has an impact on the environment. Biomass, for instance, is a renewable resource only if it is used sustainably. Overharvesting wood leads to deforestation and degradation of the land, as we saw in the description of Haiti in Chapter 3. Wind turbines can kill birds and bats, and hydroelectric turbines kill millions of fish. Manufacturing photovoltaic solar panels requires heavy metals and a great deal of water. Because all energy

Learning Goals

After reading this module, you should be able to

- discuss the environmental and economic options we must assess in planning our energy future.
- consider the challenges of a renewable energy strategy.

MODULE 40 ■ Planning Our Energy Future 481

AP[®] FRQ Practice

A comparison of battery electric vehicles (BEVs) and internal combustion engine vehicles (ICE) is covered on the 2013 AP[®] Environmental Science Exam, Question 2. To answer this question, students must

- identify three strategies the federal government might use to encourage the use of BEVs.
- calculate the cost of gasoline per mile used by an ICE, using data provided.
- calculate the cost to charge a battery on a BEV and the cost of electricity per mile, using data provided.
- calculate and compare the CO₂ release of each vehicle from provided data.
- describe two economic impacts of having more BEVs on the road.

Bell Ringer

Ask students: Now that we have learned about the many types of renewable energy, which is your favorite one? Why? *Answers will vary.*

TRM **ACTIVITY 13.7**

Renewable Energy Word Guessing Game

(30 minutes)

This activity is a fun way to review the terms and concepts from this chapter. Before class, photocopy and cut out the cards provided in **Activity 13.7: Renewable Energy Word Guessing Game**. Then divide your class into two teams, and place the stack of cards at the front of the classroom. Have two students, one from each team, come up and pick a card together. The two students share the same term. Each student then draws the term on the board for their respective team until the one of the teams correctly guesses the term. The students who are drawing cannot speak and must draw all their clues on the board. The team that guesses the term first gets a point, and then two more students come up and pick another term. Keep track of the points for each team, and play until all the terms are used up, or you run out of time.

Teaching Tip: Engage

Ask students: Do any of you use renewable energy at home? If so, which kind(s)? *Answers will vary.*

choices have environmental consequences, minimizing energy use through conservation and efficiency is the best approach. After we achieve that, we must make energy choices wisely, depending on a variety of environmental, economic, and convenience factors.

Our energy future depends on efficiency, conservation, and the development of renewable and nonrenewable energy resources

Each of the renewable energy resources we have discussed in this chapter has unique advantages. None of these resources, however, is a perfect solution to our energy needs. **TABLE 40.1** lists some of the advantages and limitations of each of these resources. In short, no single energy resource that we are currently aware of can replace nonrenewable energy resources in a way that is completely renewable, nonpolluting, and free of impacts on the environment. A sustainable energy strategy, therefore, must combine energy efficiency, energy conservation, and the development of renewable and nonrenewable energy resources, taking into account the costs, benefits, and limitations of each. Convenience and reliability are also important factors. Finally, logistical considerations, such as where an energy source is located and how we transport the energy from that source to users, are also important. This is particularly important with the generation of electricity from renewable sources in remote regions, which requires an electrical transmission grid to get it to users.

A renewable energy strategy presents many challenges

Energy expert Amory Lovins suggests that innovation and technological advances, not the depletion of a resource, have provided the driving force for moving from one energy technology to the next. Extending this concept to the present, one can argue that we will develop new energy technologies before we run out of the fuels on which we currently depend.

Despite their tremendous potential, however, renewable energy resources are unlikely to replace fossil fuels completely in the immediate future unless nations commit to supporting their development and use through direct funding and financial incentives such as tax cuts and consumer rebates. In fact, the U.S. Department of Energy predicts that fossil fuel consumption will continue to increase in the United States well into the middle of the twenty-first century.

TABLE 40.1 Comparison of renewable energy resources

| Energy resource | Advantages |
|-----------------------------|--|
| Liquid biofuels | <ul style="list-style-type: none"> • Potentially renewable • Can reduce our dependence on fossil fuels • Reduce trade deficit • Possibly more environmentally friendly than fossil fuels |
| Solid biomass | <ul style="list-style-type: none"> • Potentially renewable • Eliminates waste from environment • Available to everyone • Minimal technology required |
| Photovoltaic solar cells | <ul style="list-style-type: none"> • Nondepletable resource • After initial investment, no cost to harvest energy |
| Solar water heating systems | <ul style="list-style-type: none"> • Nondepletable resource • After initial investment, no cost to harvest energy |
| Hydroelectricity | <ul style="list-style-type: none"> • Nondepletable resource • Low cost to run • Flood control • Recreation |
| Tidal energy | <ul style="list-style-type: none"> • Nondepletable resource • After initial investment, no cost to harvest energy |
| Geothermal energy | <ul style="list-style-type: none"> • Nondepletable resource • After initial investment, no cost to harvest energy • Can be installed anywhere (ground source heat pump) |
| Wind energy | <ul style="list-style-type: none"> • Nondepletable resource • After initial investment, no cost to harvest energy • Low up-front cost |
| Hydrogen fuel cell | <ul style="list-style-type: none"> • Efficient • Zero Pollution |

| Disadvantages | Emissions (pollutants and greenhouse gases) | Electricity cost (\$/kWh) | Energy return on energy investment |
|--|---|---------------------------|--|
| <ul style="list-style-type: none"> Loss of agricultural land Higher food costs Lower gas mileage Possible net increase in greenhouse gas emissions | CO ₂ and methane | | 1.3 (from corn) 8 (from sugar cane) |
| <ul style="list-style-type: none"> Deforestation Erosion Indoor and outdoor air pollution Possible net increase in greenhouse gas emissions | <ul style="list-style-type: none"> Carbon monoxide Particulate matter Nitrogen oxides Possible toxic metals from MSW Danger of indoor air pollutants | | |
| <ul style="list-style-type: none"> Manufacturing materials requires high input of metals and water No plan in place to recycle solar panels Geographically limited High initial costs Storage batteries required for off-grid systems | <ul style="list-style-type: none"> None during operation Some pollution generated during manufacturing of panels | 0.1 | 8 |
| <ul style="list-style-type: none"> Manufacturing materials requires high input of metals and water After initial investment, no cost to harvest energy and water No plan in place to recycle solar panels Geographically limited High initial costs | <ul style="list-style-type: none"> None during operation Some pollution generated during manufacturing of panels | | |
| <ul style="list-style-type: none"> Limited amount can be installed in any given area High construction costs Threats to river ecosystems Loss of habitat, agricultural land, and cultural heritage; displacement of people Siltation | <ul style="list-style-type: none"> Methane from decaying flooded vegetation | .05–.11 | 12 |
| <ul style="list-style-type: none"> Potential disruptive effect on some marine organisms Geographically limited | <ul style="list-style-type: none"> None during operation | | 15 |
| <ul style="list-style-type: none"> Emits hazardous gases and steam Geographically limited | <ul style="list-style-type: none"> None during operation | .05–.30 | 8 |
| <ul style="list-style-type: none"> Turbine noise Deaths of birds and bats Geographically limited to windy areas near transmission lines Aesthetically displeasing to some Storage batteries required for off-grid systems | <ul style="list-style-type: none"> None during operation | .04–.06 | 18 |
| <ul style="list-style-type: none"> Producing hydrogen is an energy-intensive process Lack of distribution network Hydrogen storage challenges | <ul style="list-style-type: none"> None during operation | | 8 |

TRM Teaching Tip: Beyond the Classroom

Environmental Solutions (SP7)

(60 minutes)

Ask students, or groups of students, to create a poster based on a single renewable energy source. Make sure each of the resources listed in Table 40.1 is covered. The poster should include a picture and answer the following questions. **Handout 13.17: Renewable Energy Poster** contains a reproducible version of these questions.

- How does this technology work?
- How can this energy source be used?
- What are some examples of its current use? Can you find any local examples?
- What are the apparent environmental impacts associated with it?
- Are there hidden environmental or social costs?
- Is this technology widely used today? Why or why not?

Call on each student or group to present at the beginning of the relevant class so the presentations form the first few minutes of your class discussion on each particular type of renewable energy.

AP® FRQ Practice

The difference between renewable and nonrenewable resources is covered on the 1999 AP® Environmental Science Exam, Question 3. To answer this question, students must

- describe the difference between renewable and nonrenewable resources and provide an example of each.
- contrast total per capita resource use in developed and developing nations.
- explain the meaning of sustainable resource use and provide an example.
- discuss one policy that helps with the goal of sustainable resource use and one policy that hinders it.

In spite of their extremely rapid growth, wind and solar energy still account for far less than 1 percent of all the energy produced in the United States. Government funding or other sources of capital are needed to support research to overcome the current limitations of many renewable energy resources. One limitation that is already evident relates to the transmission of renewable electricity over the electrical distribution network. Other limitations to consider are energy cost and storage.

Improving the Electrical Grid

An increased reliance on renewable energy means that energy will be obtained in many locations and will need to be delivered to other locations. Delivery can be particularly problematic when electricity for an urban area is generated at a remote location. The electrical distribution system—the grid that we described in Chapter 12—was not originally designed for this purpose. So in addition to investing in new energy sources, the United States will have to upgrade its existing electrical infrastructure—its power plants, storage capacity, and distribution networks. Approximately 40 percent of the energy used in the United States is used to generate electricity. The U.S. electricity distribution system is outdated and subject to overloads and outages, which cost the U.S. economy over \$100 billion per year. There are regions of the country that cannot supply enough generating capacity to meet local needs, while in other locations the electrical infrastructure cannot accommodate all the electricity that is generated, including from small generators such as household PV systems. Furthermore, the current system requires that electricity be moved long distances from power plants to consumers. Approximately 5 to 10 percent of the electricity generated is lost as it is transported along electrical transmission lines, and the greater the distance, the more that is lost. While the storage capacity of batteries improves each year, batteries are probably not a sustainable solution for this problem of energy loss. Many people are focusing their attention on improving the electrical grid to make it as efficient as possible at moving electricity from one location to another, thereby reducing the need for storage capacity.

An energy economy based on nondepletable energy sources requires reliable electricity storage and affordable—or at least effective and efficient—distribution networks. U.S. energy scientists maintain that because we currently do not have a cost-effective, reliable means of storing energy, we should not depend on intermittent sources such as wind and solar energy for more than about 20 percent of our total electricity production since it could lead to risky instability in the grid. However,

Smart grid An efficient, self-regulating electricity distribution network that accepts any source of electricity and distributes it automatically to end users.

a number of European countries now have more than 20 percent renewables on their electricity grids, which may lead scientists to re-evaluate this recommendation.

One solution currently being implemented is the **smart grid**, an efficient, self-regulating electricity distribution network that accepts any source of electricity and distributes it automatically to end users. A smart grid uses computer programs and the Internet to tell electricity generators when electricity is needed and electricity users when there is excess capacity on the grid. In this way, it coordinates electricity use with electricity availability. Since 2008, government and industry contributions have brought total investment in the smart grid to almost \$8 billion, which has been used to fund more than 100 smart grid projects around the country.

How does a smart grid work? **FIGURE 40.1** shows one example. With “smart” appliances plugged into a smart grid, at bedtime a consumer could set an appliance such as a dishwasher to operate overnight. A computer on the dishwasher would be programmed to run the appliance anytime between midnight and 5:00 AM, depending on when there is a surplus of electricity. The dishwasher’s computer would query the smart grid and determine the optimal time, in terms of electricity availability, to turn on the appliance. The smart grid could also help manage electricity demand so that peak loads do not become too great. For example, smart grid technology could delay the onset of the cooling cycle in a large supermarket freezer. Perhaps the freezer units would delay by 15 minutes the time at which they would initiate a cycle. This might result in a very small increase in temperature in the freezers, but it wouldn’t be large enough to adversely affect the food. And it might delay or stagger electricity demand at a time when demand is high. We cannot control the timing of all electricity demand, but by improving consumer awareness of electricity abundance and shortages, using smart appliances, and setting variable pricing for electricity, we can make electricity use much more regular, and thus more sustainable.

Our current electrical infrastructure relies on a system of large electricity producers—regional electricity generation plants. When one plant goes off-line or shuts down, the reduction in available generating capacity puts greater demands on the rest of the system. Some energy experts maintain that a better system would consist of a large number of small-scale electricity generation “parks” that rely on a mix of fossil fuel and renewable energy sources. These experts maintain that a system of decentralized energy parks would be the least expensive and most reliable electrical infrastructure to meet our future needs. Small, local energy parks would save money and energy by transporting electricity a shorter distance. Such decentralized generators would also be less likely to suffer breakdowns or sabotage. Since each small energy park might serve only a few thousand people, widespread outages would be much less likely.

Teaching Tip: Journal Prompt

Ask students to explain why approximately 5 to 10 percent of the electricity generated in the United States is lost as it is transported along electrical transmission lines. *The current electric grid is outdated and inefficient. In some situations electricity must be transmitted long distances. The greater the distance that the electricity must move across the transmission lines, the more energy that is lost or wasted. Creating a smarter grid would help electric companies become more efficient and would save energy and money for the consumer.*

Teaching Tip: Review

(20 minutes)

Write the major renewable energy sources on the board: hydroelectric, solar, geothermal, wind, biomass, and tidal. Ask students to write down the advantages and disadvantages of each. Choose one student for each resource to share his or her answers with the rest of the class. Correct student answers as needed.

Teaching Tip: Journal Prompt

(10 minutes)

Ask students: What factors must be considered for a successful sustainable energy strategy for the United States? How achievable do you think such a strategy would be in the next decade? Explain your answer. *Answers will vary.*

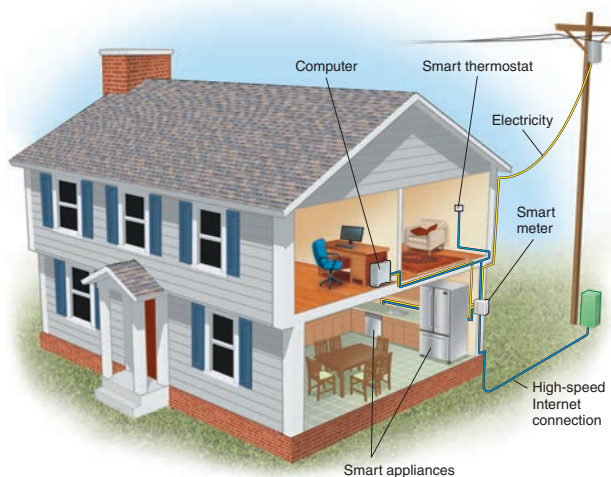


FIGURE 40.1 Using a smart grid. A smart grid optimizes the use of energy in a home by continuously coordinating energy use with energy generation.

Addressing Energy Cost and Storage

The major impediments to widespread use of wind, solar, and tidal energy—the forms of renewable energy with the least environmental impact—are cost and the limitations of energy storage technology. Fortunately, the cost of renewable energy has been falling. For example, in some markets wind energy is now cost-competitive with natural gas and coal. Throughout this book we have seen that the efficiency of production improves with technological advances and experience. In general, as we produce more of something, and get experience from making it, we learn to produce it less expensively. Production processes become dramatically more efficient, more companies enter the market, and developing new technologies has a clear payoff. For the consumer, this technological advancement also has the benefit of lowering prices: For electricity generation from solar, wind, and natural gas, we have seen that costs tend to decline in a fairly regular way as installed capacity grows.

What are the implications of this relationship between experience and efficiency? In general, any technology that has been in widespread use has an advantage over a newer technology because it is familiar and because the less expensive something is, the more people will buy it, leading to further reductions in its price. State and federal subsidies and tax incentives also help to lower the price of a technology. Tax credits and rebates have been instrumental in reducing the cost of solar and wind energy systems for consumers.

Similarly, in time, researchers will develop solutions to the problem of creating efficient energy storage systems, which might reduce the need to transport electricity over long distances. One very simple and effective approach is to use the excess capacity during off-peak hours to pump water uphill with electricity to a reservoir. Then, during hours of peak demand, operators can release the water through a turbine to generate the necessary electricity—cleanly and efficiently. Research into battery technology and hydrogen fuel cell technology continues. Battery capacity and charge/discharge efficiencies are improving rapidly and cost per kilowatt hour of battery storage has been going down. Tesla is probably the best-known company making advances in this area, with products such as the Tesla Powerwall 2, which is a lithium ion battery that can be hung on a wall in a garage or basement.

Progress on these and other technologies may accelerate with government intervention, taxes on industries that emit carbon dioxide, or a market in which consumers are willing to pay more for technologies that have minimal environmental impacts. In the immediate future, we are more likely to move toward a sustainable energy mix if nonrenewable energy becomes more expensive. Consumers have shown more willingness to convert in large numbers to renewable energy sources, or to engage in further energy conservation, when fossil fuel prices increase. We have already seen instances of this shift in behavior. In 2008, energy conservation increased when oil prices rose rapidly to almost

TRM ACTIVITY 13.9

Electricity Bill

Data Analysis (SP5)

(15 minutes)

Ask students to bring in their household's electricity bill, or have them refer to the sample bill provided in **Chapter 13 Web Resources**. Have students work in pairs and do the following. **Activity 13.9: Electricity Bill** contains a reproducible version of these instructions without the answers.

- Find and circle the kWh of electricity their household used in the given month. *Sample bill shows 617 kWh used.*

- Find and circle the total amount charged for electricity. *Sample bill shows total charge of \$87.32.*
- Calculate the total electricity cost per kWh. *Sample bill calculation is:*

$$\$87.32 \div 617 \text{ kWh} = \$0.14/\text{kWh}$$
- Compare this month's electricity use to last month's electricity use. Has it gone up or down? Why do you think? *Answers will vary.*

TRM ACTIVITY 13.8

Renewable Energy Quiz

(10 minutes)

Activity 13.8: Renewable Energy Quiz

contains a quiz you can give your students to complete in class on their own. When they have finished the questions, have them discuss their answers with a partner, then review the answers with the entire class.

Teaching Tip: Discussion Starter

Ask students to describe a scenario that uses smart grid technology and how that technology would reduce a homeowner's electric bill. *With "smart" appliances plugged into a smart grid, a consumer can set an appliance such as a dishwasher to operate during the night when a surplus of electricity exists on the power grid. The dishwasher's computer would query the smart grid and determine the optimal time, in terms of electricity availability, to turn on the appliance. The smart grid could also help manage electricity demand so that peak loads do not become too great.*

TRM Teaching the AP[®] Tip

To help your students remember the different methods of producing electricity, ask them the questions below. **Handout 13.18: Review of Different Methods of Producing Electricity** contains a reproducible version of these questions.

- How do traditional power plants generate electricity? *Power plants create steam, which turns a turbine.*
- What are the most common ways to create this steam? *Steam forms when the energy from burning coal, natural gas, or nuclear fuel heats water.*
- Can renewable energy sources create steam in order to move a turbine? *Yes, concentrating solar thermal systems and geothermal energy produce steam to move a turbine.*
- What else can move a turbine for electricity generation? *A current of water or wind can move a turbine to generate electricity.*
- Can electricity be produced without a turbine? *Yes, photovoltaic solar cells capture energy from the Sun as light and convert it directly into electricity.*

Answers to Module 40 AP[®] Practice Questions

1. b
2. d
3. c
4. c
5. d

\$150 per barrel and gasoline in most of the United States cost more than \$4 per gallon. People used public transportation more often, drove more fuel-efficient vehicles, and carpooled more than they did before the price spike. As gasoline prices decrease, conservation measures tend to decrease as well, and we saw in the latter half of 2008.

Other ways to spur conservation are initiatives that regulate the energy mix itself—for example, by encouraging that a certain fraction of electricity be generated

using renewable energy sources. One such initiative is the Regional Greenhouse Gas Initiative (RGGI), whereby nine eastern states have reduced greenhouse gas emissions from electricity generation plants in the past 10 years.

AP[®] Exam Tip

You should be able to explain the different methods of producing electricity.

MODULE**40****AP[®] Review****Preparing for the AP[®] Exam**

In this module, we have seen that conservation and efficiency need to be considered simultaneously with a wide variety of renewable energy sources. Environmental, economic, and convenience considerations must be evaluated when comparing renewable energy options against each other and with nonrenewable fuels. The path we take in our energy future will depend on the potential for a given

energy source to meet the needs of the country, along with the availability and issues of reliability, storage, and accessibility of that source. Challenges include improving the electrical grid and the adoption of smart grid technologies to address some of the challenges that are specific to renewable and sometimes intermittent energy supplies.

AP[®] Practice Questions

Choose the best answer for the following.

1. Which is NOT a disadvantage of liquid biofuels?
 - (a) They are associated with lower gas mileage.
 - (b) They create more carbon monoxide than fossil fuels.
 - (c) They can contribute to a loss of agricultural land.
 - (d) They can increase food costs.
2. Which aspect of renewable energy electricity generation requires updating the electricity transmission grid?
 - I. Electricity generators are located in numerous, remote locations.
 - II. There is a need to transport electricity long distances.
 - III. There are storage problems due to the unpredictable nature of some renewables.
 - (a) I and II
 - (b) I and III
 - (c) II and III
 - (d) I, II, and III
3. The smart grid does NOT
 - (a) use the Internet to coordinate energy use and energy availability.
 - (b) reduce the variability in electricity demand.
 - (c) have the potential to provide a cheap way to store electricity.
 - (d) increase the need for variable pricing of electricity.
4. Which renewable energy source has become cost-competitive with fossil fuels?
 - (a) tidal
 - (b) geothermal
 - (c) wind
 - (d) solar photovoltaic
5. Which will NOT increase adoption of renewable technologies?
 - (a) increased cost of fossil fuels
 - (b) a carbon dioxide emissions tax
 - (c) cheaper energy storage
 - (d) decreased government subsidies

Working Toward Sustainability

Building an Alternative Energy Society in Iceland

The people of Iceland use more energy per capita than the people of any other nation, including the United States. However, the energy Icelanders use is almost all in the form of local, renewable resources that do not pollute or contribute greenhouse gases to the environment.

This isolated European island nation has had to learn to be self-sufficient in energy or suffer the high cost of importing fuel. When the Vikings first came to Iceland over a thousand years ago, they relied on biomass, in the form of birch wood and peat, for fuel. The resulting deforestation, and the slow regrowth of forests in Iceland's cold temperatures and limited sunlight, restricted human population growth and economic development for the next thousand years. With the beginning of the Industrial Revolution in the eighteenth century, Iceland began to supplement its biomass fuel with imported coal, but the expense of importing coal also limited its economic growth.

In the late nineteenth and early twentieth centuries, Iceland began to look to its own resources for energy. It began by tapping its abundant freshwater resources to generate hydroelectricity, which became the country's major energy source for residential and industrial use. This transition led to the general electrification and economic modernization of the country and greatly reduced its dependence on imported fossil fuels. Iceland did not stop with hydroelectricity, however, but sought ways to utilize its other major renewable energy source: the thousands of geysers and hot springs on this volcanic island that would provide ready access to geothermal energy.



A geothermal energy power plant in Iceland. This thermal power station in west Iceland uses geothermal energy from Earth rather than a fossil fuel to produce electricity and hot water. (Felipe Cui-Paoluzo/Getty Images)

Geothermal energy is now the primary energy source for home heating in Iceland, and geothermal and hydroelectric resources provide energy for nearly all electricity generation in the country. Even so, the potential of these resources remains relatively underutilized. Iceland has harvested less than 20 percent of its hydroelectric potential, and there is even more potential in its geothermal resources.

Iceland continues to take advantage of local resources and global technology to develop clean, sustainable energy sources. Despite its commitment to renewable energy, Iceland is still dependent on imported fossil fuels to run its cars, trucks, buses, and fishing vessels. In 2000, Iceland embarked on an ambitious project to wean the country from fossil fuels by 2050. The goal was to use its sustainably generated electricity to split water and obtain hydrogen, then use the hydrogen as fuel. In April 2003, Iceland opened one of the world's first filling stations for hydrogen-fueled vehicles. In August of that year, hydrogen-fueled buses for public transportation were introduced in Reykjavik, the capital of Iceland. Hydrogen-fueled rental cars were also available. The financial crisis of 2008 through 2011 delayed and even reversed some of the achievements. The original hydrogen fueling station was dismantled in 2012, but in 2018, Iceland renewed its commitment to hydrogen with the construction of three hydrogen filling stations. The country is small enough that 80 percent of the Icelandic population is within easy reach of a fueling station—the highest percentage in the world.

Critical Thinking Questions

1. Can the knowledge and experience gained in Iceland be applied to many other parts of the world? Why or why not?
2. What challenges would there be if hydrogen fuel was to become the major source of energy for automobiles in the United States?

References

- Blanchette, S. 2008. A hydrogen economy and its impact on the world as we know it. *Energy Policy* 36:522–530.
- Veal, L. 2017. Hydrogen, Iceland and the Future of Transport. International Press Syndicate. Published on April 14, 2017. <https://www.indepthnews.net/index.php/sustainability/affordable-clean-energy/1074-hydrogen-iceland-and-the-future-of-transport>

Teaching Tip: Working Toward Sustainability

Environmental Solutions (SP7)

Ask students to research local use of geothermal energy. Is it available in your community? As a class, consider some of the pros and cons of geothermal energy use.

Suggested Answers to Critical Thinking Questions

1. While some of the knowledge and advances developed can be applied to other regions, the abundance of hydroelectricity and geothermal energy is unique to Iceland.
2. Answers will vary.

ACTIVITY

Name That Term

(25 minutes)

In this activity, students play a review game using the key terms from this chapter. Divide the class into two teams. Ask one student to come to the front of the class and face his or her team, back to the board. Using either a projected slide or a flashcard, display a review term to the student's team. Instruct the team to offer clues about the term until the student guesses it. When the student correctly identifies the term, display another term and continue as before, until 1 minute has passed. When the minute is over, tally and record the number of terms the student correctly identified. It is now the other team's turn. Switch back and forth between teams, making sure that as many students as possible get a turn. When all the terms have been used, tally the final score and announce the results.

TRM Exploring the Literature

Text Analysis (SP3)

Bakke, G. 2017. *The Grid: The Fraying Wires Between Americans and Our Energy Future*. Bloomsbury.

Friedland, A. J., and K. T. Gillingham. 2010. Carbon accounting a tricky business (letter). *Science* 327:410–411. International Energy Agency: <http://www.iea.org>.

McElroy, M. B. 2016. *Energy and Climate: Vision for the Future*. Oxford University Press.

Smith, T. P. 2014. Fish, tides and turbines. *Natural History* 121:32–39.

U.S. Department of Energy, National Renewable Energy Laboratory: <http://www.nrel.gov>.

U.S. Energy Information Administration, Independent Statistics and Analysis: <http://www.eia.doe.gov>.

Wolfson, R. 2017. *Energy, Environment, and Climate*. 3rd ed. W. W. Norton.

Exploring the Literature 13 contains a reproducible version of this list.

In this chapter, we have examined the role of conservation as well as increased energy efficiency in reducing the demand for energy. We have described the different categories of renewable energy and examined the two most prominent renewable energy sources: biomass and energy from flowing and standing water. Biomass energy contains modern carbon and can be obtained from wood, charcoal, and animal wastes. Energy can be harnessed from both standing water and free flowing water, typically to generate electricity. Solar energy can be harnessed both passively and actively. The most

prominent active collection of solar energy comes from photovoltaic cells that convert sunlight into electricity. Wind energy is harnessed directly and a wind turbine is very similar to the turbines used to generate electricity from fossil fuels. Geothermal energy from Earth can be used in specific locations. Hydrogen is a fuel that has much promise but is not likely to be used widely anytime soon. Each renewable energy resource has its advantages and disadvantages and these can be considered from both environmental and economic perspectives.

Key Terms

| | | |
|-----------------------|-------------------|-------------------------|
| Energy conservation | Fossil carbon | Siltation |
| Tiered rate system | Carbon neutral | Active solar energy |
| Peak demand | Net removal | Photovoltaic solar cell |
| Passive solar design | Ethanol | Wind energy |
| Thermal mass | Biodiesel | Wind turbine |
| Potentially renewable | Flex-fuel vehicle | Geothermal energy |
| Nondepletable | Hydroelectricity | Ground source heat pump |
| Renewable | Run-of-the-river | Fuel cell |
| Biofuel | Water impoundment | Electrolysis |
| Modern carbon | Tidal energy | Smart grid |

Learning Goals Revisited

Module 37 Conservation, Efficiency, and Renewable Energy

Describe strategies to conserve energy and increase energy efficiency.

Turning down the thermostat and driving fewer miles are examples of steps individuals can take to conserve energy. Buying appliances that use less energy and switching to compact fluorescent light bulbs are examples of steps individuals can take to increase energy efficiency. Buildings that are carefully designed for energy efficiency can save both energy resources and money. Reducing the demand for energy can be an equally effective or a more effective means of achieving energy sustainability than developing additional sources of energy.

Explain differences among the various renewable energy resources.

Renewable energy resources include nondepletable energy resources, such as the Sun, wind, and moving water, and potentially renewable energy resources, such as biomass. Potentially renewable energy resources will be available to us as long as we use them sustainably.

Module 38 Biomass and Water

Describe the various forms of biomass.

Biomass is one of the most common sources of energy in the developing world, but biomass energy is also used in developed countries. In theory, biomass energy is carbon neutral; that is, the carbon produced by combustion of biomass should not add to atmospheric carbon concentrations because it comes from modern, rather than fossil, carbon sources. Wood is a potentially renewable resource because, if harvests are managed correctly, it can be a continuous source of biomass energy. Ethanol and biodiesel have the potential to supply large amounts of renewable energy, but growing and processing these fuels makes demands on land and energy resources.

Explain how energy is harnessed from water.

Most hydroelectric systems use the energy of water impounded behind a dam to generate electricity. Run-of-the-river hydroelectric systems impound little or no water and have fewer environmental impacts, although they often produce less electricity.

TRM ACTIVITY

Measuring Your Impact

Choosing a Light Bulb

Environmental Solutions (SP7)

Measuring Your Impact 13: Choosing a Light Bulb asks students to calculate the costs of using incandescent and fluorescent light bulbs.

Module 39 Solar, Wind, Geothermal, and Hydrogen

List the different forms of solar energy and their application.

Passive solar energy takes advantage of relatively inexpensive strategies such as the direction windows are facing in a building. Active solar technologies use technology to obtain heat or electrical energy from the Sun and have high initial costs but can potentially supply relatively large amounts of energy. Active solar applications can be small, such as those that fit on a rooftop or in a field, or they can be extremely large, on an industrial scale.

Describe how wind energy is harnessed and its contemporary uses.

Wind turbines can be located on land or in the near-offshore environment. Frequently, a number of wind turbines are grouped together in wind farms. Wind is the most rapidly growing source of renewable electricity. It is a clean, nondepletable energy resource, but objections to wind farms are increasing because of aesthetics, sound, and hazards the turbines pose to birds and bats.

Discuss the methods of harnessing the internal energy from Earth.

Geothermal energy from underground can heat buildings directly or can generate electricity. However, geothermal power plants must be located in places where geothermal energy is accessible.

Explain the advantages and disadvantages of energy from hydrogen.

The only waste product from a hydrogen fuel cell is water, but obtaining hydrogen gas for use in fuel cells is an energy-intensive process. If hydrogen could be obtained using renewable energy sources, it could become a truly renewable source of energy.

Module 40 Our Energy Future

Discuss the environmental and economic options we must assess in planning our energy future.

Many scenarios have been predicted for the world's energy future. However, conserving energy, increasing energy efficiency, relying more on renewable energy sources, and improving energy distribution and storage will all be necessary to achieve energy sustainability. Fossil fuel use continues throughout the world today and it does not appear that it will decrease any time soon.

Consider the challenges of a renewable energy strategy.

Improving the electrical grid in the United States is vital if we are to increase reliance on renewable forms of electricity. However, because the grid is so widespread, expanding and maintaining its geographic spread and electrical capacity are expensive. Even with an expanded grid, there are numerous obstacles to increasing renewable electricity generation. The high economic cost—at least initially—for renewable forms of electricity is a challenge. Also, the difficulty and economic cost of storing electricity have no easy solutions at present.

Practice Math and Graphing

Preparing for the AP® Exam

Answer the following questions. Be sure to show all your work.

1. Practice Math

- (a) Wind capacity in the United States has undergone a rapid increase over the past 2 decades. Total capacity of wind turbines in the United States was 4,000 MW in 2000 and 85,000 MW in 2017. What was the percentage increase per year over this 17-year period? Round to the appropriate number of significant figures.
- (b) There was approximately 3,600 MW of installed geothermal capacity in the United States in 2016. Geothermal electricity generation in the United States went from 14 MWH in 2000 to 17 MWH in 2016. What was the percentage increase over this 16-year period? Round to the appropriate number of significant figures.

2. Practice Graphing

Smart meters have two-way communication between a home or business and an electrical utility. They range from recording hourly electricity usage to lowering electricity demand at specific times of peak demand on the grid. In 2007, there were approximately 1 million smart meters installed in the United States. By 2013, there were more than 50 million. Create the following two graphs with year on the *x* axis and number of meters in millions on the *y* axis.

- (a) Show the pattern of smart meter growth in the United States, assuming the growth was roughly steady from 2007–2013.
- (b) Show the pattern of smart meter growth in the United States assuming that most of the growth actually happened between 2007 and 2010, as was actually observed.

Practice Math and Graphing

AP®

Data Analysis (SP5)

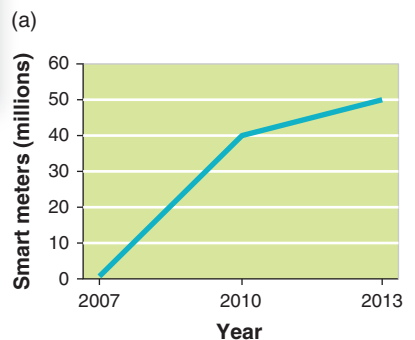
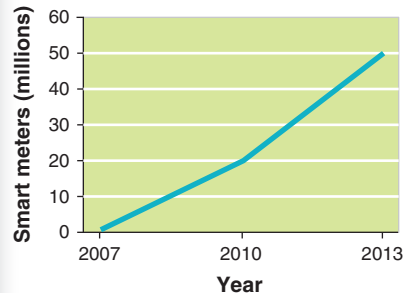
“Practice Math” asks students to use data provided to calculate the percentage increase in wind capacity in the United States from 2000 to 2017 and the percentage increase in geothermal energy over that same time. “Practice Graphing” asks students to create two graphs on smart meter growth from data provided.

Answers to Practice Math and Graphing

1. Practice Math

- (a) $85,000 \text{ MW} - 4,000 \text{ MW} = 81,000 \text{ MW increase}$
 $81,000 \div 4,000 \text{ MW} = 20 \times 100\% = 2000\% \text{ increase over 17 years}$
 $2000\% \div 17 \text{ years} = 118\%/\text{year}$
- (b) $17 \text{ MWH} - 14 \text{ MWH} = 3 \text{ MWH}$
 $3 \text{ MWH} \div 14 \text{ MWH} = 0.2 \times 100\% = 20\% \text{ increase over 16 years}$
 $20\% \text{ increase} \div 16 \text{ years} = 1.3\%/\text{year}$

2. Practice Graphing



(b)

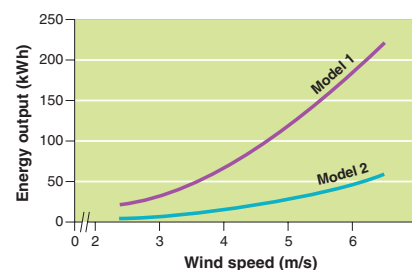
1. c
2. b
3. a
4. c
5. d
6. b
7. c
8. d
9. b
10. d
11. d
12. c
13. d
14. d
15. a
16. b
17. d
18. d
19. b
20. d

Section 1: Multiple-Choice Questions

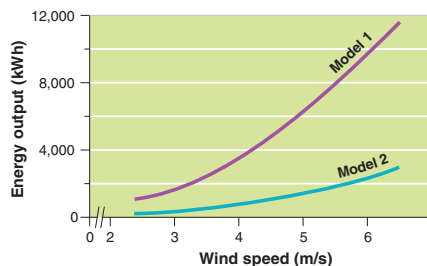
Choose the best answer for questions 1–20.

1. Which is NOT an example of a potentially renewable or nondepletable energy source?
 - (a) hydroelectricity
 - (b) solar energy
 - (c) nuclear energy
 - (d) wind energy
2. Renewable energy sources are best described as
 - (a) those that are the most cost-effective and support the largest job market.
 - (b) those that are, or can be, perpetually available.
 - (c) those that are dependent on increasing public demand and decreasing supply.
 - (d) those that are being depleted at a faster rate than they are being replenished.
3. An energy-efficient building might include all of the following EXCEPT
 - (a) building materials with low thermal mass.
 - (b) a green roof.
 - (c) southern exposure with large double-paned windows.
 - (d) reused or recycled construction materials.
4. Which source of energy is NOT (ultimately) solar-based?
 - (a) wind
 - (b) biomass
 - (c) tides
 - (d) coal
5. Which demonstrates the use of passive solar energy?
 - I. a south-facing room with stone walls and floors
 - II. photovoltaic solar cells for the generation of electricity
 - III. a solar oven
 - (a) I only
 - (b) II only
 - (c) III only
 - (d) I and III

Question 6 refers to the following graphs.



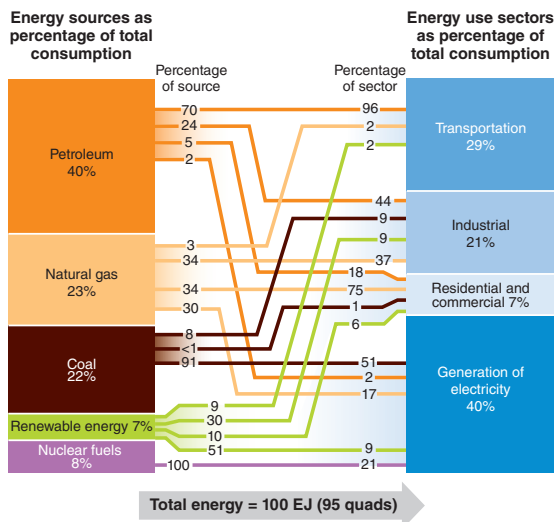
(a) Weekly energy output



(b) Annual energy output

6. A study of small wind turbines in the Netherlands tested the energy output of two models, shown in the graphs. Which statement can be inferred from these data?
 - (a) As wind speed increases, energy output decreases.
 - (b) The annual energy output of model 1 can exceed 6,000 kWh.
 - (c) As energy output surpasses 50 kWh per week, noise pollution increases.
 - (d) Model 2 is likely to cause more bird and bat deaths.
7. The primary sources of renewable energy in the United States are
 - (a) solar and wind energy.
 - (b) hydroelectricity and tidal energy.
 - (c) biomass and hydroelectricity.
 - (d) geothermal and tidal energy.

Questions 8 and 9 use the following diagram, which represents annual U.S. energy consumption by source and sector for 2007.



- Which statement best describes the sources of energy in U.S. energy consumption patterns?
 - Most of the renewable energy is used in the industrial, residential, and commercial sectors.
 - Most of the electricity generated in the United States comes from nuclear energy.
 - The industrial sector is heavily dependent on coal and renewable energy.
 - Fossil fuels continue to be the major energy source for all sectors.
- Which statement best describes U.S. energy use?
 - Transportation is the largest end use of energy in the United States.
 - Electricity generation is the largest end use of energy in the United States.
 - Electricity generation is powered mainly by nuclear energy.
 - Industry is the largest end use of energy in the United States.
- Which statement best describes the role of renewable energy in the United States?
 - It is the dominant source of energy.
 - It is the largest contributor of greenhouse gases.
 - It is a large contributor to the transportation sector.
 - Its largest contribution is to the electricity generation sector.
- Which strategy will best help humans to achieve energy sustainability?
 - building large, centralized power plants
 - improving energy efficiency
 - developing new energy technologies
 - II only
 - III only
 - I and II
 - II and III
- Biomass is created through the conversion of _____ energy into _____ energy, which can then be used to generate electricity. In contrast, tidal energy involves the conversion of _____ energy into electricity.
 - chemical; potential; potential
 - solar; kinetic; potential
 - chemical; kinetic; kinetic
 - solar; chemical; kinetic
- Concentrated solar thermal systems implement
 - active solar technology.
 - photovoltaic cell technology.
 - passive solar technology.
 - smart grid technology.
- The environmental impacts of cutting down a forest to obtain wood as fuel for heating and cooking could include
 - deforestation and subsequent soil erosion.
 - release of particulate matter into the air.
 - a large net rise in atmospheric concentrations of sulfur dioxide.
 - I only
 - II only
 - III only
 - I and II
- What is the fuel source for a flex-fuel vehicle?
 - electricity
 - biodiesel
 - E-85
 - solar

Answers to Chapter 13

AP[®] Practice Exam Free-Response Questions

1. (a) As water falls over a vertical distance, the potential energy stored in it is converted to kinetic energy. A hydroelectric power plant captures this kinetic energy and uses it to turn a turbine, just as the kinetic energy of steam turns a turbine in a coal-fired electricity generating plant. The turbine transforms the kinetic energy into electrical energy.

(b) The amount of electricity that can be generated at a particular power plant depends on two factors. First, it depends on the vertical distance through which the water falls. The greater the distance that the water will fall, the more potential energy it has and the more electricity that will be generated. Second, the flow rate, or amount of water that flows past a certain point per unit of time, affects the amount of electricity the power plant can generate. The higher the flow rate, the greater the quantity of water, the more kinetic energy is present, and the more electricity is generated.

(c) There are two main types of hydroelectric generation on land: run-of-the-river and water impoundment. In run-of-the-river hydroelectric generation, dams are usually constructed across a river. Water flows over the dam or through a channel and then returns to the river without being stored in a reservoir. In run-of-the-river hydroelectric power, relatively little flooding occurs upstream and the seasonal changes in river flow are not disrupted. This greatly alleviates the environmental impact of the project. However, it also significantly limits the generating potential and reliability of the energy production, because heavy spring runoff from rains (and in some regions, snowmelt) cannot be stored. Also, in hot, dry periods such as during the summer, the flow of water is low and little or no electricity is produced.

Water impoundment is the storage of water in a reservoir behind a dam. It is the most common type of hydro power because it usually allows for electricity generation on demand, rather than only during periods of heavy water flow. As with

16. Which factor should NOT be considered when determining the EROEI of hydrogen fuel cell vehicles?
- efficiency of isolating hydrogen from water or natural gas
 - by-products of generating electricity from hydrogen
 - energy produced by the reaction between hydrogen and oxygen
 - efficiency of electric motors
17. The primary purpose of a smart grid is to
- improve the efficiency of electricity production.
 - improve the efficiency of energy transportation through power lines.
 - improve the capacity factor of power plants.
 - coordinate electricity use with electricity availability.
18. Which is a method of generating electricity from the movement of water?
- tidal energy
 - run-of-the-river
 - water impoundment
- I only
 - II only
 - III only
 - I, II and III
19. Which is NOT an example of energy conservation?
- consolidating trips
 - installing a high efficiency heating system
 - taking public transport
 - turning the thermostat down in winter
20. Maha wants to buy a dehumidifier. An Energy Star version of this appliance costs \$300, while a standard unit costs \$150. She expects to run it for 6 hours per day all year round. If the Energy Star unit costs 5 cents less per hour to run, approximately how much money will Maha save in 5 years if she spends the extra \$150 for the Energy Star unit?
- \$150
 - \$200
 - \$350
 - \$400

Section 2: Free-Response Questions

Write your answer to each part clearly. Support your answers with relevant information and examples. Where calculations are required, show your work.

1. Hydroelectricity provides about 7 percent of the electricity generated in the United States.
- Explain how a hydroelectric power plant converts energy stored in water into electricity. (2 points)
 - Identify TWO factors that determine the amount of electricity that can be generated by an individual hydroelectric power plant. (2 points)
 - Describe the TWO main types of land-based hydroelectric power plants. (2 points)
 - Describe TWO economic advantages and TWO environmental disadvantages of hydroelectricity. (4 points)

run-of-the-river, electricity is generated by water flowing through a turbine, but the flow rate of water and subsequent energy generation is controlled by the gates of the dam. Water impoundment can produce more electricity than run-of-the-river generation.

(d) Economic advantages of hydroelectricity:

- The operating expenses of the dam are not subject to fluctuations in fuel costs.
- Revenue from recreational use of the lake behind the dam can help the local economy.
- In the absence of drought, hydropower is often very low cost.

2. The following table shows the amounts of electricity generated by photovoltaic solar cells and by wind in the United States from 2002 to 2007 (in thousands of megawatt-hours).

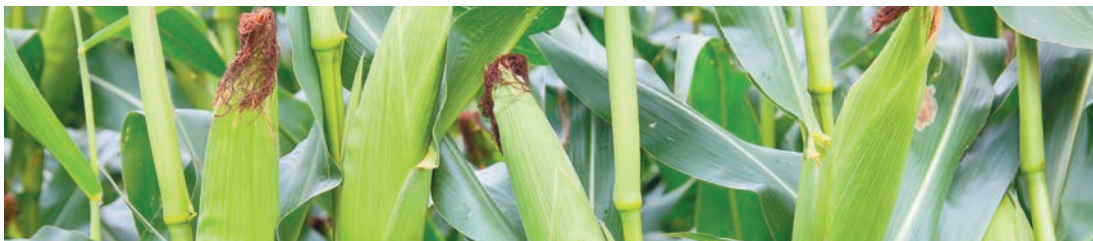
| Energy Source | Year | | | | | |
|----------------|--------|--------|--------|--------|--------|--------|
| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
| PV solar cells | 555 | 534 | 575 | 550 | 508 | 606 |
| Wind | 10,354 | 11,187 | 14,143 | 17,810 | 26,589 | 32,143 |

- Describe the trend in electricity generation by photovoltaic solar cells from 2002 to 2007. Calculate the approximate percentage change between 2002 and 2007. (2 points)
 - Describe the trend in electricity generation by wind from 2002 to 2007. Calculate the approximate percentage change between 2002 and 2007. (2 points)
 - Identify and explain any difference between the two trends you described in (a) and (b). (2 points)
 - A homeowner wants to install either photovoltaic solar cells or wind turbines to provide electricity for her home in Nevada, which gets both ample sunlight and wind. Provide two arguments in favor of installing one of these technologies, and explain two reasons for not choosing the other. (2 points)
 - Would the installation of either PV solar cells or wind turbines be considered an application of energy conservation or of energy efficiency? Explain. (2 points)
3. Biomass accounts for approximately one-half of the renewable energy produced in the United States today.
- Biomass is considered potentially renewable. Explain what this means, and contrast it with nondepletable resources (2 points)
 - Burning biomass releases carbon into the atmosphere. Compare the environmental effect of burning biomass to using fossil fuels. Is it better for the environment to replace fossil fuels with biomass? In your answer include the terms modern carbon, fossil carbon, and carbon neutral (4 points).
 - Biomass can also be processed to create biofuels, including ethanol and biodiesel. Explain the difference between ethanol and biodiesel, both in terms of how they are generated and how they are used. (4 points)

Environmental disadvantages of hydroelectricity:

- It can cause a disruption in the life cycle of certain species.
- It alters the ecological systems both above and below the dam, which may displace people or flood ancient cultural or archaeological sites.

Answers continue in the Answer Appendix on page ANS-10.



Fedor Selivanov/Shutterstock

science applied 6

Should Corn Become Fuel?

Corn-based ethanol is big business—so big, in fact, that to offset demand for petroleum, U.S. policy has required an increase in annual ethanol production from 34 billion liters (9 billion gallons) in 2008 to 136 billion liters (36 billion gallons) by 2022. By 2017, production had already risen to nearly 60 billion liters (16 billion gallons).

Ethanol proponents maintain that substituting ethanol for gasoline decreases air pollution, greenhouse gas emissions, and our dependence on foreign oil. Opponents counter that when we consider all of the inputs used to grow and process corn into ethanol, it increases air pollutants and greenhouse gases. Moreover, opponents claim that growing corn and converting it into ethanol uses more energy than we obtain when we burn ethanol for fuel and that the impact of ethanol on reducing our import of foreign oil is very small. What does the science tell us?

Does ethanol reduce air pollution?

Ethanol (C_2H_6O) and gasoline (a mixture of several compounds, including heptane, C_7H_{16}) are both hydrocarbons. Under ideal conditions, in the presence of enough oxygen, burning hydrocarbons produces only water and carbon dioxide. In reality, however, gasoline-only vehicles always produce some carbon monoxide (CO) because there can be insufficient oxygen during combustion. Carbon monoxide has direct effects on human health and also contributes to the formation of photochemical smog (see Chapter 15 for more on CO and air pollution).

Because ethanol is an **oxygenated fuel**—a fuel with oxygen as part of the molecule—adding ethanol to the fuel mix of a car should ensure that more oxygen is present and that combustion is more complete, which would reduce the production of CO. When it comes to combustion in vehicles, it is true that ethanol produces lower amounts of air pollutants than gasoline. However, when we compare the entire life cycle of growing, harvesting, and processing the corn

for ethanol, it turns out that ethanol produces more of many air pollutants than gasoline.

Is ethanol neutral in the production of greenhouse gases?

Biofuels are modern carbon, not fossil carbon. As a result, burning ethanol should not introduce additional carbon into the atmospheric reservoir because the carbon captured in growing the corn kernels and the carbon released in burning the ethanol should cancel each other out. That is, ethanol should be neutral in terms of the amount of carbon produced. However, when we once again consider the entire life cycle of ethanol, we are reminded that corn production requires fossil fuels for driving a tractor, fertilizer production, and processing the corn kernels to make ethanol. These are all sources of fossil carbon, which means that ethanol production causes a net increase in the amount of greenhouse gases being produced.

Various aspects of corn production, such as plowing and tilling, may release additional CO_2 into the atmosphere from organic matter that otherwise would have remained undisturbed in the A and B horizons of the soil. Furthermore, greater demand for corn will increase pressure to convert land that is forest, grassland, or pasture into cropland. There is increasing evidence that these conversions result in a net transfer of carbon from the soil to the atmosphere and lead to additional increases in atmospheric CO_2 concentrations. Moreover, in the United States, the ethanol production process currently uses more coal than natural gas. Because coal emits nearly twice as much CO_2 per joule of energy as natural gas (see Chapter 12), producing the ethanol may reverse many of the benefits of replacing gasoline's fossil carbon with ethanol's modern carbon. Quite possibly, producing ethanol with

Oxygenated fuel A fuel with oxygen as part of the molecule.





FIGURE SA6.1 An ethanol-producing factory. Ethanol-producing factories, such as this one in South Dakota, convert corn into ethanol to produce a fuel that can be mixed with gasoline to power automobiles. (Jim Parkin/Alamy)

coal releases as much carbon into the atmosphere as simply burning gasoline in the first place. This means that when we consider the entire life cycle of ethanol production, it is not carbon neutral (**FIGURE SA6.1**).

Does ethanol provide a substantial return on energy investment?

We can also ask how much ethanol production provides a return on the investment, which is how much energy we get out of ethanol for every unit of energy we put in. Scientists at the U.S. Department of Agriculture have analyzed this problem, examining the energy it takes to grow corn and convert it into ethanol (the inputs) and the return on this energy investment (the outputs). The energy inputs include the energy to run farm machinery, to produce chemicals (especially nitrogen fertilizer), dry the corn, transport the corn, convert it into ethanol, and ship it. The primary output is the ethanol, although several by-products are produced, including distiller's grains, corn gluten, and corn oil. Each by-product would have required energy to produce if it had been manufactured independently of the ethanol manufacturing process, and so energy "credit" is assigned to these by-products. As **FIGURE SA6.2** shows, there is a slight gain of usable energy when corn is converted into ethanol. For every unit of energy we put in, we obtain about 1.3 units of output. For comparison, for every unit of fossil fuel we invest in producing gasoline, we obtain about 15 units of output.

Does ethanol reduce our dependence on gasoline?

If there is a positive energy return on energy investment, then using ethanol should reduce the amount of gasoline we use and therefore the amount of foreign oil we must import. Our current production of 60 billion liters (16 billion gallons) of ethanol translates to about 4 percent of gasoline consumption in the United States. If our goal is to reduce gasoline consumption, much larger gains could be accomplished by having higher fuel mileage standards for cars and trucks.

What are the unintended impacts of ethanol production?

If we create greater demand for a crop that until now has been primarily used as a food source, there are many unintended impacts. For example, increased ethanol production has led to the large-scale conversion of cropland from food to fuel production. Even if we converted every acre of potential cropland to ethanol production, we could not produce enough ethanol to replace 20 percent of U.S. annual gasoline consumption. Furthermore, if all cropland in the United States were devoted to ethanol production, all agricultural products destined for the dinner table would have to be imported from other countries. Clearly this is not a practical solution.

What seems more likely is that we will be able to replace some smaller fraction of gasoline consumption

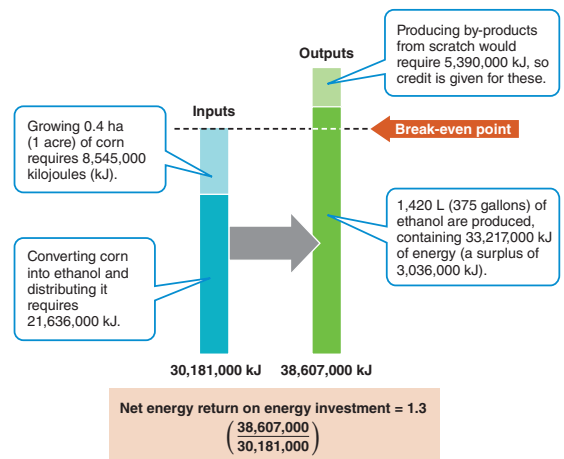


FIGURE SA6.2 Energy required to produce ethanol. An analysis of the energy costs of growing and converting 0.4 ha (1 acre) of corn into ethanol shows a slight gain of usable energy when corn is converted into ethanol. For every 1 unit of energy input, we obtain 1.3 units of energy output.

with biofuels. The Earth Policy Institute points out, however, that the 10 bushels of corn that it takes to produce enough ethanol to fill a 95-L (25-gallon) fuel tank in a vehicle contain the number of calories needed to feed a person for about a year. Higher ethanol demand would increase corn and other grain prices and would thus make it harder for lower-income people around the world to afford food.

Indeed, in the summer of 2007, corn prices in the United States rose to \$4 per bushel, roughly double the price in prior years, primarily because of the increased demand for ethanol. In more recent years, prices have stayed above \$3 per bushel and at times have gone above \$8 per bushel. People in numerous countries have had difficulty obtaining food because of these higher grain prices. In a number of years, most notably 2008 and 2015, there were food riots in many countries around the globe.

Are there alternatives to corn ethanol?

Stimulating demand for corn ethanol may spur the development of another ethanol technology—**cellulosic ethanol**, an ethanol derived from cellulose. Cellulose is the material that makes up the cell walls of plants: Grasses, trees, and plant stalks are made primarily of cellulose. If we were able to produce large quantities of ethanol from cellulose, we could replace fossil fuels with fuel made from a number of sources. Ethanol could be manufactured from fast-growing grasses such as switchgrass (*Panicum virgatum*) or Miscanthus grass (**FIGURE SA6.3**), tree species that require minimal energy input, discarded paper and agricultural waste, including corn stalks that are left behind when corn kernels are harvested for conventional ethanol production. It is also possible that algae could be used as the primary material for ethanol.

Producing cellulosic ethanol requires breaking cellulose into its component sugars before distillation. This is a difficult and expensive task because the bonds between the sugar molecules are very strong. One method of breaking down cellulose is to mix it with enzymes that sever these bonds. In 2007, the first commercial cellulosic ethanol plant was built in Iowa. At the moment, however, cellulosic ethanol is more expensive to produce than corn ethanol.

How much land would it take to produce significant amounts of cellulosic ethanol? Some scientists suggest that the impact of extensive cellulosic ethanol production would be very large, while others have calculated that, with foreseeable technological improvements, we could replace all of our current gasoline consumption without large increases in land under cultivation or significant losses in food production. Because the technology is so new, it is not yet clear who is correct. There will still be other considerations, such as the impact on biodiversity whenever land is dedicated to growing biofuels.

The good news is that many of the raw materials for cellulosic ethanol are perennial crops such as grasses. These



FIGURE SA6.3 A potential source of cellulosic ethanol. Miscanthus, a fast-growing tall grass, may be a source of cellulosic ethanol in the future. (Frank Dohleman)

crops do not require the high energy, fertilizer, and water inputs commonly used to grow annual plants such as corn. Furthermore, the land used to grow grass would not need to be plowed every year. Fertilizers and pesticides would also be unnecessary, eliminating the large inputs of energy needed to produce and apply them. Algae may be an even more attractive raw material for cellulosic ethanol because its production would not need to use land that could otherwise be used for growing food crops.

What's the bottom line?

When we compare the full life cycle of ethanol production, it is clear that ethanol results in a greater production of many air pollutants and it is not neutral in terms of greenhouse production. However, its greenhouse gas production is less than gasoline. The return on the energy invested to create ethanol is quite low compared to producing gasoline. Moreover, corn-based ethanol has the potential to replace only a small amount of total U.S. gasoline consumption. Increasing corn ethanol consumption to the levels suggested by some policy makers may require troublesome trade offs between driving vehicles and feeding the world. Cellulosic ethanol shows the potential to have a significant effect on fossil fuel use, at least in part because of lower energy inputs required to obtain the raw material and convert it into a fuel.

Questions

1. Legislation requiring that ethanol be added to gasoline was passed to improve air quality and reduce dependence on foreign oil. Do you think the latter goal is achieved by adding ethanol to gasoline?
2. What are some of the other environmental impacts of using corn-based ethanol that are not illustrated by energy calculations shown here?

Cellulosic ethanol An ethanol derived from cellulose, the cell wall material in plants.

Suggested Answers to Science Applied Questions

1. Yes, it will reduce the amount of foreign oil required, although not by very much. The other consequences of growing corn to produce ethanol suggest that there are probably much more effective ways to reduce the dependence on foreign oil.
2. Those calculations do not show other environmental impacts of growing corn such as reduction of land dedicated to growing food for people or livestock, and the environmental harm caused by herbicides and pesticides used on corn fields.

The answer to Science Applied 3 Practice AP[®] Free-Response Question is in the Answer Appendix on page ANS-11

TRM Answer to Science Applied 6 Practice AP[®] Free-Response Question

Answer to Science Applied 6 Practice AP[®] Free-Response Question contains a reproducible version of the answer to this question.

Answers to Unit 6 AP[®] Practice Exam Multiple-Choice Questions

- 1. c
- 2. b
- 3. b
- 4. c
- 5. b
- 6. d
- 7. d
- 8. d
- 9. a
- 10. d
- 11. b
- 12. a
- 13. d
- 14. d
- 15. a
- 16. c
- 17. b
- 18. c
- 19. d
- 20. a
- 21. a
- 22. c
- 23. d
- 24. b
- 25. b

Preparing for the AP[®] Exam

Practice AP[®] Free-Response Question

Write your answer to each part clearly. Support your answers with relevant information and examples. Where calculations are required, show your work.

The production of ethanol from corn is much like the production of any alcoholic beverage. Corn is harvested, ground, and cooked to form a “mash.” Added yeast use the sugar to grow and reproduce. As they grow, yeast respire CO₂ and produce ethanol as a waste product through fermentation. Since ethanol has a lower boiling point than water, the fermented product can be boiled to evaporate the ethanol, which is a process known as distillation. Evaporated ethanol is then collected through condensation.

- (a) Identify SIX energy inputs in the process of producing corn ethanol. (2 points)
- (b) Using the answers provided in question (a), write an equation that would calculate the energy return on energy investment (EROEI) for ethanol production. (2 points)
- (c) The leftover mash consists of water and corn. Ethanol producers will often dry this mash, collect the corn, and sell it as livestock feed. Why might this livestock feed be less beneficial for livestock than unfermented corn? (2 points)

- (d) If the price of food increases around the world as a result of corn ethanol production, poorer communities may revert to subsistence energy production. Explain how this reversion could impact the total environmental benefit of ethanol production. (2 points)
- (e) Cellulosic ethanol production is similar to corn ethanol production, except producers make use of enzymes that increase the sugar content of the mash, which in turn increases the energy available for yeast to grow. Describe two benefits and two disadvantages of cellulosic ethanol production relative to corn ethanol production.

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Key Terms

- Oxygenated fuel
- Cellulosic ethanol

Unit 6 AP[®] Environmental Science Practice Exam

Preparing for the AP[®] Exam

Section 1: Multiple-Choice Questions

Choose the best answer for questions 1–25.

1. Within a developing nation, an increase in the use of subsistence energy sources would most likely be caused by
 - (a) a decrease in the availability of straw, sticks, animal dung, and other local sources of fuel.
 - (b) an increase in the availability of oil.
 - (c) an increase in the cost of oil.
 - (d) the loss of forested land.

Questions 2 and 3 refer to following table:

| Energy type | Energy return on energy investment | MJ per kilogram of fuel |
|------------------------|------------------------------------|-------------------------|
| Biodiesel | 1 | 40 |
| Coal | 80 | 24 |
| Ethanol from corn | 1 | 30 |
| Ethanol from sugarcane | 5 | 30 |

2. Which fuel is most likely the least expensive fuel to produce per MJ of fuel?
 - (a) biodiesel
 - (b) coal
 - (c) ethanol from corn
 - (d) ethanol from sugarcane

TRM Answers to Unit 6 AP[®] Practice Exam

Answers to Unit 6 AP[®] Practice Exam contains a reproducible version of the answers.

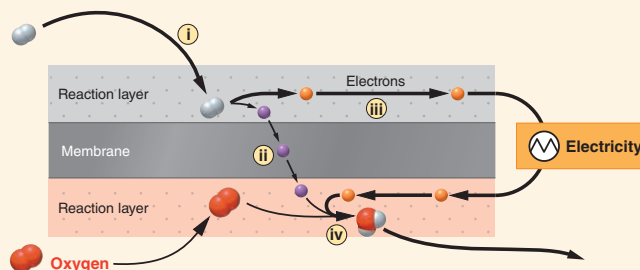
3. How many kilograms of fuel will be consumed if someone travels 200 km in a car that uses 3 MJ of biodiesel per kilometer?
- 7.5 kg
 - 15 kg
 - 22 kg
 - 66 kg
4. Which is likely to reduce the efficiency of a power plant?
- Increasing the capacity factor of the plant
 - Using anthracite coal instead of bituminous coal
 - Shutting off a turbine driven by exhaust gases
 - Pumping cold water from a nearby stream into the condenser
5. Which is a benefit of using petroleum instead of coal for energy?
- Petroleum releases about 15 percent more CO₂ than coal.
 - Petroleum flows more easily than coal.
 - Mining and transport of petroleum is less harmful to the environment.
- I only
 - II only
 - III only
 - I and II
6. Which is true regarding natural gas?
- Extraction and combustion of natural gas have less effect on global warming than extraction and combustion of coal.
 - Contamination of water during the extraction process is of little concern.
 - Liquefied petroleum gas is slightly more energy-dense than natural gas.
 - Pipelines are the primary means of transporting natural gas.
7. In 1969, M. King Hubbert calculated lower and upper estimates for the volume of total world petroleum reserves. Regardless of which estimate was used, he predicted that 80 percent of the total reserves would be used up in approximately 60 years. Which of the following likely explains why his predictions were the same for both estimates?
- The lower and upper estimates were not different enough to cause a major significant shift in his predictions.
 - Per capita energy use will increase with available energy.
 - Availability and use of petroleum is inversely correlated with cost.
- I only
 - II only
 - III only
 - II and III
8. In a nuclear power plant, control rods are used to
- control the placement of fuel rods.
 - increase the efficiency of nuclear reactions.
 - transfer heat energy from the fuel rods into water.
 - absorb excess neutrons emitted by fuel rods.
9. One particularly large nuclear power plant produces about 400 kilocuries of krypton per year. Krypton has a half-life of 10 years. After 30 years, what will be the radioactivity of the krypton waste generated in a single year?
- 50 kilocuries
 - 100 kilocuries
 - 200 kilocuries
 - 800 kilocuries
10. Which reduces the capacity factor of nuclear power plants?
- the need for long-term storage of radioactive waste
 - government regulation of low-level radioactive waste
 - competition with plants that use coal to produce energy
 - the need to periodically replace fuel rods
11. Which is a renewable energy source that does not originate from solar radiation?
- biomass
 - geothermal
 - nuclear
 - wind
12. A homeowner in the Northern Hemisphere wants to save money and energy by using a passive solar design for heating. The homeowner could consider
- opening window blinds on southern exposure sunny winter days.
 - using only Energy Star appliances.
 - placing photovoltaic cells on the roof.
 - installing a ground source heat pump.
13. Suppose you own a diesel car and the current price of diesel gasoline is \$3.00 per gallon. You pay \$750 for parts that allow the engine to be converted so it can operate on straight vegetable oil (SVO), which costs \$1.50 per gallon. The car gets 50 miles per gallon when running on either type of fuel. After how many miles will you recoup the cost of engine conversion?
- 1,500
 - 5,000
 - 10,000
 - 25,000
14. Relative to burning fossil carbon, the use of modern carbon for energy
- rarely contributes to the removal of vegetation.
 - does not use energy that originates from the Sun.
 - is cheaper and more efficient.
 - is more likely to be carbon-neutral.
15. Which consequence of water impoundment for hydroelectric energy production is most likely to release greenhouse gases?
- flooding of forests and grasslands
 - siltation
 - the generation of electricity by use of turbines
 - transfer of energy to power lines

TRM Unit 6 Additional AP® Practice Free-Response Question

Unit 6 Additional AP® Practice Free-Response Question is an additional free-response question for you to test concepts from Unit 6 with your students. This free-response question asks students to consider the long-term benefits of wind energy. To answer this question, students must

- describe how the sun and rotation of the Earth combine to produce the energy needed to run a wind turbine.
- explain what determines the capacity factor of a windmill.
- use provided data to calculate the number of wind turbines needed to generate enough electricity for the United States.

Question 16 refers to the following diagram.



16. In this depiction of a hydrogen powered fuel cell, components i, ii, iii, and iv refer to
- hydrogen, protons, neutrons, water.
 - hydrogen, protons, hydrogen ions, water.
 - hydrogen, protons, electrons, water.
 - hydrogen, electrons, protons, water.
17. The combined use of concentrated solar thermal (CST) and fossil fuel energy generation can provide for greatest grid reliability when
- CST and fossil fuel plants are built near each other.
 - fossil fuels are able to be used when CST is unavailable.
 - CST and fossil fuel energy are equally distributed to the power grid.
 - fossil fuel plants are built in desert areas where there is consistent sunshine and plenty of open space.
18. Which sources of electricity employ the use of turbines?
- photovoltaic cells, windmills, run-of-the-river hydroelectric plants
 - photovoltaic cells, windmills, water impoundment hydroelectric dams
 - concentrated solar thermal plants, nuclear plants, windmills
 - concentrated solar thermal plants, water impoundment hydroelectric dams, fuel cells
19. Which is most likely to increase the efficiency of energy use in the United States?
- government subsidies for active solar construction designs
 - decreasing the cost of fossil fuels
 - replacement of large power plants with several smaller plants
 - substitution of incandescent lighting with LEDs
20. A smart grid system
- regulates electrical energy usage according to electrical energy availability.
 - requires more energy-efficient electricity production.
 - will reduce the cost of energy production.
- I only
 - II only
 - III only
 - I and II
21. The _____ projects when world oil production will peak and when world oil will be depleted.
- Hubbert curve
 - Hadley cell
 - petroleum development index
 - Kyoto Protocol
22. Which is a subsistence energy source?
- ethanol
 - bitumen
 - wood
 - wind
23. While natural gas is considered to be cleaner than coal or oil, it has disadvantages, including
- the release of methane.
 - increased sulfur dioxide emissions.
 - groundwater contamination.
- I only
 - II only
 - III only
 - I and III
24. At a particular wind farm, 3 J of energy is expended in order to obtain 45 J of energy, and its capacity factor is 0.25. What is the EROEI of this wind farm?
- 3.75
 - 15
 - 34
 - 60

25. While only 20 percent of the world's population lives in developed countries, people in those countries use approximately _____ of the world's energy each year.
- 30 percent
 - 50 percent
 - 70 percent
 - 80 percent

Section 2: Free-Response Questions

Write your answer to each part clearly. Support your answers with relevant information and examples. Where calculations are required, show your work.

- Although hybrid and electric vehicles release less carbon dioxide per distance traveled than internal combustion engine—gasoline-powered vehicles, there remains some debate over whether hybrid vehicles are better for the environment and whether their overall efficiency is greater.
 - Provide TWO reasons why hybrid and electric vehicles might be less energy-efficient than gas-powered cars. (3 points)
 - How might the average lifetime of a hybrid or electric vehicle versus a conventional internal combustion engine vehicle alter an analysis of the total ecological footprint of the vehicles? (2 points)
 - Suppose a new all-electric vehicle costs \$40,000 and requires 1.5 MJ per passenger-mile. You trade in your old gasoline-powered vehicle, which required 4 MJ per passenger-mile, for \$2,000.
 - Supposing that a gallon of gasoline contains 20 MJ and costs \$4.00, how many miles must you drive before your purchase becomes cost effective? (3 points)
 - How might the use of “smart grid” technology reduce the environmental footprint of an electric vehicle? (2 points)
- Electricity accounts for 40 percent of overall energy use in the United States. It is a secondary source of energy since we obtain it through the conversion of a primary source of energy, like coal or wind.
 - How is electricity generated in a typical power plant? (2 points)
 - Define capacity and capacity factor. Explain how capacity factors may differ between plants powered by nonrenewable fuels such as coal, and those powered by wind and solar. (4 points)
 - Energy demands can vary depending on season, weather, and time of day. What problem can occur due to this varying demand for energy? What could an electric company do to deal with this issue and increase energy conservation? (2 points)
 - If an average home in a city uses 12,000 kWh per year, how many homes can a 700 MW power plant with a 0.5 capacity factor support? (2 points)

of the average conventional internal combustion engine vehicle, the analysis of which vehicle may have a greater ecological footprint should be done.

(c) (i) Since the new vehicle costs \$40,000 and you received \$2,000 for your old vehicle, you must save \$38,000 in fuel costs to make your purchase cost-effective. With the price of gas at \$4.00 per 20 MJ, you can determine the total number of MJ that \$38,000 can buy:

$$\$38,000 \times \frac{20 \text{ MJ}}{\$4} = 190,000 \text{ MJ}$$

You save $4 - 1.5 = 2.5$ MJ per passenger-mile driven. So, the purchase becomes cost-effective after $190,000 \text{ MJ} \div 2.5 \text{ MJ} = 76,000$ miles.

(ii) A smart grid coordinates energy use with energy availability using two-way communication between electricity consumers and electricity generators. End-user appliances utilize computers that coordinate with the distribution network to reduce electricity use during peak demand, and defer all possible electricity use to times of low demand when there is excess electricity capacity. By using smart grid technology with electric vehicles, owners could increase the overall efficiency of the electricity production/automobile charging/automobile use system. Such increased efficiency could reduce the ecological footprint of the vehicles by decreasing the amount of fossil fuel energy used to generate electricity and possibly lower the number of new energy generation plants that would need to be built.

- (a) Fuel is delivered to a boiler and is burned. The energy contained within the combusted fuel is transferred to water, which becomes steam. The kinetic energy contained within the steam is transferred to the blades of a turbine, a device that can be turned by water, steam, or wind. As the energy in the steam turns the turbine, the shaft in the center of the turbine turns the generator, which generates electricity.

Answers continue in the Answer Appendix on page ANS-12.

Answers to Unit 6 AP® Practice Free-Response Questions

- (a) There are several reasons why hybrid and electric vehicles might be less energy efficient than gas-powered cars:
 - If the electricity to fuel the electric vehicle is generated from coal, the process of mining coal and converting it into electricity is only about 35 percent efficient, which severely reduces the overall efficiency of an electric-powered car.
 - Hybrid and electric vehicles require more expensive components and may involve a more labor-intensive construction process. The energy used to build the car must be factored into the overall efficiency of the car.
 - Hybrid and electric vehicles typically have lower operating costs than similarly sized conventional vehicles, so the lower operating costs may encourage more driving efficiency.
 - Batteries use materials that require energy intensive mining of relatively rare metals. If you factor this into the total energy to manufacture and operate a vehicle, it may change the overall energy balance of the car.
- (b) Cars require energy to build, operate, and recycle. If the total lifetime of a hybrid or electric car is shorter or longer than that

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