Reinforced Binding

Environmental Science

A Study of Interrelationships

Sixteenth Edition

Sample Chapter
Student Edition

McGraw Hill

Eldon D. Enger
Bradley F. Smith

Environmental Science

A Study of Interrelationships

SIXTEENTH EDITION

High School Edition

ELDON D. ENGER
Delta College

BRADLEY F. SMITH
Western Washington University

Contributing Authors:

CRAIG D. PHELPS
Rutgers University

MAARTEN VONHOF
Western Michigan University

DAVID MURPHY
St. Lawrence University

GRACE WANG
Western Washington University

Reinforced Binding

What does it mean?
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ENVIRONMENTAL SCIENCE, SIXTEENTH EDITION

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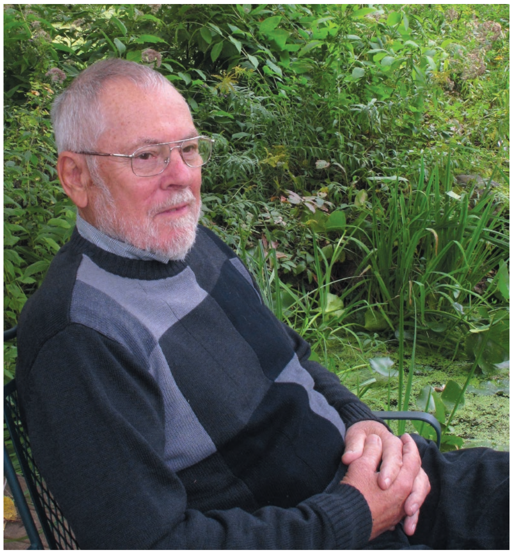
To Judy, my wife and friend,
for sharing life's adventures

ELDON ENGER

For my lovely wife Daria,
who has survived 45 years with me
and 16 editions.

BRAD SMITH

About the Authors



Courtesy of Eldon D. Enger

Eldon D. Enger is an emeritus professor of biology at Delta College, a community college near Saginaw, Michigan. He received his B.A. and M.S. degrees from the University of Michigan. Professor Enger has over 30 years of teaching experience, during which he has taught biology, zoology, environmental science, and several other courses. He has been very active in curriculum and course development. A major curriculum contribution was the development of an environmental technician curriculum and the courses that support it. He was also involved in the development of learning community courses in stream ecology, winter ecology, and plant identification. Each of these courses involved students in weekend-long experiences in the outdoors that paired environmental education with physical activity—stream ecology and canoeing, winter ecology and cross-country skiing, and plant identification with backpacking.

Professor Enger is an advocate for variety in teaching methodology. He feels that if students are provided with varied experiences, they are more likely to learn. In addition to the standard textbook assignments, lectures, and laboratory activities, his classes included writing assignments, student presentation of lecture material, debates by students on controversial issues, field experiences, individual student projects, and discussions of local examples and relevant current events. Textbooks are very valuable for presenting content, especially if they contain accurate, informative drawings and visual examples. Lectures are best used to help students see themes and make connections, and laboratory activities provide important hands-on activities.

Professor Enger received the Bergstein Award for Teaching Excellence and the Scholarly Achievement Award from Delta College and was selected as a Fulbright Exchange Teacher twice—to Australia and Scotland. He has participated as a volunteer in several Earthwatch Research Programs. These include studying the behavior of a bird known as the long-tailed manakin in Costa Rica, participating in a study to assess the possibility of reintroducing endangered marsupials from off-shore islands to mainland Australia, helping with efforts to protect the nesting beaches of the leatherback turtle in Costa Rica, and assisting with on-going research on the sustainable use of fish, wildlife, and forest resources in the Amazon Basin in Peru. He also participated in a People to People program, which involved an exchange of ideas between U.S. and South African environmental professionals.

He has traveled extensively, which has allowed him first-hand experience with coral reefs, ocean coasts, savannas, mangrove swamps, tundra, prairies, tropical rainforests, cloud forests, deserts, temperate rainforests, coniferous forests, deciduous forests, and many other special ecosystems. These experiences have provided opportunities to observe the causes and consequences of many environmental problems from a broad social and scientific perspective.

He volunteers at a local nature center, land conservancy, and Habitat for Humanity affiliate. Since 2005, he and his wife have spent a month each year with other volunteers from their church repairing houses damaged by tornados, floods, and hurricanes throughout the United States.

Professor Enger and his wife Judy have two married sons and four grandchildren. He enjoys a variety of outdoor pursuits such as cross-country skiing, snowshoeing, hiking, kayaking, hunting, fishing, camping, and gardening. Other interests include reading a wide variety of periodicals, beekeeping, singing in a church choir, picking wild berries, and preserving garden produce.

Bradley F. Smith is the Dean Emeritus of Western Washington University in Bellingham, Washington, having served as Dean from 1994 to 2012. Prior to assuming the position as Dean in 1994, he served as the first Director of the Office of Environmental Education for the U.S. Environmental Protection Agency in Washington, D.C., from 1991 to 1994. Dean Smith also served as the Acting President of the National Environmental Education and Training Foundation in Washington, D.C., and as a Special Assistant to the EPA Administrator.

Courtesy of Bradley F. Smith

Before moving to Washington, D.C., Dean Smith was a professor of political science and environmental studies for 15 years, and the executive director of an environmental education center and nature refuge for five years.

Dean Smith has considerable international experience. He was a Fulbright Exchange Teacher to England and worked as a research associate for Environment Canada in New Brunswick. He is a frequent speaker on environmental issues worldwide and serves on the International Scholars Program for the U.S. Information Agency. He also served as a U.S. representative on the Tri-Lateral Commission on environmental education with Canada and Mexico. He was awarded a NATO Fellowship to study the environmental problems associated with the closure of former Soviet military bases in Eastern Europe. He is a Fellow of the Royal Institute of Environmental Science in the U.K.

Dean Smith is a commissioner of the Washington State Fish and Wildlife Commission (served as Chair from 2015–2020). He is the chair of the board of trustees for Bellingham Technical College (BTC). BTC operates a fish hatchery as part of their aquaculture program that produces 5 million salmon a year for Puget Sound. Dean Smith is a member or the Governors Orca Whale Task Force. He also serves on the North Pacific Research Board and on the Bering Sea Fisheries Advisory Board and on the board of Washington Sea Grant. Previously, he served as chair of the Washington State Sustainability Council, as president of the Council of Environmental Deans and Directors, as a Trustee of the National Environmental Education Foundation, and as a member of the National Advisory Council for Environmental Policy and Technology for the USEPA. He also served on President Bill Clinton's council for Sustainable Development (Education Task Force). From 2004 to 2013 he served on the Steering Committee of the Commission for Education and Communication for the International Union for the Conservation of Nature (IUCN) in Gland, Switzerland.

Dean Smith holds a Ph.D. from the School of Natural Resources and the Environment at the University of Michigan.

Dean Smith and his wife, Daria, live along the shores of Puget Sound in Bellingham, Washington, and spend part of the summer at their summer home on the shores of Lake Huron in the Upper Peninsula of Michigan. He has two married grown children and two grandchildren, and is an avid outdoor enthusiast.

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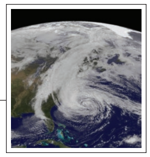
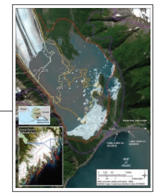


NASA Earth Observatory image by Robert Simmon with data courtesy of the NASA/NOAA GOES Project Science team



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The Role of Environmental Science in Society

We live in a time of great change and challenge. Our species has profoundly altered the Earth. Our use of fossil fuels to provide energy is altering climate, our use of Earth's soil resources to feed ourselves results in extinctions, overexploitation of fish populations has resulted in the population declines of many marine species, and freshwater resources are becoming scarce. At the same time, we see significant improvement in other indicators. Energy-efficient and alternative energy technologies are becoming mainstream, population growth is beginning to slow, air and water pollution problems are being addressed in many parts of the world, and issues of biodiversity loss, climate change, and human health are beginning to be addressed on a worldwide basis.

However, there are still major challenges, and there are additional opportunities to lighten our impact on Earth. Understanding the fundamental principles that describe how the Earth's systems work is necessary knowledge for everyone, not just scientists who study these systems. It is particularly important for political, industrial, and business leaders because the political, technical, and economic decisions they make affect the Earth.

Why "A Study of Interrelationships"?

Environmental science is an interdisciplinary field. Because environmental problems occur as a result of the interaction between humans and the natural world, we must include both scientific and social aspects when we seek solutions to environmental problems. Therefore, the central theme of this book is interrelatedness. It is important to have a historical perspective, to appreciate economic and political realities, to recognize the role of different social experiences and ethical backgrounds, and to integrate these with the science that describes the natural world and how we affect it. *Environmental Science: A Study of Interrelationships* incorporates all of these sources of information when discussing any environmental issue.

Environmental science is also a global science. While some environmental problems may be local in nature—pollution of a river, cutting down a forest, or changing the flow of a river for irrigation—other problems are truly global—climate change, overfishing of the oceans, or loss of biodiversity. In addition, individual local events often add together to cause a worldwide problem—the actions of farmers in China or Africa can result in dust storms that affect the entire world, or the individual consumption of energy from fossil fuels increases carbon dioxide concentrations in the Earth's atmosphere. Therefore, another aspect of the interrelationships theme of this text is to purposely include features that highlight problems, issues, and solutions involving a variety of cultures.

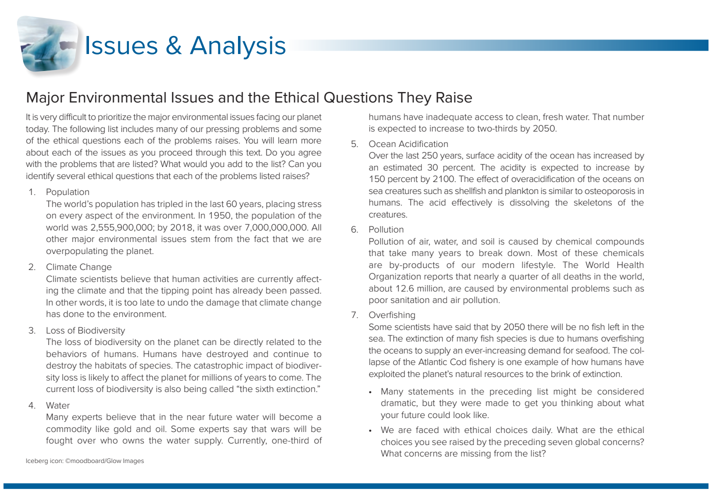
This text has been translated and published in Spanish, Chinese, and Korean. Therefore, students in Santiago, Shanghai, Seoul, or Seattle are learning the "hows and whys" involved in thinking and acting sustainably. At the end of the day, we all share the same air, water, and one not-so-big planet. It's important for all of us to make it last.

What Makes This Text Unique?

We present a balanced view of issues, diligently avoiding personal biases and fashionable philosophies.

It is not the purpose of this textbook to tell readers what to think. Rather, our goal is to provide access to information and the conceptual framework needed to understand complex issues so that readers can comprehend the nature of environmental problems and formulate their own views. Two features of the text encourage readers to think about issues and formulate their own thoughts:

- The **Issues & Analysis** feature at the end of each chapter presents real-world, current issues and provides questions that prompt students to think about the complex social, political, and scientific interactions involved.



Issues & Analysis

Major Environmental Issues and the Ethical Questions They Raise

It is very difficult to prioritize the major environmental issues facing our planet today. The following list includes many of our pressing problems and some of the ethical questions each of the problems raises. You will learn more about each of the issues as you proceed through this text. Do you agree with the problems that are listed? What would you add to the list? Can you identify several ethical questions that each of the problems listed raises?

1. Population
   The world's population has tripled in the last 60 years, placing stress on every aspect of the environment. In 1950, the population of the world was 2,555,900,000; by 2018, it was over 7,000,000,000. All other major environmental issues stem from the fact that we are overpopulating the planet.
2. Climate Change
   Climate scientists believe that human activities are currently affecting the climate and that the tipping point has already been passed. In other words, it is too late to undo the damage that climate change has done to the environment.
3. Loss of Biodiversity
   The loss of biodiversity on the planet can be directly related to the behaviors of humans. Humans have destroyed and continue to destroy the habitats of species. The catastrophic impact of biodiversity loss is likely to affect the planet for millions of years to come. The current loss of biodiversity is also being called "the sixth extinction."
4. Water
   Many experts believe that in the near future water will become a commodity like gold and oil. Some experts say that wars will be fought over who owns the water supply. Currently, one-third of humans have inadequate access to clean, fresh water. That number is expected to increase to two-thirds by 2050.
5. Ocean Acidification
   Over the last 250 years, surface acidity of the ocean has increased by an estimated 30 percent. The acidity is expected to increase by 150 percent by 2100. The effect of overacidification of the oceans on sea creatures such as shellfish and plankton is similar to osteoporosis in humans. The acid effectively is dissolving the skeletons of the creatures.
6. Pollution
   Pollution of air, water, and soil is caused by chemical compounds that take many years to break down. Most of these chemicals are by-products of our modern lifestyle. The World Health Organization reports that nearly a quarter of all deaths in the world, about 12.6 million, are caused by environmental problems such as poor sanitation and air pollution.
7. Overfishing
   Some scientists have said that by 2050 there will be no fish left in the sea. The extinction of many fish species is due to humans overfishing the oceans to supply an ever-increasing demand for seafood. The collapse of the Atlantic Cod fishery is one example of how humans have exploited the planet's natural resources to the brink of extinction.

- Many statements in the preceding list might be considered dramatic, but they were made to get you thinking about what your future could look like.
- We are faced with ethical choices daily. What are the ethical choices you see raised by the preceding seven global concerns? What concerns are missing from the list?

Iceberg icon: ©moodboard/Glow Images

- The **What's Your Take?** feature found in each chapter asks students to take a stand on a particular issue and develop arguments to support their position, helping students develop and enhance their critical thinking skills.

What's Your Take?

The grizzly bear (*Ursus arctos horribilis*) has been receiving federal protection under the U.S. Endangered Species Act for over 30 years. The federal government has now proposed removing that protection on the basis of increasing numbers of bears in the Greater Yellowstone ecosystem and elsewhere. There is considerable disagreement among conservation biologists about how many bears are needed for the species to be "recovered." When a species is delisted, management is handed over to individual states. If it proposes an acceptable plan, a state may introduce a management plan that includes the hunting of the previously listed species. What kind of ethic underlies the Endangered Species Act? What kind of ethic underlies a management plan that includes hunting? Develop an ethical argument for or against the delisting of the grizzly bear.

Plant icon: ©Bear Dance Studios/Mark Dierker

We recognize that environmental problems are global in nature.

Three features of the text support this concern:

- Throughout the text, the authors have made a point to use **examples** from around the world as well as those from North America.
- Many of the boxed readings—**Focus On; Going Green; Science, Politics, & Policy;** and **Issues & Analysis**—are selected to provide a global flavor to the basic discussion in the text.

Focus On

Refugees—Involuntary Migrants

Refugees are involuntary migrants who flee their home countries because they fear persecution, war, or violence. It is also possible for persons to leave their home country because of natural disasters (drought, floods, etc.) that endanger their lives. Refugees are essentially international migrants who are seeking a safe place to live. According to the Office of the United Nations High Commissioner for Refugees (UNHCR), there were about 30 million refugees in the world at the end of 2019. Over half of them were from Afghanistan, Syria, and South Sudan, where war caused people to flee their home country.

When refugees cross borders, they have limited rights and protections because they are not citizens of the countries they enter. While most host countries recognize a humanitarian responsibility to help these people, the refugees are a significant social and economic burden. After all, refugees are generally poor, have not paid taxes to the host country, and are unlikely to be able to pay for services. Thus governments seek to control the entry of refugees and may restrict their movement, require settlement in refugee camps, and limit their access to health care, education, and other services.

The influx of a large number of people disrupts the local social structure of the host country. Any funding that is shifted to helping refugees reduces the amount of money available to fund programs for legal citizens. In addition, if refugees remain in an area, they will try to find jobs to earn money. Others may beg or steal. One of the outcomes of this tension between local citizens and refugees is the development of nationalistic or anti-immigrant groups among the host countries' citizens.

A sign from a demonstration in London, England October 2016
Rachel La Corte/AP Images


A camp in Turkey for Syrian refugees.
SOPA Images/Getty Images

Butterfly icon: ©Kris Bradley/flickr RF/Getty Images

We recognize that many environmental issues involve complex social, economic, and cultural aspects.

- The first three chapters focus on the underlying social, economic, health, and ethical aspects involved in understanding how people view environmental issues.
- The **Science, Politics, & Policy feature** shows how the scientific understanding of environmental problems is filtered through the lens of social and political goals to determine policy.
- Critical Thinking questions appear at the end of each chapter and require students to evaluate information, recognize bias, characterize the assumptions behind arguments, and organize information.

Science, Politics, & Policy

A History of Mercury Regulations

Science Facts

Mercury is a metal that is liquid at room temperature. It has been known to be toxic for centuries. However, when mercury enters aquatic ecosystems it can be converted to methylmercury by the action of bacteria. The methylmercury becomes concentrated in aquatic food chains and becomes a human health problem when certain species of fish are eaten by humans. The toxic effects of methylmercury have been known since the 1930s. Since methylmercury impairs brain development, fetuses, infants, and children are particularly susceptible. Because of the level of methylmercury and other toxic materials in fish, every state has advisories against eating certain kinds of fish from certain locations.

Because of the known health effects of elemental mercury and methylmercury, the EPA successfully regulated several of the major sources of mercury emissions such as cement plants and those industries that use mercury in their manufacturing processes. The primary remaining source of mercury in the environment is the stack gases from power plants that burn coal or oil. Mercury from power plants is released into the atmosphere and enters watersheds, where it is converted to methylmercury and becomes incorporated into the bodies of organisms.

Politics and Court Actions

The *George W. Bush administration* (2001–2009) in essence allowed power plants to be exempt from the Clean Air Act, which enabled power plants to avoid the cost of retrofitting their equipment to reduce mercury emissions. In 2008, a lawsuit was filed by several environmental organizations in the U.S. Circuit Court of Appeals in Washington, D.C. The appeals court overturned the Bush administration's mercury regulations and instructed the EPA to come up with a new rule. In 2009, an electric power industry group, Utility Air Regulatory Group, asked the Supreme Court to review the ruling by the appeals court, arguing that the Bush administration had legally decided not to regulate power plants under the Clean Air Act. The Supreme Court denied the request.

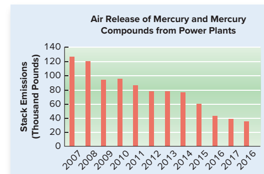
During the Obama administration (2009-2017) there were several regulatory and court actions. In December 2011, in response to the appeals court order to produce a new rule on mercury releases from power plants, the EPA published the Mercury and Air Toxics Standards (MATS) rule . MATS set a limit on the amount of mercury that power plants could release. Power plants were given four years in which to comply with the ruling. The rule would have ultimately reduced mercury emissions by 90 percent. Because there are several kinds of power plants that use different kinds of coal and other fuels, the setting of rules was a complicated process. In general, new plants must meet much more stringent requirements than existing plants.

In 2015, as a result of a lawsuit by Michigan and 20 other states and industry groups, the Supreme Court ruled 5 to 4 that the EPA should have considered the cost to industry of implementing the rule. The Washington D.C. circuit court reviewed the Supreme Court's ruling and decided that the EPA did not need to stop enforcement of the MATS rule while they completed the cost-benefit analysis. The states appealed the circuit court's ruling to the Supreme Court. In March 2016, Chief Justice John Roberts rejected a request to stay the Mercury and Air Toxic Standards rule. So the EPA could proceed with its enforcement actions while it conducted its investigations of the cost of implementing the rule. *The Trump administration began in* 2017. President Trump had promised more jobs in the coal industry, and less regulation on industry. In December 2018, in response to the Supreme Court ruling that the cost to industry should have been considered when the MATS rule was established, the EPA determined that the cost to industry was greater than the value of the health benefits of reducing mercury in the environment. Therefore, it was not "appropriate and necessary" to regulate mercury emissions from power plants. By 2020, the rule had not been finalized.


Emissions from coal-fired power plants are the major source of mercury in the environment.
Larry Lee Photography/Getty Images

Power Industry Reaction

Despite years of political maneuvering and court challenges, there is still no clear policy on mercury releases from power plants. However, the power industry has reacted to the availability of natural gas and the MATS rule by cancelling plans to build new coal-fired power plants and by shutting down many older (more polluting) coal-fired plants. Between 2010 and 2018 the amount of electricity generated by coal-fired plants declined by 38 percent as many coal-fired plants were shut down. This resulted in a reduction in the demand for coal. Between 2013 and 2019, coal production fell by nearly 25 percent, and thousands of jobs were lost as several coal companies filed for bankruptcy. However, there is a silver lining. Throughout the years this issue has been fermenting, the actual mercury emissions from power plants have fallen by 70 percent, primarily because of the reduction in the number of coal-fired power plants. (See graph.)



Rock icon: ©Shutterstock/totajla

We recognize that it is important to focus on the positive.

Environmental science often seems to focus on the negative, since one of the outcomes of any analysis of an environmental situation is to highlight problems and point out where change is needed. We often overlook the many positive actions of individuals and organizations. Therefore, each chapter has two features that call attention to the positive:

- **Going Green** boxes describe actions that are having a positive environmental impact. Some of these actions are taken by governments, some are by corporations, and some are individual efforts.

Going Green

From Toilet Water to Tap Water

Reuse of wastewater to recover water is becoming an important strategy in water-stressed areas. Options for water sources used for drinking water continue to evolve. All water, to some extent, is recycled. River water often is withdrawn and used by one city, which returns treated wastewater to the river. A town downstream uses this water as a source for drinking water for its citizens. In situations where municipalities are experiencing shortages of water, many have identified treated wastewater as a source of water that can be reused for other purposes.

Many wastewater recycling programs provide water for agriculture, landscape, or industrial use. Using wastewater for irrigation accounts for 10 percent of irrigation water in developing countries. This is known as *nonpotable reuse*. However, many municipalities are now using treated wastewater as a source for drinking water. No federal laws govern reusing treated wastewater for drinking. However, wastewater destined for reuse as potable water typically undergoes two additional steps not usually part of a typical wastewater treatment plant. Microfiltration and reverse osmosis can remove tiny particles (bacteria, viruses, sediment) and dissolved molecules from the wastewater. In most cases, a city's treated wastewater doesn't go directly into the tap but is piped into the ground, or released into lakes or reservoirs that the municipality uses as its source of drinking water. It mixes with the groundwater or surface water and enters a water treatment plant, where it is processed to meet drinking water standards before being funneled to consumers' taps. This process is known as *indirect potable reuse*. Orange County, California, and St. Petersburg, Florida, use treated wastewater to recharge groundwater. Fairfax County, Virginia, releases its treated wastewater into a reservoir used as a source of drinking water. About 20 percent of the water entering the reservoir is wastewater. The country of Singapore uses treated wastewater for industrial needs, and during water shortages it is added to a reservoir that is a water supply for drinking water.

A few cities, in areas with severe water shortages, send treated wastewater directly to a water treatment plant. This is known as *direct potable reuse*. Windhoek, Namibia, is in an extremely water-stressed part of Africa and has been recycling wastewater since 1968. Today, with the construction of a new treatment plant, about 35 percent of its drinking water comes from recycled wastewater. In the United States, Big Spring, Texas, and Wichita Falls, Texas, have both constructed wastewater treatment plants that supply water directly to drinking water treatment plants.

Mary Knox Merrill/Getty Images

Yet, because of the controversy surrounding this type of water recycling, public acceptance has become as crucial as politics or cost in whether it's implemented. In Toowoomba, Australia, about 100 kilometers (60 miles) west of Brisbane, residents soundly defeated a 2006 proposal to add recycled wastewater to the drinking water supply, despite the area's perpetual water shortage. As periodic drought and population growth create conditions of water shortage and knowledge about wastewater recycling grows, more cities will be looking to wastewater as a source of drinking water. Would you have difficulty drinking "recycled" wastewater? In truth, don't you drink such water already?

Tree icon: stumayhew/Flickr/Getty Images

- **Acting Green** is an end-of-chapter feature that asks students to consider making personal changes that are relatively simple and will have a positive environmental impact.

Acting Green

1. Learn to identify five plants native to your area.
2. Visit a nature center, wildlife refuge, or state nature preserve. List 10 organisms you identified.
3. Participate in a local program to restore a habitat or eliminate invasive species.
4. Participate in Earth Day (April 22) and Arbor Day (in the spring, but the date varies by state) activities in your community.
5. Visit the National Wildlife Federation website and learn about its Backyard Wildlife Habitat Program.
6. Visit a disturbed site–vacant lot, roadside, abandoned farmland. What evidence do you see that succession is taking place?
7. Participate in a local river or shoreline cleanup program.
8. Make an attempt to spend some time every week in nature. When you do, do so "unplugged."

New to This Edition

The sixteenth edition of *Environmental Science: A Study of Interrelationships* is the result of extensive analysis of the text and the evaluation of input from environmental science instructors who conscientiously reviewed chapters during the revision. We have used the constructive comments provided by these professionals in our continuing efforts to enhance the strengths of the text.

Current Content As with previous editions, the authors have incorporated the most recent information available at the time of publication.

Revised Art Program Over 120 illustrations, graphs, and charts are new or revised to present detailed information in a form that is easier to comprehend than if that same material were presented in text form.

Several Significantly Revised Chapters

Chapter 1 Environmental Interrelationships The chapter has been completely reorganized to provide a better conceptual flow of information. There is greater emphasis on urbanization, globalization, and governance. There is also a new **Issues & Analysis** on federal land-use in the American West and a new **Focus On** dealing with COVID-19.

Chapter 2 Environmental Ethics There is a new **Science, Politics, & Policy** feature on the ethical and political dimensions of climate change.

Chapter 3 Risk, Economics, and Environmental Concerns The **Science, Politics, & Policy:** The Developing Green Economy and the **Issues & Analysis:** The Economics and Risks of Mercury Contamination were significantly revised and updated.

Chapter 5 Interactions: Environments and Organisms There is a new **Focus On** feature dealing with the concept of mass balance, and the **Science, Politics, & Policy** feature on attitudes toward wolves was revised to reflect recent changes in policy.

Chapter 6 Kinds of Ecosystems and Communities A new **Focus On** reading deals with the role of fire in natural ecosystems, and a new **Going Green** feature discusses the North American model of wildlife conservation.

Chapter 7 Populations: Characteristics and Issues The content was updated with the most recent data from the Population Reference Bureau. There is a new **Issues & Analysis:** The Wolves and Moose on Isle Royale with graph of population changes of moose and wolves.

Chapters 8, 9, and 10 all deal with aspects of energy. These chapters have been updated with the most current data available. In **chapter 9 Nonrenewable Energy Sources**, There is a new **Going Green:** Closure of Coal-Fired Power Plants. **Issues & Analysis:** Subsidies for the Energy Sector has been updated to 2016, and material has been reorganized into a table to make it easier to follow. **chapter 10 Renewable Energy Sources**, has a new introduction that compares EROI and Net Energy. There is new material on the nature of solar cells, geothermal heat pump systems, and a tidal current system with accompanying illustrations.

Chapter 11 Biodiversity Issues This chapter has been completely rewritten and reorganized with 25 new illustrations. The new organization focuses on the various levels of biodiversity, the value of biodiversity, threats to biodiversity, and efforts to combat the loss of biodiversity.

Chapter 12 Land-Use Planning There is a new **Science, Politics, & Policy:** Community Planning and Zoning and Conflicts of Interest.

Chapter 14 Agricultural Methods and Pest Management There is a new **Focus On:** Honeybees.

Chapter 15 Water Management There is a new **Focus On:** Cities Where the Water Taps Could Soon Run Dry.

Chapter 16 Air Quality Issues The introductory material on Metropolitan Areas, Traffic, and Air Pollution was significantly rewritten with subheads added to make things easier to understand.

The section on photochemical smog was rewritten and illustrations were revised to include more recent changes in the chemical mechanisms involved in the development of smog.

Science, Politics, & Policy: A History of Mercury Regulations was modified to highlight the different approaches of Bush, Obama, and Trump administrations. In addition, several subheads were added to make it easier to follow the flow. A graph showing the reduction in mercury emissions from power plants was added.

Chapter 17 Climate Change: A Twenty-First Century Issue The chapter has been updated with material on the Madrid climate meeting and a new section on the effect of climate change on oceans was added. There is a new **Going Green:** How Countries Respond to Climate Change.

Chapter 18 Solid Waste Management and Disposal The chapter includes a new section on the impact of China's decision to stop purchase of recycled materials and the impact this has on the recycling industry. There is a new **Issues and Analysis:** Plastics in our Environment.

Chapter 19 Environmental Regulations: Hazardous Substances and Wastes The chapter has been updated throughout. There is a new **Issues & Analysis:** PFAS: A Class of Persistent Organic Pollutants. The **Focus On:** The Hanford Facility: A Storehouse of Nuclear Remains has a new table showing the magnitude of the original problem and the current degree of cleanup.

Chapter 20 Environmental Policy and Decision Making The chapter has been completely rewritten. It begins with a discussion of major global environmental issues needing policy initiatives. This is followed by a discussion of the process of establishing environmental policy with the United States political system as a model and the significance of major U.S. environmental legislation. This is followed by a discussion of the role of the United Nations in fostering international environmental agreements and the difficulties involved in reaching consensus.

There is a new chapter introduction that describes changes in attitudes to environmental policy. There are also new **Science, Politics, & Policy:** The Endangered Species Act–Two Perspectives; a new **Going Green:** Principles for Responsible Investment; and a new **Issues & Analysis:** The Future Has Yet To Be Written.

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Eldon D. Enger
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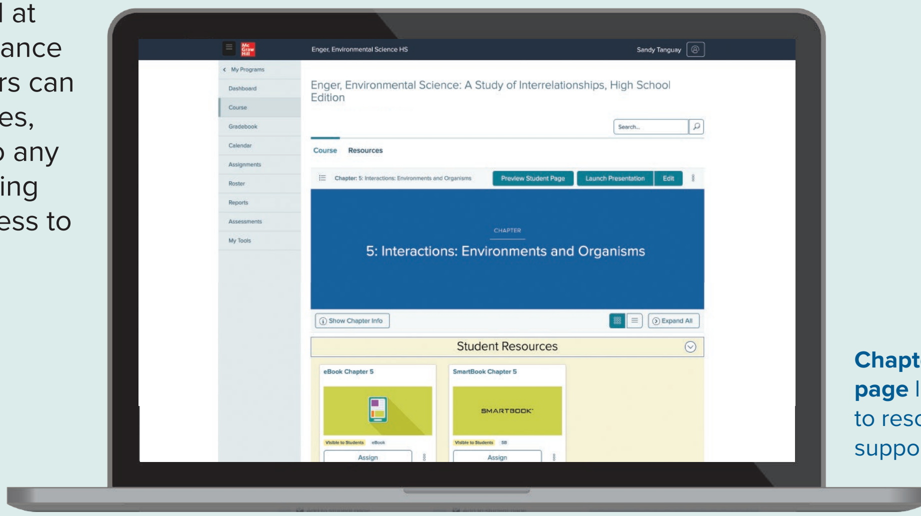

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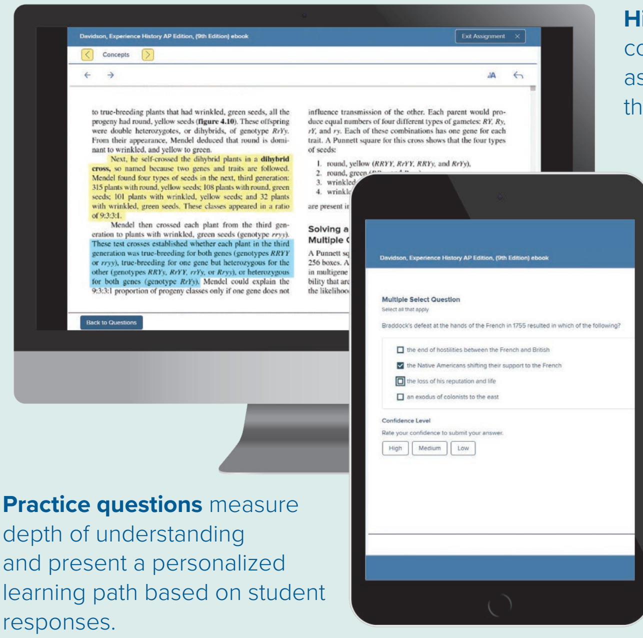

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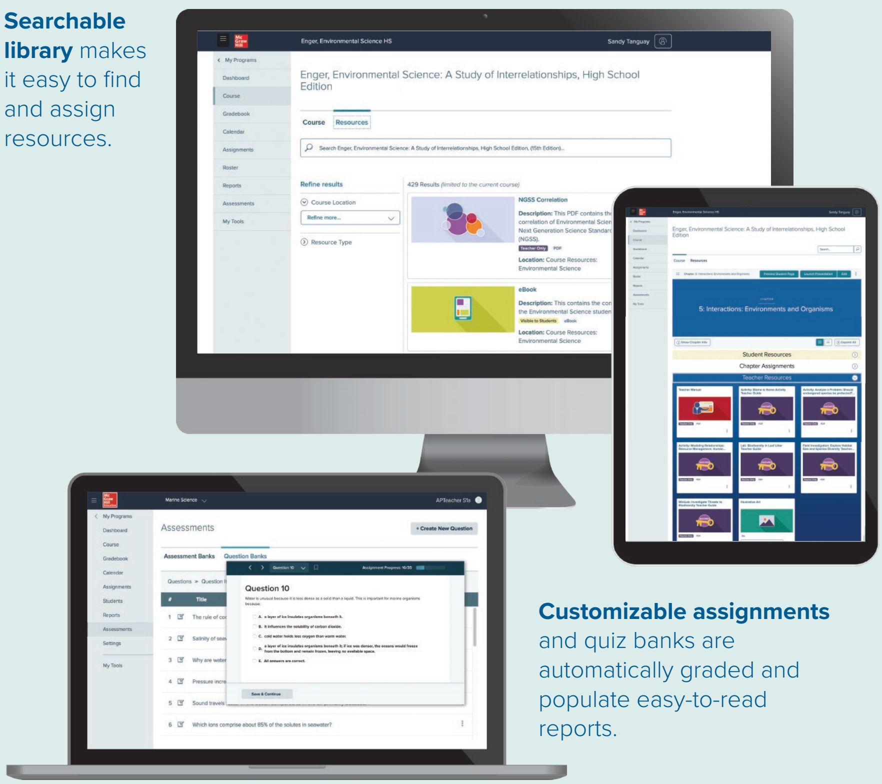

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chapter

10 Renewable Energy Sources

Sunlight provides a continuous source of energy to Earth. Sunlight is converted to the energy in biomass, which is the world's most commonly used renewable energy source.
Fabio Cardoso/Corbis/Getty Images

CHAPTER OUTLINE

OBJECTIVES

After reading this chapter, you should be able to:

- Distinguish renewable energy sources from nonrenewable sources.
- Recognize that renewable energy sources currently provide about 14 percent of world energy.
- Recognize that fuelwood is a major source of energy in many parts of the less-developed world and that fuelwood shortages are common.
- Identify industries that typically use the wastes they produce to provide energy.
- Describe technical and economic factors that must be considered when burning municipal solid waste to produce energy.
- Identify negative environmental effects of using crop residues to provide energy.
- Describe the economic factors that must be taken into account when evaluating the use of crop residues or energy plantations to provide energy.
- List four processes used in the production of energy from biomass.
- Describe four environmental issues related to the use of biomass to provide energy.
- Describe environmental issues related to the development of hydroelectric power.
- Describe how active and passive solar heating designs differ.
- Describe two methods used to generate electricity from solar energy.
- Describe how wind, geothermal, and tidal energy are used to produce electricity.
- Recognize that wind, geothermal, and tidal energy can be developed only in areas with the proper geologic or geographical features.
- Recognize that energy conservation can significantly reduce our need for additional energy sources.

Which Renewable Energy Technologies Should We Use?

Energy Return on Investment and Net Energy

Energy is crucially important to society. From powering our lightbulbs to powering our tractors, it undergirds all activity within the economy. But energy itself is not free—we must invest energy to get energy. All energy sources require an input of energy to develop their potential. For example, in order to produce a barrel of oil, a considerable amount of energy went into developing the well to produce the oil. Energy was used to explore for the source of the oil. Energy was used to drill the well to get to the oil. Energy was used to pump the oil to the surface. If one does the energy accounting for both the total energy obtained and the energy invested to get the energy out, you can calculate the Energy Return on Investment (EROI).

$$\text{EROI} = \frac{\text{Energy gained}}{\text{Energy required to get energy}}$$

For example, if 10 barrels of oil are produced, but an investment of 1 barrel of oil was needed to get the oil, the EROI would be as follows:

$$\text{EROI} = \frac{\text{Energy gained (10 barrels of oil)}}{\text{Energy invested (1 barrels of oil)}} = \frac{10}{1} = 10$$

Net energy is a similar concept to EROI, measuring the amount of energy remaining after accounting for the energy required to get the energy. The equation is: Net energy = Energy gained − Energy required to get that energy.

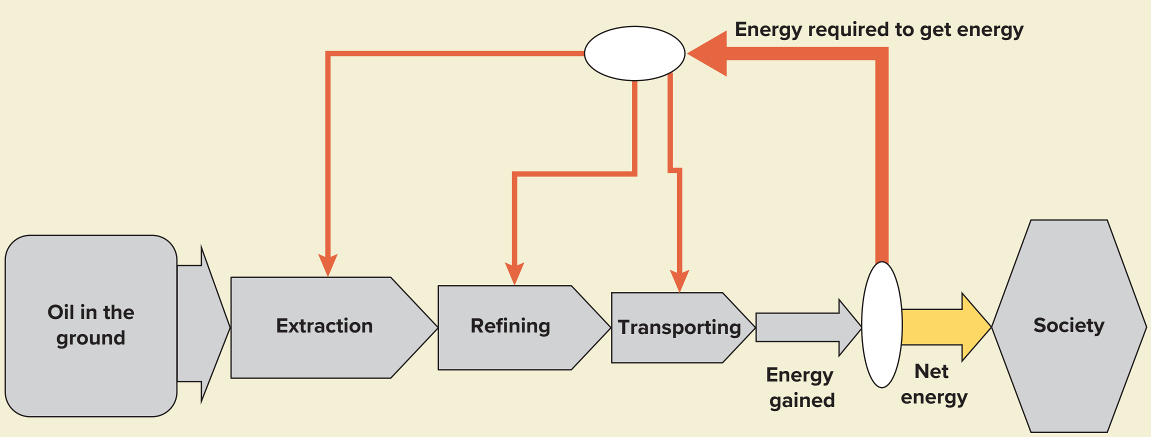
Thus, Net energy = Energy gained (10 barrels) − Energy required to obtain energy (1 barrel) = 9 barrels.

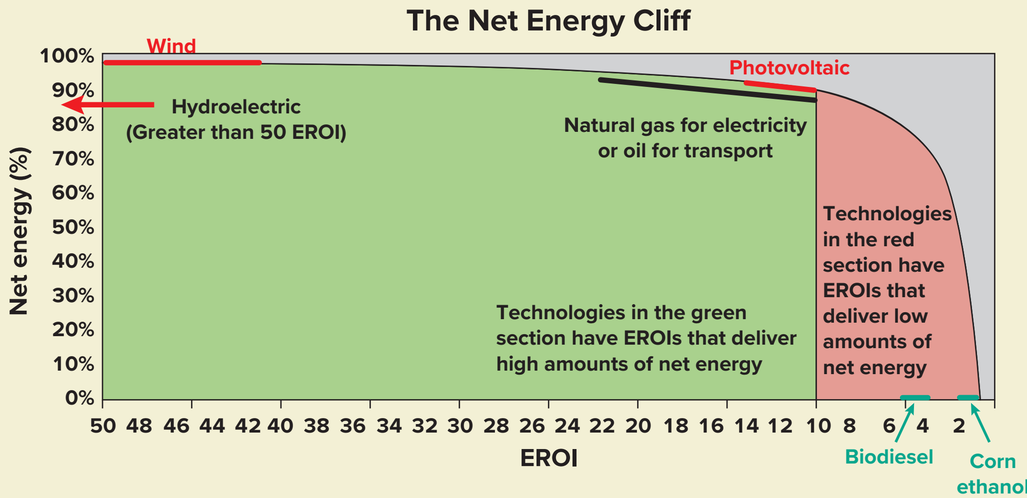
$$\text{Percent net energy} = \frac{10 - 1}{10} = \frac{9}{10} = 0.9 \times 100 = 90 \text{ percent}$$

Understanding these two concepts is critical to evaluating energy resources and technologies. EROI is the ratio of the output of energy to the input of energy, while net energy is the actual energy remaining after energy investments are deleted. The Net Energy Diagram shows how energy flows from the environment to society.

The energy represented by the yellow arrow is available to society to use for energy-demanding activities such as constructing buildings, powering vehicles, or illuminating lights. The energy represented by the red arrows is used to prepare and deliver an energy source to the public. Examples are drilling new oil wells, producing gasoline from crude oil, or building solar photovoltaic panels. Note that the amount of energy available to society from the original source shrinks as energy is used to prepare and deliver the energy to society. For obvious reasons, society would like the net energy (yellow arrow) to be as big as possible and the energy investments (red arrows) to be as small as possible, since then society is benefiting as much as possible from the energy that is extracted from the Earth.

Net Energy Diagram





But the relation between EROI and net energy is not as straightforward as one might think. For example, an oil production process might have an EROI of 20, meaning that it produces 20 units of energy for every unit of energy invested in that production process. A photovoltaic panel, on the other hand, might produce 14 units of energy for each unit invested. Does this mean that this source of oil is 6 units better than a photovoltaic panel?

The answer is no, and the reason for this is seen in the Net Energy Cliff diagram. Since both net energy and EROI are measures of the same variables (i.e., “energy gained” and “energy required to get that energy”) they are intimately related, and they can be plotted on the same graph.

The Net Energy Cliff diagram displays how net energy declines with EROI. The vertical axis shows net energy as a percentage, and the graph shows that as EROI declines, the amount of net energy delivered to society changes very slowly until the EROI drops below 10. By examining our energy sources in this way, we can see that there is little difference in the net energy delivered to society from energy resources with EROIs above 10 and a huge difference when those EROIs drop below 10. For example, oil with an EROI of 20 will deliver 95 percent of its energy as net energy, and a photovoltaic panel with an EROI of 14 will deliver 93 percent of its energy as net energy. Oil sands, on the other hand, have an EROI of 3, delivering only 66 percent net energy, while corn ethanol, with an EROI of 1.3, deliver only 23 percent net energy. In the end, low-EROI resources provide society with less energy to construct buildings, move vehicles, and power other energy-demanding activities.

EROI is an important metric for evaluating our energy resources, but it is important to also understand that net energy is the energy that is useful to society, and as long as the EROI of a resource is above roughly 10, it is a worthwhile endeavor from a net energy perspective. On the other hand, we should do our best to avoid resources and technologies with EROIs less than 10, and especially those lower than 5. So, which renewable energy technologies have EROIs above the EROI = 10 threshold? The table shows the most important renewable energy technologies and whether their EROIs are above 10.

The EROI of Common Renewable Energy Technologies

Renewable Energy Technology	EROI greater than 10	Comments
Conventional hydropower	Yes	Hydropower has long delivered energy at very high EROIs.
Wind turbines	Yes	Most conventional wind turbines deliver EROIs above 20, and as the technology improves so does the EROI.
Solar photovoltaic	Yes	Recent research has confirmed that all the main types of photovoltaic panels, including crystalline silicon and thin films, have EROIs above 10.
Geothermal electricity	Maybe	Depends on the conditions of the geothermal reservoir.
Tidal/wave energy	Not Yet	The energetic cost of the technology is still too high, but the potential is there given enough research and development.
Corn ethanol	No	Corn ethanol is an energy-intensive process with an EROI of about 1.
Biodiesel	No	Biodiesel has an EROI of 5 or less because biodiesel production is derived from crops like soybeans or oil palms. The process of growing, harvesting, and processing the crop requires large energy inputs.

10.1 The Status of Renewable Energy

The burning of fossil fuels (oil, natural gas, and coal) and electricity from nuclear power provide about 87 percent of the energy used in the world. The burning of fossil fuels is also responsible for most of the human-caused carbon dioxide emissions. During the 10-year period from 2009 to 2019, energy consumption increased by about 21 percent. We should expect continued substantial increases in the demand for energy into the future.

Renewable energy is provided by processes that replenish themselves or are continuously present as a feature of the solar system. The sun is the primary source of renewable energy. In terms of world energy usage, biomass is the primary renewable energy source. The process of photosynthesis converts sunlight energy into plant biomass.

$$\text{Carbon dioxide} + \text{Water} + \text{Sunlight energy} \longrightarrow \text{Biomass (Chemical energy)} + \text{Oxygen}$$

This energy is stored in the organic molecules of the plant as wood, starch, oils, or other compounds. Any form of biomass—plant, animal, alga, or fungus—can be traced back to the energy of the sun. Since biomass is constantly being produced, it is a form of renewable energy. Solar, wind, geothermal, and tidal energy are renewable energy sources because they are continuously available.

There is currently a great deal of interest in renewable forms of energy. There are several factors that stimulate this interest. Since fossil fuels are nonrenewable, as they become scarce the price rises. When fossil fuels are cheap, many renewable forms of energy cannot compete economically. However, as the price of fossil fuels increases, many forms of renewable energy become economically viable. A third factor is the concern about climate change, which is driven by carbon dioxide emissions, primarily from the burning of fossil fuels. In general, renewable energy sources do not add to carbon dioxide emissions.

Currently, renewable energy sources—biomass, hydroelectricity, wind turbines, solar energy, geothermal energy, and tidal energy—supply about 13.5 percent of the world's total energy. Biomass accounts for about 9 percent of the energy used in the world, since firewood and other plant materials are the primary source of energy in much of the developing world.

Hydroelectric power accounts for 2.5 percent and the remaining renewable technologies account for 2 percent. (See figure 10.1.) Some optimistic studies suggest that renewable sources could provide half of the world's energy needs by 2050. It is unlikely that that will occur, but renewable sources certainly will become much more important as costs of renewable sources fall and countries respond to the reality of climate change.

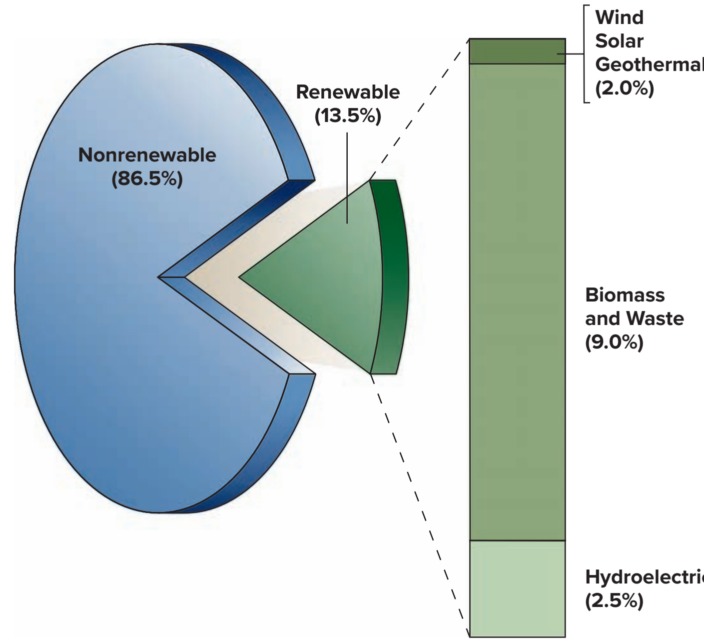


FIGURE 10.1 Renewable Energy as a Share of Total Energy Consumption (World 2018) Of the energy consumed in the world, about 86 percent is from nonrenewable fossil fuels and nuclear power. Renewable energy sources provide 13.5 percent, and the burning of biomass and waste accounts for nearly 70 percent of all renewable energy consumed.

Source: Data from International Energy Agency.

10.2 Major Kinds of Renewable Energy

While many consider renewable energy to be the answer to energy supply and climate change problems, there are still many technical, economic, and cultural challenges to overcome before renewable energy will meet a significant percentage of humans' energy demands. This section will examine the major sources of renewable energy and look at their potential and challenges.

Biomass Conversion

Biomass fulfilled almost all of humankind's energy needs prior to the Industrial Revolution. All biomass is traceable back to green plants that convert sunlight into plant material through photosynthesis. As recently as 1850, 91 percent of total U.S. energy consumption was biomass in the form of wood. Since the Industrial Revolution, the majority of the developed world's energy requirements have been met by the combustion of fossil fuels. Biomass, however, is still the predominant form of energy used by people in the less-developed countries. For example, in Africa, about 45 percent of the energy supply is obtained from biomass. India obtains about 20 percent and Bangladesh obtains about 23 percent of its energy from biomass.

Major Types of Biomass

There are several distinct sources of biomass energy: fuelwood, municipal and industrial wastes, and agricultural crop residues and animal waste.

Fuelwood Because of its bulk and low level of energy compared to equal amounts of coal or oil, wood is not practical to transport over a long distance, so most of it is used locally. In less-developed countries, wood has been the major source of fuel for centuries. In fact, wood is still the primary source of energy for about 30 percent of the world's population. In these regions, the primary use of wood is for cooking. In much of the less-developed world, cooking is done over open fires. Using fuel-efficient stoves instead of open fires could reduce these energy requirements by 50 percent. Improving efficiency would protect wood resources, reduce the time or money needed to obtain firewood, and improve the health of people because they would breathe less wood smoke. (See figure 10.2.)

Even developed countries that have abundant forest resources, such as the United States, Canada, Norway, Finland, Denmark, and Sweden, obtain 4 to 30 percent of their energy from biomass, primarily fuelwood.

(a) Inefficient use of wood

(b) Mud stoves are more efficient than open fires

FIGURE 10.2 Wood Use for Cooking Many people in the developing world use wood as a primary fuel for cooking. Reliance on wood is a major cause of deforestation. (a) In many parts of the world such as Africa, cooking is often done over open fires. This is a very inefficient use of fuel. (b) The use of simple mud stoves as in this situation in India greatly increases efficiency.
(a): Fabio Lamanna/Shutterstock; (b): Hamim CHOWDHURY/Getty Images

Waste Wastes of various kinds are a major source of biomass and other burnable materials produced by society. Certain industries, such as lumber mills, paper mills, and plants that process sugar from sugarcane, use biomass as a raw material for their products and in the process produce wastes such as sawdust, wood scrap, waste paper, or bagasse (sugarcane stalks), which are burnable. These industries typically burn these wastes to provide energy for their operations. Municipal solid waste is also a source of energy. About 80 percent of municipal waste is combustible, and over 60 percent is derived from biomass. Plastics, textiles, rubber, and similar materials contribute the rest of the burnable portion of trash. (See figure 10.3.)

The burning of municipal solid waste to produce energy makes economic sense only when the cost of waste disposal is taken into account. In other words, although energy from solid waste is expensive, one can deduct the avoided landfill costs from the cost of producing energy from waste. Where landfill costs are high, municipal waste-to-energy plants make economic sense. In the United States, about 13 percent of solid waste is burned. Europe and Japan have much less available land and have placed restrictions on landfills. Thus, these countries have a much higher rate of burning of solid waste. Countries in Western Europe have over 400 waste-to-energy plants. Japan burns about 80 percent of its waste, and Germany burns nearly all of its waste that is not recyclable.

Crop residues and animal wastes As we seek alternative sources of energy, crop residues have been identified as possibilities. In many parts of the world, the straw and stalks left on the field are collected and used to provide fuel for heat and cooking. Animal wastes are also used for energy. Animal dung is dried and burned or processed in anaerobic digesters to provide a burnable gas.

However, there are several impediments to this development. Crop residues are bulky and have a low energy-to-weight ratio. Thus, harvesting crop residues to burn or convert to ethanol makes sense only if the travel distance from field to processing plant is short. Removal of crop residues from fields has several negative agricultural impacts. It leads to increased erosion, since the soil is more exposed, and reduces the benefits provided by organic matter in the soil, since the crop residues are not incorporated into the soil. Finally, the production of ethanol from cellulose is currently not economical.

(a) Sawdust and wood scrap can be used to produce energy

(b) Paper mills burn waste

(c) Trash can be burned to provide energy

FIGURE 10.3 Energy from Waste Many segments of the forest products industry, such as lumber and paper mills, use the waste they produce as a source of energy for their industrial processes. Municipal solid waste also contains large amounts of burnable material that can be used to generate energy.
(a): Reimphoto/Getty Images; (b): Photodisc/Getty Images; (c): Creatas/Getty Images

Focus On

Biomass Fuels and the Developing World

Although most of the world uses fossil fuels as energy sources, much of the developing world relies on *biomass* as its source of energy. The biomass can be wood, grass, agricultural waste, or dung. According to the United Nations, 2.4 billion people (one-third of the world's population) use biomass as fuel for cooking and heating dwellings. Worldwide, about 50 percent of the wood harvested is used for energy. In some regions, however, the percentage is much higher. For example, in sub-Saharan Africa, fuelwood provides about 80 percent of energy consumed.

This dependence on biomass has several major impacts:

- Often women and children must walk long distances and spend long hours collecting firewood and transporting it to their homes.
- Because the fuel is burned in open fires or inefficient stoves, smoke contaminates homes and affects the health of the people. The World Health Organization estimates that in the developing world, 4 million people die each year from diseases caused by poor indoor air quality related to burning biomass. A majority of those who become ill are women and children because the children are in homes with their mothers who spend time cooking food for their families.
- Often the fuel is harvested unsustainably. Thus, the need for an inexpensive source of energy is a cause of deforestation. Furthermore, deforested areas are prone to soil erosion.
- When dung or agricultural waste is used for fuel, it cannot be used as an additive to improve the fertility or organic content of the soil. Thus, the use of these materials for fuel negatively affects agricultural productivity.

Nepali woman carrying brushwood.
Bartosz Hadyniak/Getty Images

Butterfly icon: ©Kris Bradley/flickr RF/Getty Images

Energy plantations Many crops can be grown for the express purpose of energy production. Crops that have been used for energy include forest plantations, sugarcane, corn, sugar beets, grains, kelp, palm oil, and many others. Two main factors determine whether a crop is suitable for energy use. Good energy crops have a very high yield of dry material per unit of land (dry metric tons per hectare). A high yield reduces land requirements and lowers the cost of producing energy from biomass. Similarly, the amount of energy that can be produced from a biomass crop must be more than the amount of energy required to grow the crop. In some circumstances, such as the heavily mechanized corn farms of the U.S. Midwest, the amount of energy in ethanol produced from corn is not much greater than the energy used for tractors, to manufacture fertilizer, and to process the grain into ethanol. (See Issues & Analysis: Does Corn Ethanol Fuel Make Sense?)

Biomass Conversion Technologies

In order to use biomass as a source of energy, it must be burned. Often it is important to convert the biomass into a different form that is easier to transport and use. There are several technologies capable of making the energy of biomass available for use. These include direct combustion and cogeneration, ethanol production, anaerobic digestion, and pyrolysis.

Direct combustion The most common way that biomass and waste are used for energy production is by burning them to produce heat or electricity. In much of the developing world, the primary use of energy derived from biomass is as fires to provide heat for space heating and cooking.

Large-scale operations are used to power industrial processes or to generate electricity. Large biomass electric-power generation systems have lower efficiencies than comparable fossil-fuel systems because of the higher moisture content of biomass. However, if a biomass-fired power plant can be used to provide both heat and electricity (cogeneration system), the economics and energy efficiency improve significantly. This is how biomass combustion is used in the wood products, paper, and sugar industries.

Biofuels production Ethanol can be produced by fermenting sugars. The sugars can be obtained directly from plants or may be produced by converting the starch or cellulose of plants to sugars.

Typically, sugar or starch is extracted from the biomass crop by crushing and mixing with water and yeast and then keeping the mixture warm in large tanks called fermenters. The yeast breaks down the sugar and converts it to ethanol and carbon dioxide. A distillation process is required to remove the water and other impurities from the dilute alcohol product. Historically, Brazil did not have significant oil reserves and needed to import oil to provide fuel for automobiles. However, it was able to use its large crop of sugarcane to produce ethanol and developed policies that required that vehicles be produced that used ethanol as a fuel. Ethanol is sold in a variety of mixtures for automobile fuel, from 100 percent ethanol to 27 percent ethanol and 73 percent gasoline. In total, ethanol provides over 30 percent of Brazil's automobile fuel.

In the United States, corn is used to produce ethanol, which is then blended with gasoline. Most gasoline in the United States contains about 10 percent ethanol because it is mandated by an act of Congress. The presence of ethanol does have beneficial effects. Blending ethanol into gasoline increases the octane number of the fuel, which can improve engine efficiency. On the other hand, ethanol has a lower energy density, which means that it has a lower fuel efficiency, resulting in fewer kilometers per liter or miles per gallon of fuel. The effect of ethanol use on air pollution is complicated. It reduces some air pollutants such as carbon monoxide but increases others such as ground-level ozone. E85 is a fuel that is 85 percent ethanol and 15 percent gasoline. It can be used in later-model cars that are known as flex-fuel vehicles. (See figure 10.4.)

Biodiesel can be produced from the oils in a variety of crops, including soybeans, rapeseed, and palm oil as well as animal fats. These raw materials need to be modified chemically before they can be used as fuel. Currently, about 2 percent of the diesel fuel consumed in the world is biodiesel.

FIGURE 10.4 Biofuels Biofuels (E85 and biodiesel) are available for purchase in many parts of the world.
Judy Enger

Anaerobic digestion Anaerobic digestion involves the decomposition of wet and green biomass or animal waste through bacterial action in the absence of oxygen. This process produces a mixture, consisting primarily of methane and carbon dioxide, known as biogas. The most commonly used technology involves small digesters on farms that generate gas for use in the home or for farm-related activities. Millions of small methane digesters are in use in countries like China, India, and Korea. (See figure 10.5.) Large, industrial-size farming operations also use anaerobic digesters to process animal waste and capture biogas. (See figure 10.6.) Similarly many sewage treatment plants capture biogas. In both instances the methane collected can be used to provide heat or run machinery. Anaerobic digestion also occurs in landfills. In many landfills the methane gas produced eventually escapes into the atmosphere. However, the gas can be extracted by inserting perforated pipes into the landfill. In this way, the gas will travel through the pipes, under natural pressure, to be used as an energy source, rather than simply escaping into the atmosphere to contribute to greenhouse gas emissions. Some newer landfills have even been designed to encourage anaerobic digestion, which reduces the volume of the waste and provides a valuable energy by-product.

What's Your Take?

Many states require electric utilities to "generate" a certain amount of the electricity they produce from renewable sources. To meet their requirements, many electric utilities simply buy the "renewable" electricity from another company and do not invest in technologies that are renewable. Should they be allowed to do this? Choose one side or the other and develop arguments to support your point of view.

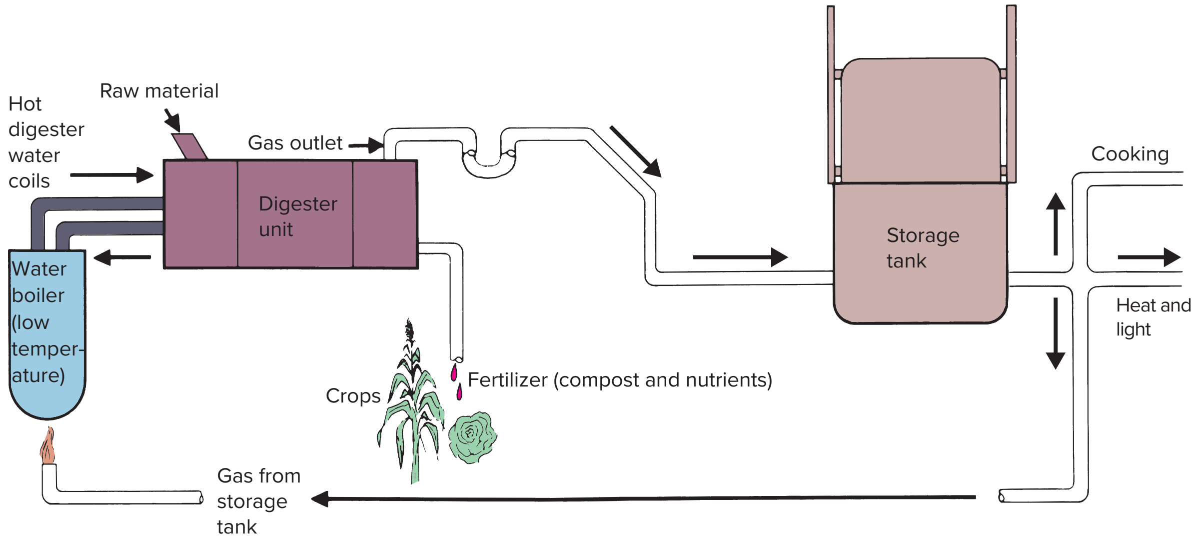


FIGURE 10.5 Methane Digester In the digester unit, anaerobic bacteria convert animal waste into methane gas. This gas is then used as a source of fuel. The sludge from this process serves as a fertilizer. In many less-developed countries, this type of digester has the advantages of providing a source of energy and a supply of fertilizer and managing animal wastes, which helps reduce disease.

FIGURE 10.6 Anaerobic Bioreactor This bioreactor is used to produce methane from animal manure on a large dairy farm.
Ashley Cooper/Getty Images

FIGURE 10.7 Desertification The demand for fuelwood in many regions has resulted in the destruction of forests. This is a major cause of desertification.
Susan Meiselas/Magnum Photos

Pyrolysis Pyrolysis is a process for converting solid biomass to a more useful fuel. Biomass is heated or partially burned in an oxygen-poor environment to produce a hydrocarbon-rich gas mixture, an oil-like liquid, and a carbon-rich solid residue (charcoal), which have a higher energy density than the original fuel. In developing countries, charcoal kilns are simply mounds of wood or wood-filled pits in the ground that are set afire and then covered with earth. The smoldering fire slowly converts the wood to charcoal.

Gasification is a form of pyrolysis, carried out with more air and at high temperatures, to optimize the gas production. The resulting gas, known as producer gas, is a mixture of carbon monoxide, hydrogen, and methane, together with carbon dioxide and nitrogen. The gas is more versatile than the original solid biomass, and it can be used as a source of heat or used in internal combustion engines or gas turbines to produce electricity.

Environmental Issues

Although the use of biomass and waste as an energy source is often thought to be environmentally benign, it has many significant environmental impacts.

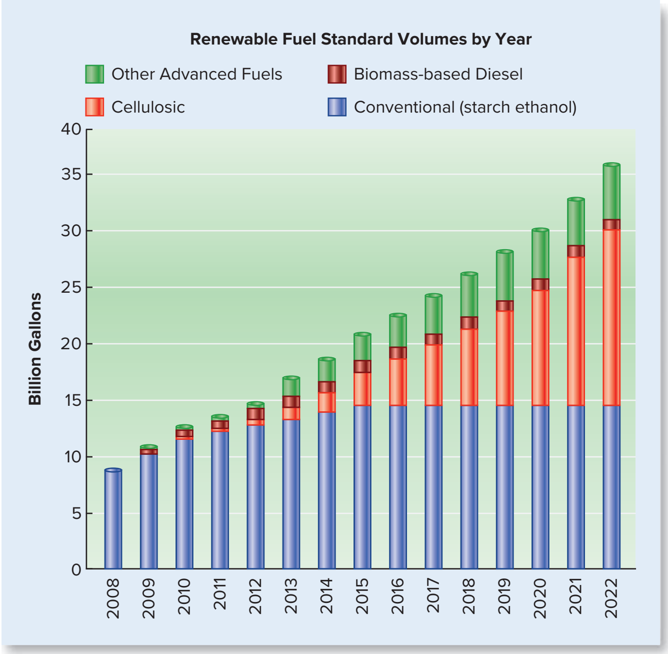
Habitat and biodiversity loss It is estimated that throughout the world there are 1.3 billion people who cannot obtain enough wood or must harvest wood at a rate that exceeds its growth. This has resulted in the degradation of much forestland in Asia and Africa and has hastened the rate of desertification in some regions. (See figure 10.7.)

Science, Politics, & Policy

The Renewable Fuel Mandate

Scientific studies have provided a great deal of information about how energy can be produced from biomass. Scientists have tracked the increasing amount of CO_2 in the atmosphere. An international body of scientists and policymakers has determined that human activities are responsible for increasing atmospheric CO_2 and other greenhouse gases that are causing climate change. The production of ethanol from sugars and starches is well understood. Theoretically it should also be possible to produce ethanol from cellulose, which is the primary structural molecule of plants. Using all these bits of scientific information along with a desire to reduce dependence on oil imports and stimulate agriculture and alternative energy industries, Congress passed two bills—the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007—that mandated specific amounts of renewable fuels in gasoline and diesel fuel. Although these two laws addressed many energy-related issues, the following items relate to the renewable fuel mandate:

- Subsidies were provided to build ethanol plants.
- Different kinds of renewable fuels were identified—corn-based ethanol, cellulosic ethanol, biodiesel, and advanced fuels. Each kind of renewable fuel must demonstrate that it produces lower amounts of greenhouse gases than standard fuels: corn ethanol 20 percent less, biodiesel 50 percent less, advanced biofuels 50 percent less, and cellulosic ethanol 60 percent less.
- Gasoline producers were required to blend specific amounts of renewable fuels into their gasoline or pay a fine.
- A schedule of increasing amounts of each of the kinds of renewable fuels was required in gasoline from 2005 to 2022. (See graph.)
- A tax credit of US $0.45 per gallon of ethanol was provided to gasoline producers who incorporated ethanol into their gasoline.



Unintended Consequences

Between 2005, when the Energy Policy Act of 2005 was passed, and 2012, the amount of corn used for ethanol production increased from 15 percent to about 40 percent of corn production.

- This resulted in a temporary increase in the price of corn and the amount of land planted to corn. The amount of land increased 19 percent and the price nearly doubled between 2005 and 2012.
- Farmers took erodible farmland out of conservation programs and planted corn because they could make more money by planting corn than they could from agriculture programs that paid them to remove marginal lands from production.
- Since the additional demand for corn to make ethanol caused the price to rise, farmers who needed to feed corn to livestock had to pay higher prices, resulting in increased costs of meat and dairy products.
- Since farmers planted more corn and less of other crops, the prices of other crops rose because of a lower supply.

Companies that produced gasoline experienced problems.

- They could not add more than 10 percent ethanol to gasoline because many vehicles could be damaged by higher amounts of ethanol. Thus, fuel producers were limited in the amount of ethanol they could put into gasoline, and they have not met mandated amounts since 2011.
- They were required to begin using ethanol made from cellulose in 2010 but were unable to do so because it was not available. By 2020, gasoline producers were required by the renewable fuel mandate to use 10.5 *billion* gallons of cellulosic ethanol. EPA reduced the target to 540 *million* gallons because of production problems. However, by 2018 only about 15 *million* gallons were produced. In addition, the cost of cellulosic ethanol is much higher than that of corn ethanol. Most of the U.S. cellulosic ethanol producers had ceased production by 2020.
- Because of the 10 percent limit on gasoline and the unavailability of cellulosic ethanol, refiners have paid fines for not meeting the mandated amounts.

Current status

- Between 2012 and 2019, the area planted in corn and the price of corn returned to normal.
- The percent of corn used for ethanol remains near 40 percent.
- The tax credit of US $0.45 per gallon of ethanol gasoline producers received expired in 2011. The additional cost was passed on to the consumer.
- Although flex-fuel vehicles can use E85 fuel, which is 85 percent ethanol and 15 percent gasoline, most do not do so because the cost per mile driven is higher for E85. (See Issues & Analysis at the end of this chapter for details.)
- Since 2013, EPA has reduced requirements for renewable fuels below that mandated by law, primarily because advanced fuels and cellulosic ethanol are not available.
- EPA granted exemptions from the mandated use of ethanol to many (31 in 2019) small refineries because they demonstrated financial hardship.
- EPA has allowed fuel with 15 percent ethanol (E15) to be marketed throughout the year. Its sale had been prohibited in summer months.
- EPA reclassified biogas from landfills, sewage treatment plants, and waste digesters as advanced fuel.
- The Government Accountability Office, which analyzes the effectiveness of government policies, released a report in 2019 stating that the renewable fuel mandate was not meeting its goal of reducing greenhouse gases because advanced biofuels and cellulosic ethanol, which would reduce emissions more effectively, have not been produced as expected.

Another issue associated with biomass energy is the loss of biodiversity. Destroying natural ecosystems to plant sugarcane, grains, palm oil, or other plants can reduce the biodiversity of a region. The plantations lack the complexity of a natural ecosystem and are susceptible to widespread damage by pests or disease.

Air pollution Burning wood is a source of air pollution. Often the people in developing countries use wood in open fires or poorly designed, inefficient stoves. This results in the release of high amounts of smoke (particulate matter) and other products of incomplete combustion, such as carbon monoxide and hydrocarbons, which contribute to ill health and death.

Respiratory illnesses are particularly common among women and children who spend the most time in the home. Even in the developed world, air pollution from the burning of biomass is a problem. Some cities have a total ban on burning wood. Many areas require woodstoves to have special pollution controls that reduce the amount of particulates and other pollutants released and prevent the use of wood stoves on high pollution days.

The burning of solid waste presents some additional problems. Because solid waste is likely to contain a mixture of materials, including treated paper and plastic, there are additional air pollutants released from the burning of waste. For example, waste-to-energy plants often require sophisticated filters to capture pollutants that emerge when burning such a variety of materials. The most common air pollutants from solid waste are sulfur dioxide, which causes acid rain, NO_x, which causes smog and respiratory issues, and dioxins, which result from the burning of plastic and are known to cause cancer.

Carbon dioxide and climate change A consensus exists among scientists that biomass fuels and wastes used in a sustainable manner result in no net increase in atmospheric carbon dioxide. This is based on the assumption that all the carbon dioxide given off by the use of biomass fuels was taken from the atmosphere during photosynthesis. However, recently, concern has been raised about the short-term impact of increased use of biofuels on climate change. When biomass is burned, the carbon dioxide emitted to the atmosphere will remain there for roughly 100 years before it is cycled back into plants via photosynthesis. So, even though biomass fuels may be carbon neutral at the century scale, burning them today increases carbon dioxide levels now and for the next century. This could increase the severity of climate change. Regardless, burning biomass is almost always better in terms of climate change impact than burning fossil fuels.

Effects on food production Although the use of marginal or underutilized land to grow energy crops may make sense, using fertile cropland does not. Since there are millions of people in the world who do not have enough food to eat, the conversion of land from food crops to energy crops presents ethical issues.

The use of crop residues and animal waste as a source of energy also presents some problems. These materials supply an important source of organic matter and soil nutrients for farmers. This is particularly true among subsistence farmers in the developing world. They cannot afford fertilizer and rely on these materials to maintain soil fertility. However, they also need energy. Thus, they must make difficult decisions about how to use this biomass resource.

Hydroelectric Power

People have long used flowing water to power a variety of machines. Some early uses of water power were to mill grain, saw wood, and run machinery for the textile industry. Flowing water has energy that can be captured and turned into electricity. This is called hydroelectric power, or *hydropower.*

At present, hydroelectricity provides about 16 percent of the world's electricity. In some areas of the world, hydroelectric power is the main source of electricity. In South and Central America, 56 percent of the electricity comes from hydroelectric power. Norway gets 95 percent of its electricity and nearly 60 percent of all its energy from hydroelectricity. Canada gets nearly 60 percent and the United States gets about 7 percent of its electricity from hydroelectric plants.

Technology for Obtaining Hydropower

The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. (See figure 10.8.) Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. Most of this hydroelectricity comes from large dams, which rank among humanity's greatest engineering feats. Table 10.1 lists the locations and sizes of the largest hydroelectric facilities. In 2012, China completed construction of the Three Gorges Dam on the Yangtze River. It is the largest hydroelectric producing facility in the world. It has a generating capacity of 22,500 megawatts. A large coal or nuclear power plant generates about 1,000 megawatts of electricity. (1 megawatt = 1 million watts). Although most hydroelectricity comes from large plants (thousands of megawatts) built on large reservoirs, small (less than 50 megawatts) plants are also important contributors. They can be built on small rivers, and in some areas of the world where the streams have steep gradients and a constant flow of water, hydroelectricity may be generated without a reservoir. China has over 46,000 small stations, and the United States has about 1,600. In addition, microhydroelectric power systems (less than 1 megawatt) can be built in remote places to supply electricity for local needs such as a home, ranch, or village.

Potential for Additional Hydropower

Over the past 10 years, the energy furnished by hydroelectricity worldwide increased by nearly 30 percent. The potential for developing hydroelectric power is best in mountainous regions and large river valleys. Future increases in hydroelectric power will come mainly from the development of large plants (thousands of megawatts) on reservoirs.

Some areas of the world, such as Canada, the United States, Europe, and Japan, have already developed about 50 percent of their hydroelectric potential. Most of the potential for development of new hydroelectric power facilities is in Africa, Asia, South America, Eastern Europe, and Russia.

(a) Kuroyon Dam, Japan

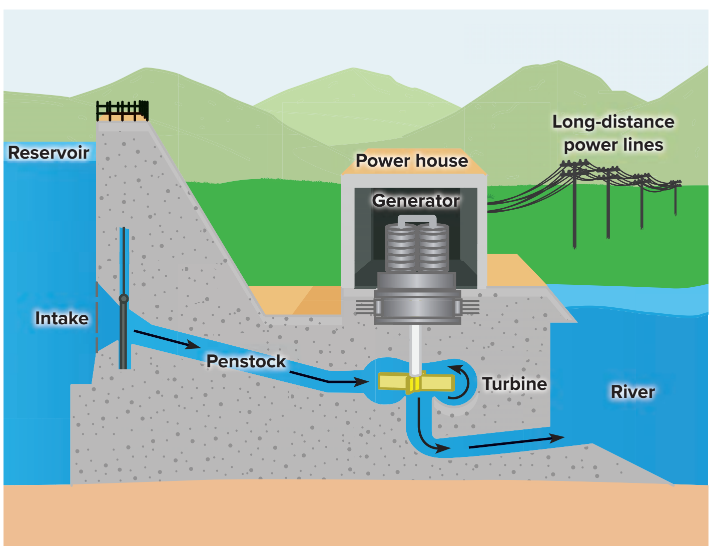


FIGURE 10.8 Hydroelectric Power Plant (a) The water impounded in this reservoir is used to produce electricity. In addition, this reservoir serves as a means of flood control and provides an area for recreation. (b) This figure shows how a hydroelectric dam produces electricity.

(a): Akira Kaede/Getty Images

Environmental Issues

Although hydroelectric power is a renewable energy source and does not emit air or water pollutants, there are still environmental consequences associated with developing hydroelectric facilities. The most obvious impact of hydroelectric dams is the flooding of vast areas of land, much of it previously forested or used for agriculture. The size of reservoirs created can be extremely large. The James Bay project on the Le Grande River in northern Quebec has submerged over 13,000 square kilometers (5,000 square miles) of land. The construction of the Three Gorges Dam in China inundated 153 towns and 4,500 villages and caused the displacement of over a million people. In addition, numerous archeological sites were submerged, and the nature of the scenic canyons of the Three Gorges was changed.

Table 10.1 World's Largest Hydroelectric Plants

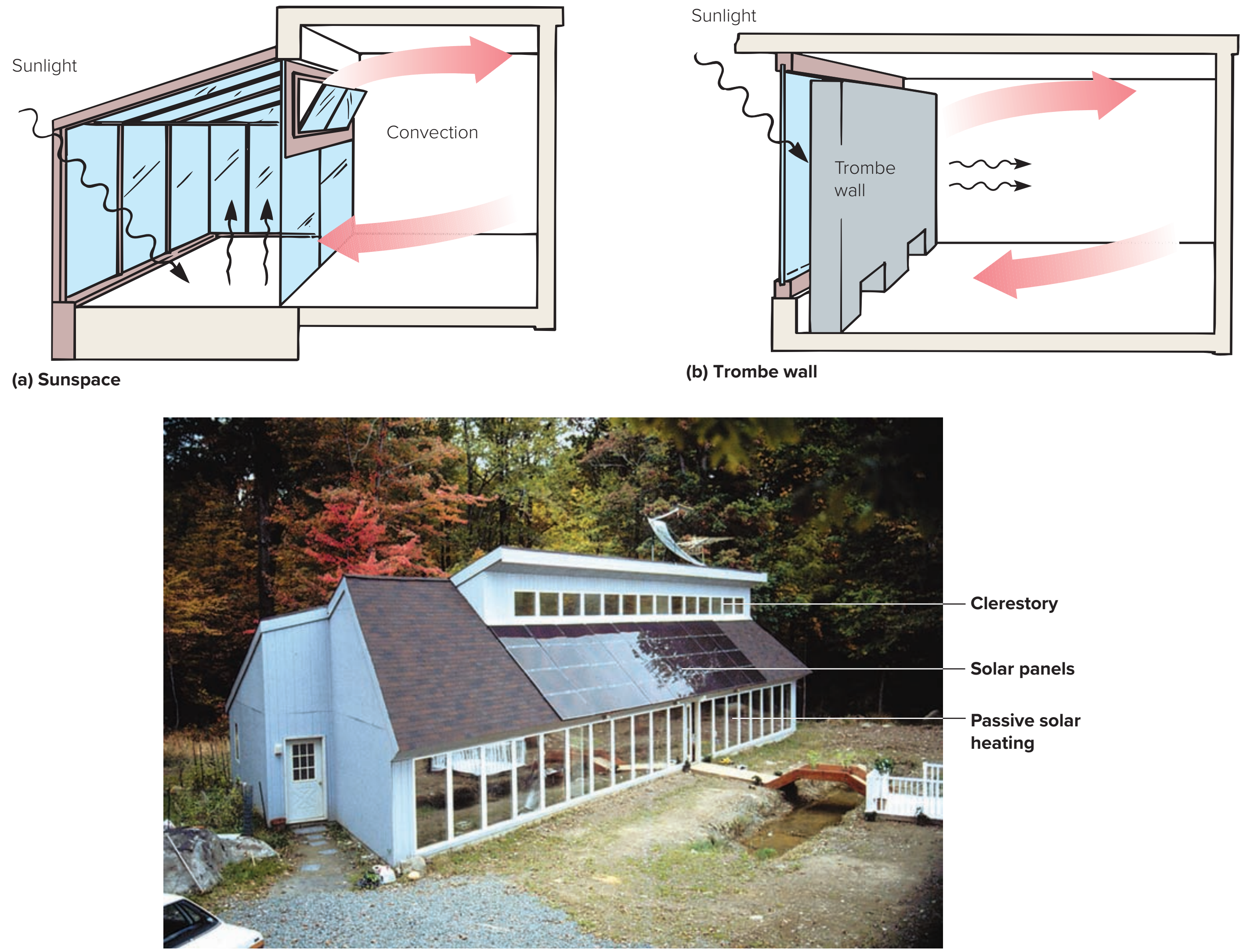
Name	Country	Rated Capacity Megawatts
Three Gorges Dam	China	22,500
Itaipu	Brazil/Paraguay	14,000
Xiluodu	China	13,860
Guri (Simón Bolívar)	Venezuela	10,235
Tucuruí	Brazil	8,370
Belo Monte	Brazil	8,176
Grand Coulee	United States	6,809
Xiangjiaba	China	6,448
Longtan Dam	China	6,426
Sayano Shushenskaya	Russia	6,400
Krasnoyarskaya	Russia	6,000
Nuozhadu	China	5,850
Robert-Bourassa	Canada	5,616
Churchill Falls	Canada	5,428
Jinping-II	China	4,800

Dams and reservoirs also greatly alter watersheds. Damming a river alters the normal flow of the river and changes the quality of water (temperature, amount of particulate matter, oxygen content, etc.) in the river downstream of the dam. Dams also alter the migration patterns of fish and often prevent fish from migrating upstream to spawn. These impacts can be reduced by requiring that dams release enough water to maintain minimum flows downstream of a dam and by creating fish ladders that allow fish to move upstream past the dam. Silt, normally carried downstream to the lower reaches of a river, is trapped by a dam and deposited on the bed of the reservoir. This silt slowly fills a reservoir, decreasing the amount of water that can be stored and used for electrical generation. The river downstream of the dam is also deprived of silt, which normally fertilizes the river's floodplain during high-water periods.

The flooded area behind a new dam contains vegetation that decomposes. The bacteria involved in decomposition have two negative effects. They release carbon dioxide and some of them can convert mercury that is naturally in the soil into methylmercury that can accumulate in fish. This poses a health hazard to those who depend on these fish for food. It is thought that both of these problems are temporary and will be reduced once the flooded vegetation is decomposed.

Solar Energy

The sun is often mentioned as the ultimate answer to the world's energy problems. It provides a continuous supply of energy that far exceeds the world's demands. In fact, the amount of energy received from the sun each day is 600 times greater than the amount of energy produced each day by all other energy sources combined. However, solar energy, in all its forms, provides less than 1 percent of energy needs. The major problems with solar energy are that, by



(a) Sunspace

(b) Trombe wall

(c) Solar home

FIGURE 10.9 Passive Solar Designs (a) A sunspace is like a greenhouse attached to a house. The heat captured in the sunspace can be transferred to the living space. (b) A Trombe wall is a heat-absorbing body placed near a window that reradiates heat to the house when the sun goes down. (c) This house shows several features that make use of solar energy. The clerestory at the top allows sunlight to enter and provide lighting. The south-facing windows allow sunlight to warm the house, and the solar panels on the roof capture additional solar energy.

(c): Courtesy of National Renewable Energy Laboratory/NREL/PIX

nature, it is both intermittent and diffuse. It is available only during the day when it is sunny, and it is spread out over the entire Earth, falling on many places like the oceans where it is difficult to collect. All systems that use solar energy must store energy or use supplementary sources of energy when sunlight is not available. Because of differences in the availability of sunlight, some parts of the world are more suited to the use of solar energy than others.

Solar energy is utilized in three ways:

1. In a passive heating system, the sun's energy is converted directly into heat for use at the site where it is collected.
2. In an active heating system, the sun's energy is converted into heat, but the heat must be transferred from the collection area to the place of use.
3. The sun's energy also can be used to generate electricity by heating water to turn turbines or by using photovoltaic cells.

Passive Solar Systems

Anyone who has walked barefoot on a sidewalk or blacktopped surface on a sunny day has experienced the effects of passive solar heating. In a **passive solar system**, light energy is transformed to heat energy when it is absorbed by a surface. Homes and buildings can be designed to use passive solar energy for heating and lighting, which reduces the need for nonrenewable energy sources. (See figure 10.9.)

In the Northern Hemisphere, the south side of a building always receives the most sunlight. Therefore, buildings designed for passive solar heating usually have large south-facing windows. Materials that absorb and store the sun's heat can be built into the sunlit floors and walls. The floors and walls heat up during the day and slowly release heat at night, when the heat is needed most. This passive solar design feature is called *direct gain.*

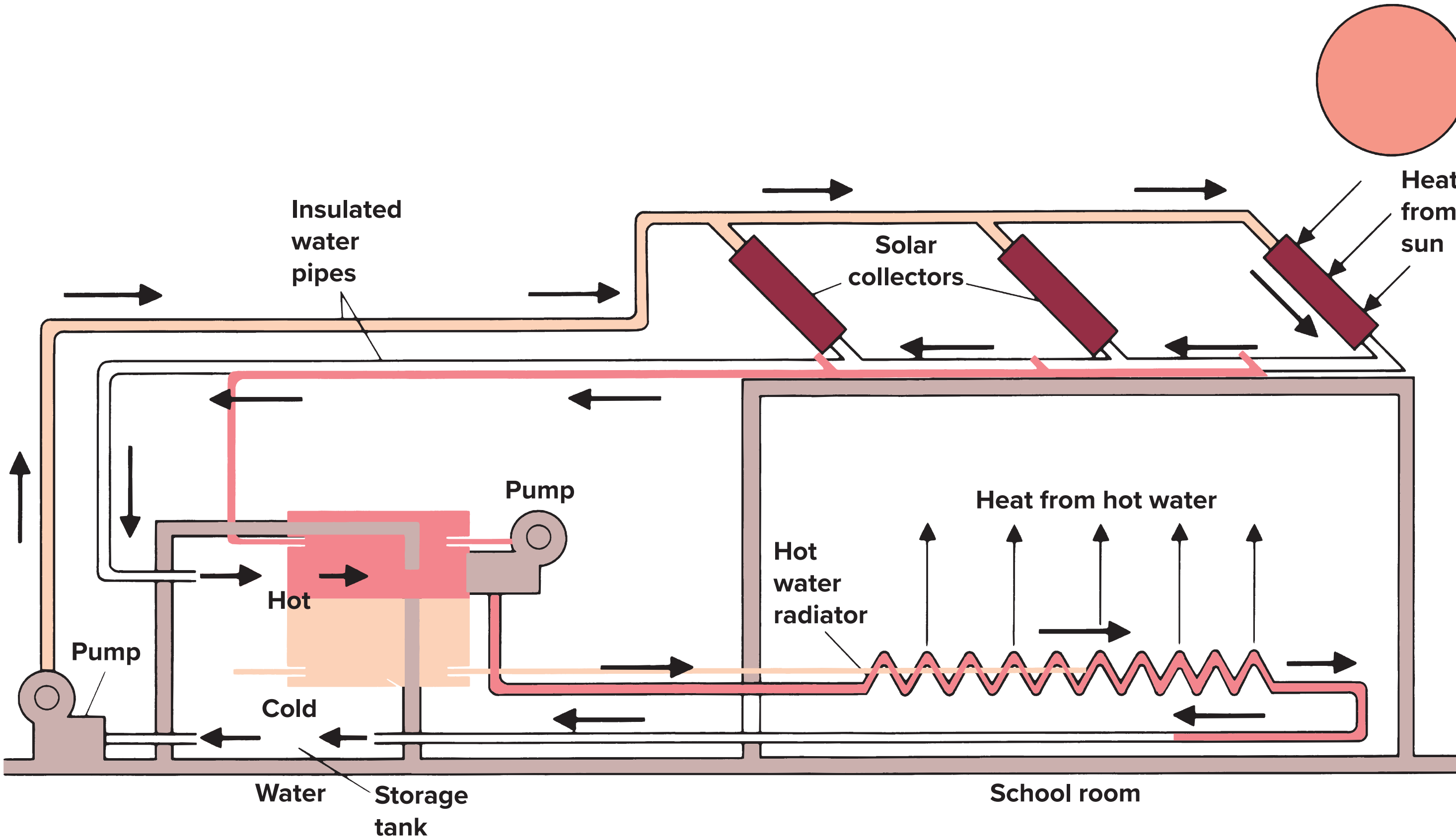


FIGURE 10.10 An Active Solar Heating Design An active solar system requires a solar collector, a pump, a heat storage system, and a system of pipes to convey the heat from one place to another.

Other passive solar heating designs involve sunspaces or Trombe walls. A *sunspace* (which is much like a greenhouse) is built on the south side of a building. As sunlight passes through glass, it warms the sunspace. Proper ventilation allows the heat to circulate into the building. A *Trombe wall* is a very thick, south-facing wall painted black and made of a material that absorbs a lot of heat. A pane of glass installed a few centimeters in front of the wall helps hold in the heat. The wall heats up slowly during the day; then, as it cools gradually during the night, it gives off its heat inside the building.

Many passive solar systems also provide daylighting. *Daylighting* is simply the use of natural sunlight to brighten a building's interior, reducing the need for electricity to light the interior of a building. To lighten north-facing rooms and upper levels, a clerestory—a row of windows near the peak of the roof on the sunny side of the building—is often used along with an open floor plan inside that allows the light to bounce throughout the building.

Of course, too much solar heating and daylighting can be a problem during hot summer months. There are design features that can help keep passive solar buildings cool in the summer. For instance, overhangs can be designed to shade windows when the sun is high in the sky in the summer but allow sunlight to enter during the winter when the sun is lower in the sky. Sunspaces can be closed off from the rest of the building during the summer when heating is not needed. And a building can be designed to use fresh-air ventilation in the summer.

Active Solar Systems

An **active solar system** requires a solar collector (usually a flat plate collector), a pump, and a system of pipes to transfer the heat from the site where it is captured to the area to be heated. (See figure 10.10.)

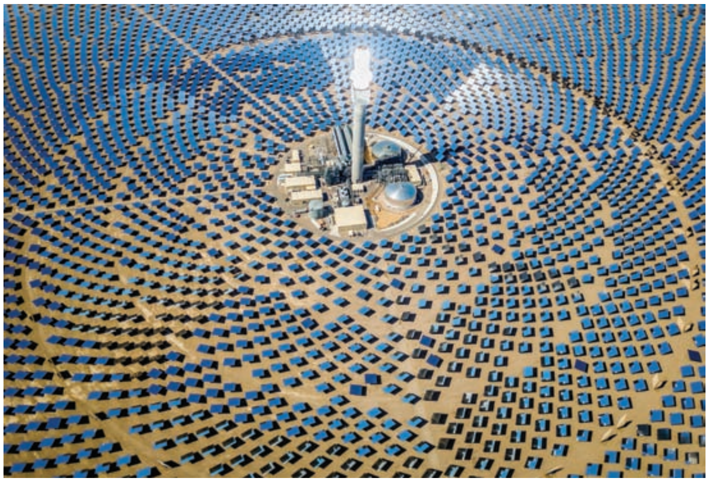
Active solar collector systems are most commonly used to provide heat energy for water heaters, pools, and homes.

Because sunlight is intermittent, active solar heating systems require heat storage mechanisms and usually also require conventional energy sources to provide energy when solar energy is inadequate. Rock, water, or specially produced products are used to store heat during the day, and the storage medium releases heat when the sun is not shining.

An active solar space heating system makes economic sense if it can offset considerable amounts of heating energy from conventional systems over the life of the building or the system. Active solar systems are most easily installed in new buildings, but in some cases they can be installed in existing structures. A major consideration in the use of an active solar system is the initial cost of installation.

Solar-Generated Electricity

Solar energy can be used to generate electricity in two different ways. It can be used to create steam that is used to run a turbine similar to that of a conventional power plant, or photovoltaic cells can be used to generate electricity directly from sunlight.



(a) Solar power tower

(b) Parabolic trough

FIGURE 10.11 Conventional Solar Generation of Electricity (a) A power tower produces steam by focusing sunlight at a central point. (b) A parabolic trough heats oil that transfers heat to water and converts it to steam. In both cases, the steam is used to turn a turbine and produce electricity.

(a): Mlenny/Getty Images; (b): Warren Gretz, staff photographer/NREL.

Conventional electric generation To produce electricity using a turbine, the energy from the sun must be collected and concentrated to heat water to make steam. There are basically two designs used. One design, called a *solar power tower*, uses mirrors to focus sunlight at a central point that raises the temperature and allows for the production of steam. There are about 20 such solar power plants in the world. About half of the current facilities are small (5–20 megawatts). The larger ones range from 50 to 400 megawatts. The United States has completed two large plants, the 110-megawatt Crescent Dunes Solar Energy Project in Nevada and the 392-megawatt Ivanpah Solar Power Facility in California. About 16 large (50–450 megawatt) solar power tower facilities are being developed or are under construction in Chile, China, Australia, Greece, the United Arab Emirates, and South Africa.

Currently, the most successful commercial design is the parabolic trough, which can heat oil in pipes to about 400°C (750°F). This heat can be transferred to water, which is turned into steam that is used to run conventional electricity-generating turbines. There are about 85 plants of this type in the world, and several more are being built. The 359-megawatt Solar Energy Generating System (SEGS) in the Mojave Desert in California consists of nine separate units and is the largest parabolic trough solar electric generation facility in the world. There are five other large parabolic trough plants in Arizona, California, Florida, and Nevada. Figure 10.11 shows examples of a power tower and a parabolic trough. There are about 70 parabolic trough plants in several countries, 45 of them in Spain.

Photovoltaics Photovoltaic (PV) solar cells are a sandwich of materials that contain a semiconductor as the critical component. Semiconductors release electrons when they absorb light. These electrons flow from one place to another. Thus, a solar cell can convert sunlight directly to electricity. (See figure 10.12.) Originally the semiconductor material used in solar cells was silicon, and it is still the most widely used material.

New varieties of semiconductors have been invented that are beginning to be used in solar cells. Examples are cadmium telluride (CdTe), amorphous silicon (a-Si), copper iridium gallium selenide (CIGS), and gallium arsenide (GaAs). These semiconductors are typically used in a new form of solar cell known as a thin-film solar cell.

Groups of solar cells can be combined into modules called solar panels, and groups of panels can be connected to form arrays. Individual PV modules are low-voltage, direct current (DC) devices which are not compatible with most

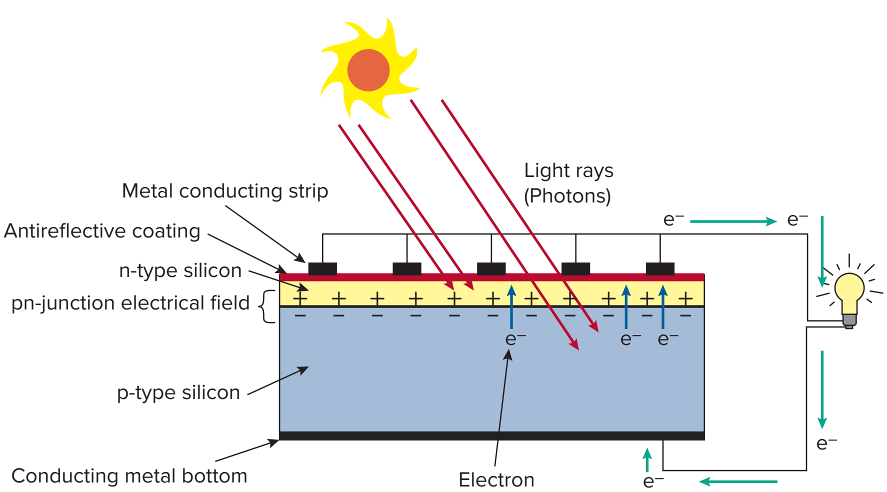
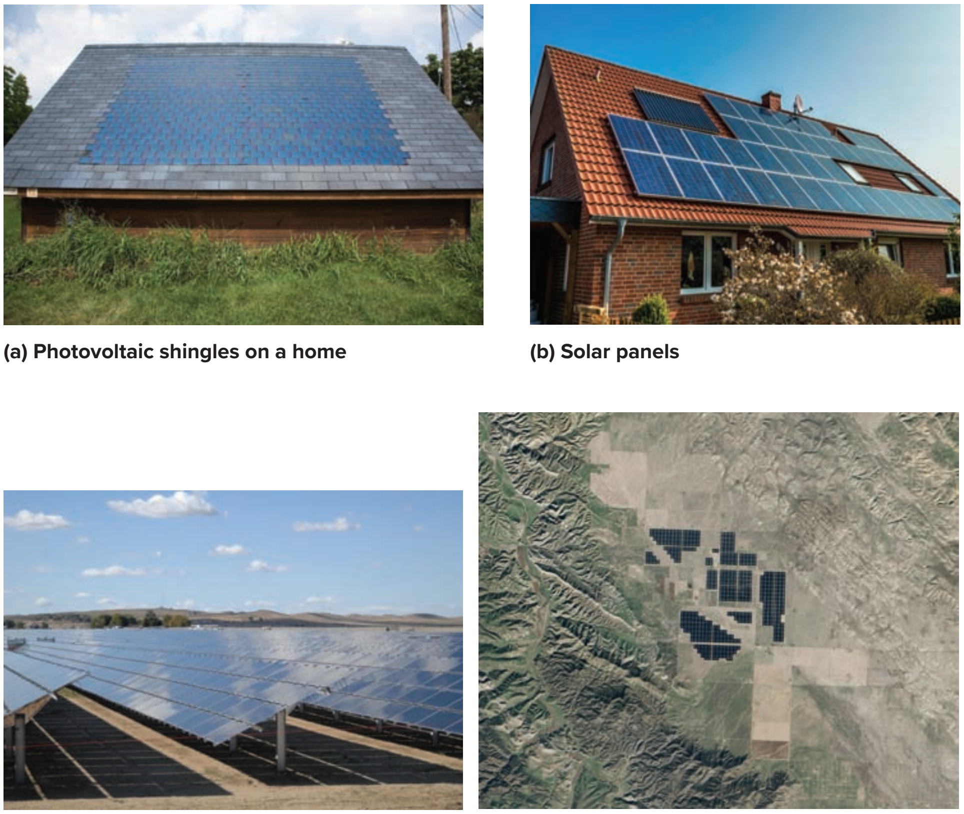


FIGURE 10.12 Solar Cell A solar cell consists of two layers of a semiconductor like silicon. Sunlight consists of units of light called photons. When the silicon is hit by photons, electrons are displaced and can move from one place to another. The flow of electrons we call an electric current. So a solar cell converts light to electricity.



(a) Photovoltaic shingles on a home

(b) Solar panels

(c) Topaz solar farm photovoltaic power plant

(d) Aerial view of Topaz Solar Farm

FIGURE 10.13 Photovoltaic Applications Photovoltaic devices can be used in many ways. (a) Photovoltaic shingles can be installed on roofs. (b) Solar panels can be installed on the surfaces of homes and other buildings. (c) Large numbers of solar panels can be combined to serve as power plants that supply the electrical grid. (d) The Topaz Solar Farm occupies 19 km^2 (7.3 mi^2).

(a): Bill Brooks/Alamy Stock Photo; (b): Diyana Dimitrova/Shutterstock; (c): Jesse Allen/USGS/NASA; (d) Sarah Swenty/USFWS

grid-connected homes that use alternating current. Inverters are used in homes to convert the direct current from the PV devices to alternating current that can be used by the house or sent to the larger grid system.

Thin-film photovoltaics use layers of semiconductor materials only a few micrometers thick. Furthermore, they can be folded or formed into a variety of shapes, which has made it possible for photovoltaics to double as rooftop shingles, roof tiles, building facades, or the glazing for skylights or atria. However, they are generally less efficient and don't last as long as traditional silicon solar cells.

Three factors drive the photovoltaic industry: cost of the solar installation, efficiency of the system, and government policy. As the cost of the system is reduced and efficiency increases, the price per kilowatt-hour of electricity falls. Currently, the cost of installation is falling and efficiency is increasing. Thus, the price of electricity from photovoltaics is falling . Electricity from photovoltaics is now less expensive in some places than electricity from the grid. However, the cost of installing a photovoltaic system on a house is expensive. Many governments and some utility companies offer subsidies for installing photovoltaic systems in order to assist homeowners with the initial cost of installing the system.

In recent years, the amount of PV power installed worldwide has been increasing dramatically. During 2019, about 98,000 megawatts of photovoltaics were installed worldwide, which resulted in a cumulative installed capacity of 586,000 megawatts. This was an increase of about 20 percent over 2018. U.S. cumulative solar energy capacity increased by 22 percent between 2018 and 2019. Much of this growth is attributable to government subsidies. Many European countries have pledged to reduce their dependence on fossil fuels and subsidize renewable energy installations. China, the United States, Japan, Germany, India, and Italy lead in the amount of photovoltaics installed.

Part of the reason for the significant growth in photovoltaics is the construction of large photovoltaic arrays to produce electricity for power companies. In 2019 and 2020 India completed two plants that have a capacity of more than 2,000 megawatts. China has a plant with a capacity of over 1,500 megawatts and several others being built in the 500-1000 megawatt range.

The largest photovoltaic power plants in the United States are the Solar Star plant in California (579 megawatts), the Copper Mountain Solar Facility in Nevada (552 megawatts), the Desert Sunlight Solar Farm in California (550 megawatts), and Topaz Solar Farm in California (550 megawatts). Figure 10.13 shows typical applications of photovoltaic technology.

Environmental Issues

Since solar energy is renewable, it has minimal environmental impact. However, the manufacture of the silicon or other materials that make up the units requires large amounts of energy. Thermal or photovoltaic power plants require large amounts of land to position their mirrors or solar collectors. The four large U.S photovoltaic plants mentioned earlier range in size from 13 km^2 to 19 km^2 (5 to 7.3 mi^2). The large Chinese and Indian plants occupy about 40 km^2 (15 mi^2). The installation of photovoltaics or water heating systems on buildings does not require additional space and is often incorporated into the design of the building.

Wind Energy

For centuries, wind has been used to move ships, grind grains, pump water, and do other forms of work. In more recent times, wind has been used to generate electricity. (See figure 10.14.)

In 2008, the U.S. Department of Energy published a report that stated that it was technically feasible to generate 20 percent of electricity in the United States from wind by 2030. Some areas are better suited for producing wind energy than others. Figure 10.15

FIGURE 10.14 Wind Energy Fields of wind-powered generators can produce large amounts of electricity.
Doug Sherman/Geofile

shows the wind energy potential of regions within the United States. However, location can be a problem. Although places such as the Dakotas have the strongest winds, they are remote from energy-using population centers, and large losses in the amount of electricity would occur as it is transmitted through electric lines.

Because winds are variable, so is the amount of energy generated by each wind turbine. This means that electrical energy from wind must be coupled with other, more reliable sources of energy.

Since the technology to generate electricity from wind is relatively easy to install, sizable increases in capacity occur each year. In 2019, there were about 622,000 megawatts of installed capacity worldwide. This was an increase of 10.5 percent over 2018. The United States, Germany, and China constitute about 60 percent of the installed capacity. Although there has been rapid development of new wind power capacity, it is important to recognize that the total electrical energy produced by wind today is still only 2 percent of total worldwide energy consumption.

Environmental Issues

Wind generators do have some negative effects. The moving blades are a hazard to birds and bats. Newer wind turbines, however, have slower-moving rotors that many birds such as the golden eagle find easier to avoid. A study done on a wind farm in Norway found that painting one of the three blades of the wind turbine black reduced bird deaths by about 70 percent. In addition, some people consider the sight of a large number of wind generators to be visual pollution.

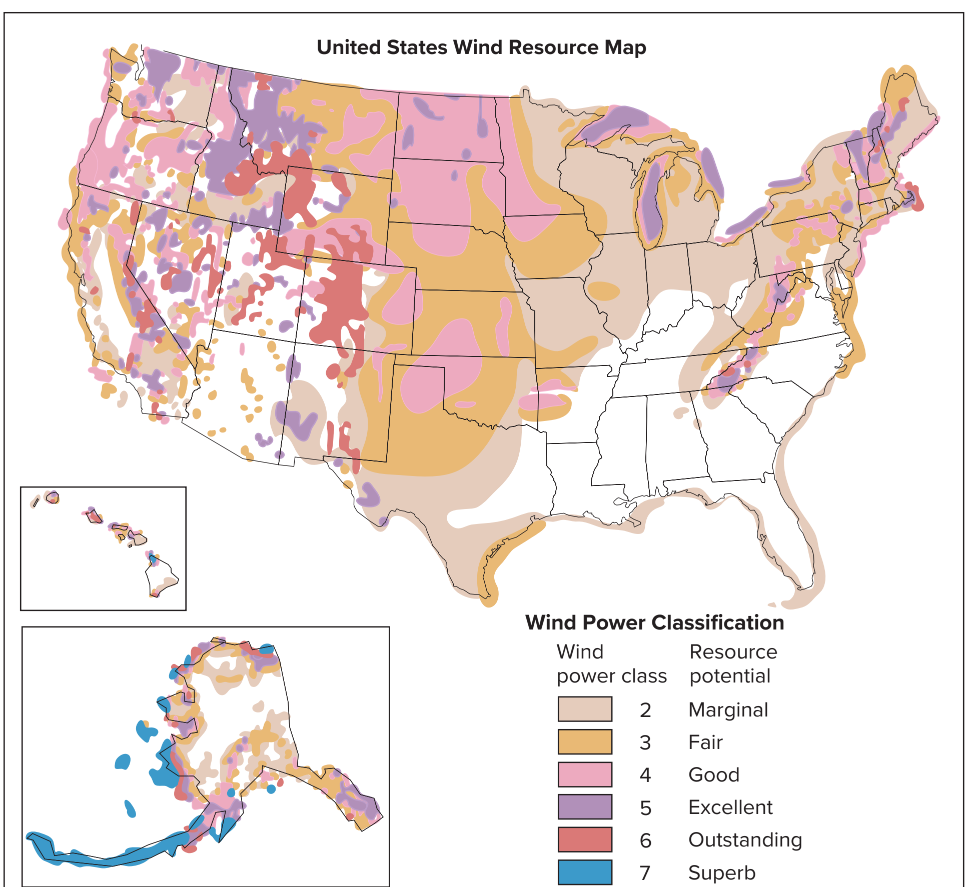


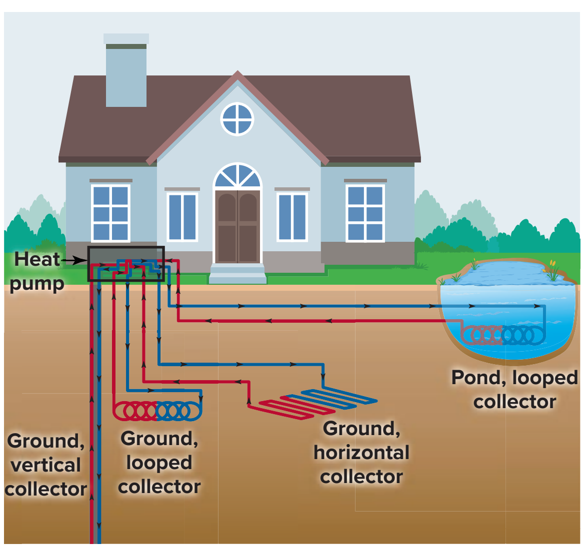
FIGURE 10.15 Wind Energy Potential This map ranks regions of the United States in terms of their potential to supply electricity from wind energy.
Source: U.S. Department of Energy.

Geothermal Energy

Geothermal energy is obtained in two different ways. In geologically active areas where hot magma approaches the surface, the heat from the underlying rock can be used to heat water. The heated water can then be used directly either to heat buildings or to generate electricity by way of a steam turbine. (See figure 10.16.)

The United States produces about 25 percent of the world's geothermally generated electricity. The Geysers Geothermal Complex north of San Francisco, California, is the world's largest geothermal electricity producer. There are over 20 geothermal power plants that combined produce about 835 megawatts of electricity. Additional geothermal electric plants are located in Nevada, Utah, Hawaii, Oregon, New Mexico, and Idaho. When combined with California they produce about 3,600 megawatts of electricity. However, to put this in perspective, geothermal electricity accounts for less than 1 percent of total electricity consumption in the United States. Other countries that produce significant amounts of geothermal

(a) Geothermal power plant



(b) Geothermal heat pump system

FIGURE 10.16 Geothermal Energy (a) Steam obtained from geothermal wells is used to produce electricity in Iceland. (b) Geothermal heat pumps can extract heat from the Earth and deliver it to homes. The diagram shows 4 different ways in which heat can be extracted from the ground. When air conditioning is needed, the system can be reversed, and heat is pumped from the home to the Earth.

(a): Photomick/iStock/Getty Images; (b): U.S. Department of Energy.

electricity are the Philippines, Turkey, Kenya, Italy, Mexico, Japan, New Zealand, Indonesia, and Iceland. In Iceland, half of the geothermal energy is used to produce electricity and half is used for heating. In the capital, Reykjavik, all of the buildings are heated with geothermal energy at a cost that is less than 25 percent of what it would be if oil were used.

It is also possible to use heat pumps to obtain geothermal energy from areas that are not geologically active. All objects contain heat energy, which can be extracted from and transferred to other locations. In the winter, geothermal heat pump systems use a system of pipes to extract heat from the ground and pump it into buildings, in the same way a refrigerator moves heat from the inside of the refrigerator to the outside. In the summer, geothermal heat pumps simply reverse directions and cool buildings by pumping heat from buildings into the ground. Typically the amount of heat energy harvested is three to four times the amount of electrical energy used to run the system.

Environmental Issues

The use of geothermal energy from geologically active areas creates some environmental problems. The steam often contains hydrogen sulfide gas, which has the odor of rotten eggs and is an unpleasant form of air pollution. (The sulfides from geothermal sources can be removed.) The minerals in the steam corrode pipes and equipment, causing maintenance problems. The minerals are also toxic to fish if wastewater is discharged into local bodies of water. There are very few environmental issues with using geothermal heat pump systems to warm and cool buildings.

Tidal Power

Tides are caused by the gravitational force exerted by the moon and the sun. The magnitude of the gravitational attraction between two objects depends on the masses of the objects and the distance between them. The moon exerts a larger gravitational force on the Earth because, although it is much smaller in mass than the sun, it is a great deal closer than the sun. This force of attraction causes the oceans, which make up 71 percent of the Earth's surface, to bulge along an axis pointing toward the moon. (There is also a bulge on the side of the Earth farthest from the moon because the moon is pulling the Earth away from the water on its surface.) Tides are produced by the rotation of the Earth beneath this bulge in its watery coating, resulting in the rhythmic rise and fall of water levels that can be observed along coasts. Thus, there are two high and two low tides each day. When the sun, moon, and Earth are in a line, the combined effects of sun and moon generate higher tides.

Certain coastal regions experience higher tides than others. This is a result of the amplification of tides caused by local geographical features such as bays and inlets. To produce practical amounts of power, a difference between high and low tides of at least 5 meters (16 feet) is required. About 40 sites around the world have this tidal range. The higher the tides, the more electricity can be generated from a given site and the lower the cost of electricity produced. Due to the constraints just described, it has been estimated that the potential to produce electricity from tides is only about 60,000 megawatts.

Technology for Obtaining Tidal Energy

The technology required to convert tidal energy into electricity is very similar to that used in traditional hydroelectric power plants. The energy of flowing water can be used to generate electricity. There are two different ways to capture tidal energy. Both depend

Going Green

The Role of Hybrid and Electric Vehicles

Background

In many metropolitan areas, emissions from automobiles are a major contributor to air-quality problems. In addition, carbon dioxide (CO_2) released from the burning of fuels is a greenhouse gas that contributes to a warming of the Earth that leads to climate change. An increase in the efficiency with which the chemical energy of fuel is converted to the motion of automobiles would greatly reduce these problems. In addition, since sources of fossil fuels are limited, they will become less available, and greater efficiency will extend the limited supplies.

Recognition of these issues has caused governments to mandate greater efficiency in automobiles, which has led to an ongoing process of modifying vehicles to improve performance and fuel efficiency. These include: using lighter materials to reduce vehicle weight, streamlining the shape to reduce air resistance, using better tires to reduce friction with the road, making changes to engines that increase efficiency, and many other modifications. Hybrid and electric vehicles are a major advance in automotive technology.

Engineering Principles

A great deal of energy is needed to get a vehicle to begin moving from a stop (accelerate), and it takes an equal amount of energy to stop a vehicle once it is moving (decelerate). Internal combustion engines operate most efficiently when they are running at a specific speed (rpm) and work at greatly reduced efficiency when the vehicle is accelerating or decelerating. Thus, using an internal combustion engine to accelerate is not efficient, and it contributes significantly to air pollution. When the brakes are applied to stop the vehicle, the kinetic energy possessed by the moving vehicle is converted to heat in the braking system. So the energy that has just been used to accelerate the vehicle is lost as heat when the vehicle is brought to a stop. Furthermore, in metropolitan areas, an automobile sits in traffic with its engine running a significant amount of the time. Thus, the stop-and-go traffic common in city driving provides conditions that significantly reduce the efficient transfer of the chemical energy of fuel to the kinetic energy of turning wheels.

Kinds of Hybrid and Electric Vehicles

Since electric motors are more efficient than internal combustion engines, they are used in several kinds of vehicles, and nearly all automobile manufacturers include one or more hybrid vehicles in their product mix. Hybrid electric vehicles use two kinds of motors to propel the car: an electric motor powered by electrical energy stored in batteries and an internal combustion engine that burns fuel. In general, the electric motors provide the energy to start the car moving (accelerate) and to move the car when it is driven at low speed. An internal combustion engine provides the extra power needed to reach higher speeds and to charge the battery. The battery is recharged when the car switches back to the internal combustion engine. The battery is also recharged by a process called regenerative braking, in which the kinetic energy of the car is captured during braking and stored as electrochemical energy in the battery. Since the internal combustion engine does not need to provide all the energy for acceleration and works in combination with an electric motor, it is smaller, weighs less, and consumes less fuel than engines of conventional vehicles.

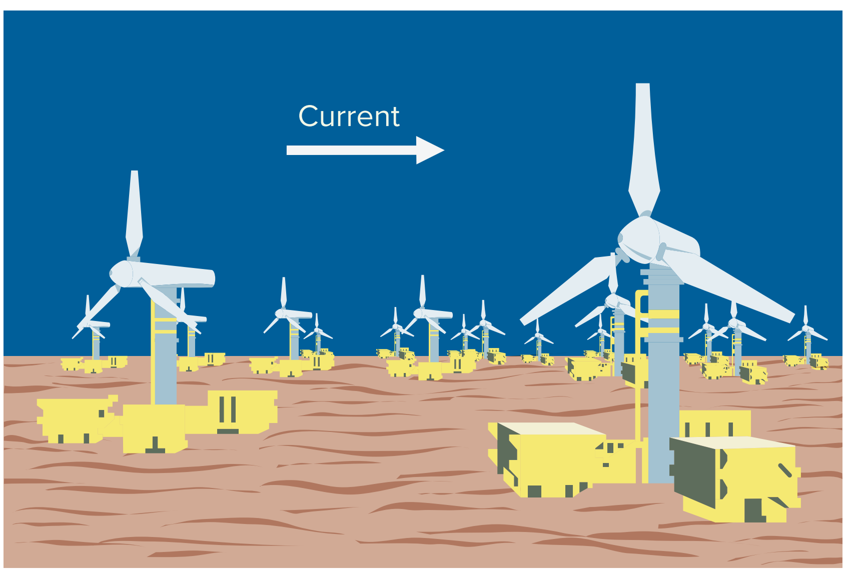
A hybrid vehicle has several advantages in stop-and-go traffic typical of cities. The electric motor is used for much of the time during stop-and-go driving, and the internal combustion engine is not running at all while the vehicle is stopped. Furthermore, regenerative braking charges the battery when the driver is required to stop.

- There are basically two kinds of conventional hybrid electric vehicles: Those that use the internal combustion engine in combination with the electric motor to propel the car and to charge the battery and those that only use the internal combustion engine to charge the battery.
- Plug-in hybrid electric vehicles differ from conventional hybrids in that they use electricity from the grid to charge the battery. In addition, the battery is larger and can propel the vehicle for longer distances before an internal combustion engine is needed.
- Full electric vehicles have also become important. Since they only have batteries as a source of energy, they must be plugged into the grid to be recharged. Currently, they are used primarily as commuter cars, since most have a range of 160 km (100 mi) or less on a full charge. They also generally require several hours to achieve a full charge of the battery. Several newer models can travel 320 km (200 mi) or more. Although they use no fuel and produce no emissions during operation, the electricity used to charge them comes from a power plant. If the power plant is fired by coal or natural gas, fuel consumption and emissions do occur at that location. If the electricity is from a renewable source, there are few emissions.

New models of conventional hybrid, plug-in hybrid, and full electric vehicles are being introduced into the market every year. Most car manufacturers have plans to produce all-electric vehicles, and several currently have models for sale. The success of new models will depend on a mixture of the following factors: government incentives (increased fuel taxes, tax rebates, and other subsidies), the cost of gasoline, the purchase price of the vehicle, the size of the vehicle, and the driving range of the vehicle.

on specific geography that provides large tidal changes along with massive movements of water. One method is to build a dam or "barrage" across a tidal bay or estuary. Building such dams is expensive. Therefore, the best tidal sites are those where a bay has a narrow opening, thus reducing the length of dam required. At certain points along the dam, gates and turbines are installed. As the tide comes in, the level of the water on the seaward side of the barrage becomes higher than the water level in the bay or estuary. When the difference in the elevation of the water on the two sides of the barrage is adequate, the gates are opened. As the water flows from the high side to the low side of the dam, the flowing water causes turbines to spin and produce electricity. When the tide falls, the level on the ocean side of the barrage is lower than that of the bay, and the water rushing to the sea also provides electricity.

(a) Rance River tidal power station



(b) Tidal stream turbine

FIGURE 10.17 Tidal Generating Station (a) The Rance River Estuary Power Plant in France is the world's largest tidal electricity-generating station. (b) A tidal stream turbine system uses wind-turbine like blades to capture energy from currents in the ocean and convert it to electricity.

(a): Maher Attar/Getty Images; (b): Source: Energy Industries Council

The second method, called a tidal current system, involves placing wind turbine-like machines on the seafloor, where strong currents are created by tidal changes.

Although the technology required to harness tidal energy is well established, tidal power is expensive, and only three major barrage-type tidal generating stations are in operation; the 254-megawatt Sihwa Lake Tidal Power Station in South Korea, the 240-megawatt Rance River Tidal Power Plant on the northern coast of France, and a 20-megawatt facility at Annapolis Royal in Nova Scotia, Canada. The Rance River generating station has been in operation since 1966 and has been a very reliable source of electricity for France. (See figure 10.17.) Several sites throughout the world are being evaluated for their potential.

Only one tidal current system, the MeyGen project in the ocean north of Scotland, is producing significant amounts of power. It is currently operating four turbines producing about six megawatts. There are plans to install up to 269 turbines capable of generating 398 megawatts of electricity. This additional capacity will take many years to complete. With this successful demonstration, many other potential sites for tidal stream power plants are being explored. Figure 10.17 shows examples of both kinds of tidal energy methods.

Environmental Issues

Tidal energy is a renewable source of electricity and does not contribute to climate change. However, changing tidal flows by damming a bay or estuary could result in negative impacts on aquatic and shoreline ecosystems, as well as affecting navigation and recreation.

Studies undertaken to identify the environmental impacts of tidal power have determined that each site is different and the impacts depend greatly on local geography. Local tides changed only slightly due to the Rance River barrage, and the environmental impact has been negligible, but this may not be the case for all other sites. In all cases the barriers and turbines will affect the migration of fish and other marine species. Tidal stream projects will impact bottom-dwelling organisms and animals that swim in the water column.

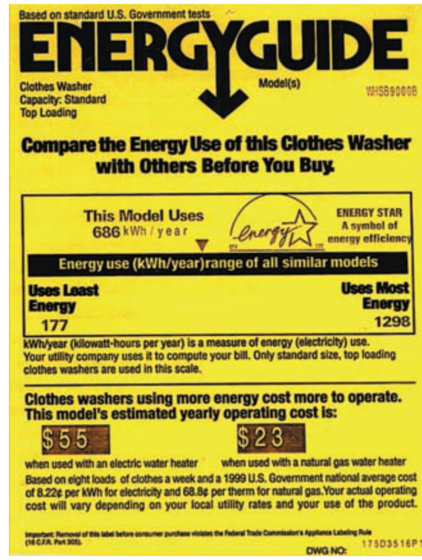
10.3 Energy Conservation

The amount of energy used by a society is determined by many factors. These include the level of economic development, the cost of energy, societal expectations, and government policies related to energy use.

Many cultural or lifestyle factors have been shaped by the availability of relatively low-cost energy. Large homes, outdoor lighting, large lawns, home entertainment centers, automobile travel, and many "labor-saving" devices (leaf blowers, riding lawn mowers, dishwashers, etc.) use large amounts of energy. If the cost of energy were higher, people would be likely to make different choices about what is essential and would evaluate energy efficiency more carefully.

There is typically a relationship between the cost of an item and its energy efficiency. Often, poorly designed, energy-inefficient buildings and machines can be produced inexpensively. The short-term cost (purchase price) is low, but the long-term cost for upkeep and energy utilization is high. Typically, the cost of more efficient buildings or machines is higher, but the difference in initial price is

(a)



(b)

(c)

FIGURE 10.18 Energy Conservation The use of (a) LED lightbulbs, (b) energy-efficient appliances, and (c) low-emissive glass could reduce energy consumption significantly.

(a): Keith Homan/Shutterstock; (b):Roger Loewenberg/McGraw-Hill; (c): McGraw-Hill Education/LouAnn Wilson, photohgrapher

made up by savings in energy cost over several years. This is known as the payback period.

The United States and Canada have a much higher per capita energy consumption than other countries with similar economic status. (See chapter 8.) Therefore, it seems plausible that energy conservation measures should be able to substantially lower per-person energy consumption. Energy conservation can be thought of as a "source" of energy, since it reduces energy demands and thus makes it easier to meet future energy needs. In addition, it saves money for the consumer.

Some conservation technologies are sophisticated and require substantial investment, while others are simple and cost little to achieve. (See figure 10.18.) For example, highly efficient compact fluorescent lightbulbs that can be used in regular incandescent fixtures give the same amount of light for 25 percent of the energy, last about six times longer, and produce less heat. LED bulbs are even better. They use about 20 percent of the energy and last 25 times longer than incandescent bulbs. Since lighting accounts for 14 percent of U.S. electricity consumption, widespread use of these lightbulbs would significantly reduce energy consumption.

Low-emissive glass for windows can reduce the amount of heat entering a building, while allowing light to enter. The use of this glass in new construction and replacement windows could have a major impact on the energy picture. Many other technologies, such as automatic dimming devices or automatic light-shutoff devices, are being used in new construction. Installing energy-saving windows and doors, replacing inefficient heating systems and appliances, or upgrading insulation in buildings would save a great deal of energy but require a substantial investment. Conversely, reducing the temperature in buildings during the winter or increasing the temperature in the summer costs little and would reduce the energy needed to provide heat and air conditioning.

Government Incentives

The shift to a more efficient use of energy needs encouragement. Some people may be persuaded to reduce their energy use by moral arguments, but most are unlikely to change their lifestyles unless there are significant penalties for wasteful use or rewards for reducing energy consumption. In recent years, the U.S. government has passed laws or established policies that will reduce average energy consumption. Most of these initiatives provide economic rewards in the form of tax incentives or impose economic penalties (taxes and fines). The following are examples of government actions designed to improve energy efficiency.

- Imposition of improved fuel economy standards for new automobiles and trucks.
- Tax incentives for those who upgrade insulation, windows, doors, heating and cooling systems, and other appliances.
- Phaseout in 2014 of most uses of incandescent lightbulbs, which are very inefficient. The development of fluorescent and LED bulbs to replace them quickly followed.
- Established higher energy efficiency standards for appliances.
- Investment in more efficient electricity distribution.
- Improvement in high-speed rail transportation.

Electric utilities are also part of the energy conservation picture. Many electric utilities have energy conservation programs that help their customers reduce their energy needs. Since the building of new power plants is expensive, electric utilities have an incentive to keep electricity use from increasing. Many utilities give rebates on the purchase of energy-efficient appliances and heating and cooling systems.

Issues & Analysis

Does Corn Ethanol Fuel Make Sense?

To evaluate the feasibility of using ethanol as fuel, it is necessary to do some accounting from three points of view: energy gain, economic competitiveness, and land use implications.

Energy Analysis

Many studies have assessed the amount of energy needed to produce ethanol. Currently in North America, ethanol is made by fermenting the starch contained in corn. It is essentially the same process as that used to make beer and wine. Therefore, the energy input to make ethanol includes fuel used by farmers to till, plant, harvest, and transport corn. In addition, fertilizer, herbicides, and other agricultural chemicals require energy to produce and apply. Finally, the fermenting of corn to make ethanol and the distillation of the ethanol from a dilute solution both require energy. Various attempts have been made to account for all of these energy inputs, and the results indicate that the EROI of corn ethanol is roughly 1.3 to 1. That means that for every unit of energy spent making ethanol, the ethanol produced contains only 1.3 units, for a net energy profit of only 0.3 units.

Flex-fuel vehicles have engines and other components designed to use high concentrations of ethanol as fuel. The most commonly available mixture is E85 fuel, which contains 85 percent ethanol and 15 percent gasoline. Since ethanol has only 67.2 percent of the energy of gasoline, a vehicle will travel fewer miles on a gallon of ethanol or E85 fuel than on a gallon of gasoline. (See chart.)

Gallons Needed to Provide Equivalent Energy		
Gasoline	***Ethanol***	***E85 fuel***
1	1.49	1.42

In the United States, ethanol is most commonly added to gasoline (up to 10 percent) to increase the octane of the gasoline/ethanol mixture. This mixture can be used in unmodified engines and improves engine performance, resulting in less air pollution. Since 2015, E15 gasoline (15 percent ethanol and 85 percent gasoline) has been available for use in newer cars. It is often marketed as having an octane rating of 88 (normal E10 gasoline has an octane rating of 87) and as costing less than regular (E10) gasoline. It should cost less because the increased amount of ethanol reduces mileage by 4 to 5 percent.

The amount of ethanol produced in 2019 was about 57.8 billion liters (about 15.8 billion gallons). If the amount of energy needed to produce the ethanol is subtracted, the net gain in energy is equivalent to about 18 billion liters (4.8 billion gallons) of ethanol. This is about 3.3 percent of the amount of gasoline used in 2019.

Economic Analysis

Since ethanol only contains 67.2 percent and E85 only contains 72 percent of the energy of gasoline, they must cost less than gasoline to be competitive. Thus, in order for E85 to be more economical than regular gasoline, its cost must only be 72 percent of the price of gasoline. In other words, it must cost 28 percent less than regular gasoline. Although E85 costs less than regular gasoline, it does not cost 28 percent less, and thus it is more expensive to use than regular gasoline.

Price/Gallon to Provide Equivalent Energy per Dollar		
Gasoline	***Ethanol***	***E85 fuel***
\$3.00	\$2.00	\$2.15

Land-Use Analysis

In 2019, 142 billion gallons of gasoline were used in the United States. Ethanol has only 67.2 percent of the energy content of gasoline. Therefore, if ethanol were to totally substitute for gasoline, 211 billion gallons of ethanol would be needed. Published calculations of the amount of ethanol that can be produced from an acre of corn range from 328 to 575 gallons per acre. If we take the most favorable number (575 gallons per acre), it would take 367 million acres of corn to provide 211 billion gallons of ethanol. The amount of arable land in the United States is 915 million acres. Thus, 367 million acres is 40 percent of all the arable land in the United States.

What Do You Think?

- Because it is a renewable fuel, is it important to provide ethanol as a fuel?
- Should the public be required to use ethanol fuel?
- Should the production of ethanol be subsidized?

Summary

About 14 percent of the world's energy comes from renewable energy sources, of which 10 percent is from biomass. Fuelwood is a minor source of energy in industrialized countries but is the major source of fuel in many less-developed nations. Biomass can be burned to provide heat for cooking or to produce electricity, or it can be converted to alcohol or used to generate methane. In some communities, solid waste is burned to reduce the volume of the waste and also to supply energy. The use of biomass to provide energy in the less-developed world contributes to habitat and biodiversity loss and contributes to air pollution because the fuel is often burned in inefficient stoves or over open fires.

Hydroelectric power provides about 16 percent of the world's electricity and can be increased significantly in many parts of the world. However, its development requires flooding areas and thus may require the displacement of people. Other environmental effects of developing hydroelectric plants are: altering the habitat for fish and other organisms and altering stream flow. Solar energy can be collected and used in either passive or active heating systems and can also be used to generate electricity in two different ways. Mirrors can be used to concentrate sunlight to produce steam, which can be used to power a turbine. Photovoltaic cells can be used to produce electricity. Lack of a constant supply of sunlight is solar energy's primary limitation. Wind power may be used to generate electricity, but it may require wide, open areas and a large number of wind generators. The use of geothermal and tidal energy to produce electricity is determined largely by specific geological and geographical features of the land and is quite limited. Geothermal heat pump systems can heat and cool buildings efficiently almost anywhere in the world.

Energy conservation can reduce energy demands without noticeably changing standards of living. However, the public typically needs incentives to make changes that do not provide immediate benefits. Therefore, most energy conservation programs are associated with economic incentives, which take the form of added costs (fines, taxes) or subsidies (tax deductions).

Acting Green

1. Contact your local electric utility or visit its website and determine what percentage of the electricity produced comes from fossil fuels, nuclear energy, hydroelectric, or other renewable energy sources.
2. Does your electric utility offer an opportunity to purchase green energy? If so, what does it cost?
3. Develop a list of ten ways you could reduce energy use. Implement five of them.

Review Questions

1. What are the general characteristics of renewable energy sources?
2. What percent of world energy comes from renewable energy sources?
3. What renewable energy source provides the majority of renewable energy?
4. List industries that typically make use of the waste they produce to provide themselves with energy.
5. Why is burning of municipal waste to produce energy more common in Europe than in North America?
6. How is the biofuel ethanol produced?
7. List three negative environmental impacts of using biomass to provide energy.
8. What are negative environmental impacts of developing hydroelectric power?
9. Compare a passive solar heating system with an active solar heating system.
10. Describe two different ways sunlight is used to make electricity.
11. List two reasons people oppose additional wind energy development.
12. List three energy conservation techniques.

Critical Thinking Questions

1. Imagine you are an official with the Department of Energy and are in the budgeting process for alternative energy research. Decide where you would invest money and explain why you made your choice. What do you think the political repercussions of your decision would be? Why?
2. Do you believe that large dam projects like the Three Gorges Dam project in China are, on the whole, beneficial? Do you believe they are not beneficial? What alternatives would you recommend? Why?
3. Energy conservation is one way to decrease dependence on fossil fuels. What are some things you can do at home, work, or school that would reduce fossil-fuel use and save money?
4. What alternative energy resources that the text has outlined are most useful in your area? How might these be implemented?